## Title
Optimizing the orchestration of resemiotization with teacher "talk moves" : a model of guided-inquiry instruction in middle school science



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UNIVERSITY OF CALIFORNIA, SAN DIEGO

# Optimizing the Orchestration of Resemiotization with Teacher "Talk Moves": A Model of Guided-Inquiry Instruction in Middle School Science

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Education

in

Teaching and Learning

by

Rachel Diana Millstone

Committee in charge:

Professor Hugh Mehan, Chair
Professor Gerald Balzano
Professor Edwin Hutchins

2010

The dissertation of Rachel Diana Millstone is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California, San Diego

2010

# DEDICATION

To my father, H. George Millstone,

who had the gift of stopping time and listening well,

so that it was easy to hear who I could become;

and to my mother, Mary,

who picks the roses.

# EPIGRAPH

"A picture held us captive.  And we could not get outside it, for it lay in our language and language seemed to repeat it to us inexorably."

Ludwig Wittgenstein, ***Philosophical Investigations***

"A child said: What is the grass? Fetching
it to me with full hands;
How could I answer the child? I do not
Know what it is any more than he."

Walt Whitman

I had no prejudices about what kinds of music I liked; I listened to everything with the rapt attention of a neophyte.  Later, when I was learning to become a musician, I would play 33 rpm records at 45 rpm and hear the bass parts revealed, rescued from the bowels of the arrangement an octave higher, and the fast sections of the upper octaves on forty-fives so that they could be learned at a slower speed.  *I realized from these experiments that anything, no matter how complex, could be deconstructed and learned if you slowed it down enough to really hear it."*

-Sting, ***Broken Music***

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This work would not have been possible without the guidance, support, and encouragement of many people. I cannot begin to adequately express my gratitude for the many ways in which so many individuals contributed to the fruition of this work. I will attempt here to express what I can in words.

First, I would like to acknowledge "Dave" and "Carla," the two dedicated educators who allowed me a daily view into their worlds of teaching. Thank you for graciously opening your classroom doors to me, and for tolerating my interference with grace and good humor. Thank you to all the 2007-2008 eighth grade students of "5A" and "5B." Your words still echo in my mind. Every single day you gave me a glimpse into raw resiliency and hope. Thank you, as well, to the administrators of the school where these dedicated teachers work with these amazing youth; your passion, urgency, and tireless dedication for improving education for all students, is unsurpassed in my experiences working with schools.

Part serendipity and part tenacity on my part, afforded me the exceptional guidance of three distinguished professors to comprise my dissertation committee. I would like to say that from the negotiation of the topic to the final typed word, this work would not have been possible without the careful attention and dedication of each of them. First, to Jerry Balzano. Thank you for the many conversations about Ludwig Wittgenstein, gesture, language, and representation, especially in the early stages of designing the constructs that imbued the research questions with meaning and brought them "to life." Thank you to Ed Hutchins for opening my mind to the world of distributed cognition and embodied cognition, two of the frameworks that informed my study. This study would not exist at all if I had not stumbled across your outstanding elective course in cognitive science. And, thank you to my larger-than-life phenomenal chair, Bud Mehan, for his endless patience and careful attention to my thinking and writing throughout the years. It was a great honor to have had him as an adviser- to learn from one so dedicated to the social justice issues plaguing our schools. He is both the most knowledgeable educational researcher and most beloved champion of teachers I have ever known. Thank you from the bottom of my heart.

I owe a great deal of gratitude to the many professors who inspired the topic of this project, and helped me shape it through different iterations via a journey of readings, lectures, and discussions, including in order of my encounters with them: Paula Levin, Claire Ramsey, Alison Wishard-Guerra, Amy Binder, Ana Celia Zentella, Jim Levin, Barbara Sawrey, Fred Goldberg, and Tom Humphries. Thank you for introducing me to new intellectual canvases and for assisting me on this journey to rigorous scholarship and thought in educational research.

I also have had the privilege of working with wonderful faculty and staff colleagues in the Education Studies Program (EDS) at the University of California, San Diego. In particular, I wish to thank Randy Souviney, former Director of EDS, for his unconditional belief in me, and for his dedication to the continued intellectual and professional development of the faculty. I owe a very special thank you to Paula Levin, for her endless support and gentle, but consistent encouragement to persist in this endeavor to the end. She inspired me to never give up, and to “begin anywhere,” when I got lost. Thank you to Cheryl Forbes for serving as a model to me in every way, through every step of the process from the IRB to the “crunch time” of final drafts. Thank you to

Chris Halter for allowing me to run my ideas by him at a moment's notice in the office, and for assisting me when my computer crashed in the final stages of dissertation writing! Thank you to Marcia Sewell, who reminded me that this was "just like the marathon" – something we have mastered in the physical realm in far fewer hours than this; and to Libby Butler, who kept me accountable on "writing days." Thank you to Rusty Bresser, who exudes balance and loaned some of that to me on the tougher days; thanks to Susan Scharton for sharing her wry wit and gentle encouragement every single time I saw her. And thank you to my two gems, Giselle van Luit and Melissa Wolf, who know how to access deep reservoirs of love, and did so over and again through the years.

I am fortunate to have several groups of friends who also supported and encouraged me, especially throughout the final weeks of the writing process. Special thanks to Bill Morris who "knows what it takes," and to Laura Bloom, for her supportive "one-liner" phone calls and reminders to prioritize and practice discipline. Thank you also to Ruth Levy, Sue Greenberg, Sue Brown, and LeAnne Adams for their support and encouragement, and most of all for their permission to submerge into the waters of writing for so long. And thank you to Scott Meltzer for his inspiration and sage wisdom, and especially to his daughter, Maital, who shared her ruby slippers, literally and figuratively.

I would also like to express my profound gratitude to several important people in my life. To my nephews Aidan, Ethan, Noah, and Liam, who allowed me to leave them in tears each break to "go to school and write my book." I will never know what I missed from your childhoods, but I hope that one day you will read this and be proud. Thank you to my two wonderful sisters, Heidi and Deetzah, for their unconditional support and love no matter what, and for reminding me of Norman's story of the centipede at crucial times in the process.  And to Rufus, who shared his pools of peace with me, and helped me to hold on.

And finally, thank you to Jim Levin, Maxwell Moholy, and Lee Vang for their technical assistance and contributions to this manuscript.  Thank you to the ladies of the "Cherry Slipper" cohort group: Suzanne Stolz, Krysti DeZonia, and Melissa Herzig for working to see each one of us through this process.   And especially to Suzanne, my writing partner, confidante, and the kindest, most substantive of human beings.  We wrote at coffee shops – so many- and told our stories of which this work is only one.

Much of this work had its roots in my love for literature, which grew from my many experiences in the classroom of one incredible high school English teacher, Bob Litchfield.  This man inspired an entire generation of youth from a local neighborhood of San Diego.  I was but one of the many children lucky enough to have been touched by the passion he embodied.  Thank you for all the things, including this, I would never have dreamed I could do had I not known such a teacher.  I still tell my science students there is poetry in the Krebs Cycle.

And finally, thank you Dad, who almost made it to share this dream- it will be your hands that will hood me.

# VITA

## EDUCATION

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University of California, San Diego — June 2010
Ed.D., Teaching and Learning

San Diego State University, San Diego, California — May 2001
Master of Arts, American Literature

San Diego State University, San Diego, California — December 1990
California Professional Clear Teaching Credential: Life Science, English
GATE certified

Stanford University, Stanford, California — June 1987
Bachelor of Science
Major: Biological Science
Emphasis: English Literature

University of California, San Diego — Summer 1985
Internship: Veterans' Administration Hospital
Paul Wolf, M.D., Chief of Pathology and Hematology

## PROFESSIONAL EMPLOYMENT

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Secondary Science Lecturer/Supervisor — 2001-present
Education Studies, University of California, San Diego
Courses taught:
EDS 381 (Health Education)
EDS 129A (Educational Foundations for Secondary Education)
EDS 375 (Secondary Science Methods)
EDS 379A,B,C (Secondary Intern Practicum)
EDS 206 (Teaching Performance Assessment Portfolio)

Extension Instructor, University of California, San Diego — 2000-2006
Courses taught:
Perspectives on Health Education for Teachers
Geoscience Institute, Scripps Institute of Oceanography
Marine Biology Institute, Scripps Institute of Oceanography

Resource Teacher/UCSD Intern Support Provider — 2000-2001
San Diego City Schools, San Diego, California
* Mentor secondary English, math, science interns; model demonstration lessons; lesson plan with interns; assess progress; practice reflective conversation; adjunct lecturer of teaching practices, UCSD; group facilitator of Language Arts methods discussions, UCSD.

Teacher: American Literature (Seminar, Advanced, Regular) — 1999-2000
Teacher: English 3,4 and Contemporary Voices — 1998-1999
Teacher: Biology 1,2 — 1996-1999
Crawford High School, San Diego, California
Teacher: 7th/8th Grade Cluster and Regular English — 1996-1998
Challenger Middle School, San Diego, California

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| Instructor/Counselor: Young Writers' Camp<br>San Diego Area Writing Project<br>University of California, San Diego, California | 1996-1998 |
| Teacher: 8th grade Sheltered Life/Physical Science, Math, A.V.I.D.<br>Teacher: 8th grade Bilingual Life/Earth Science<br>Memorial Academy for International Baccalaureate Preparation, San Diego, California | 1993-1996<br>1992-1993 |
| Teacher: 8th grade math, English (intersession)<br>Montgomery Junior High School, San Diego, California | 1994 |
| Administrator: SAT Exams<br>San Diego Unified School District, San Diego, California | 1993-1999 |
| Substitute Teacher: Grades 7-12 (science)<br>San Diego City Schools, San Diego, California | 1991 |
| Teacher Assistant: A.P. English reader, A.V.I.D. tutor, science laboratory assistant<br>University City High, Patrick Henry High, Madison High, Hoover High<br>San Diego City Schools, San Diego, California | 1988-1991 |
| Laboratory Safety Technician<br>Department of Health and Safety, Stanford, California | 1987-1988 |
| Laboratory Instructor: Vertebrate Biology<br>Stanford University, Stanford, California | 1986 |

**PROFESSIONAL EXPERIENCE**

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| California Department of Fish and Game<br>Volunteer | 2008 |
| Project WET, Project WILD, Project Learning Tree<br>San Diego Regional Trainer for Educators | 2008 |
| Secondary Academic Language Tools (SALT) Instructor<br>California Reading and Literature Project | 2006 |
| Performance Assessment for California Teachers (P.A.C.T.)<br>Science Trainer-of-trainers in conjunction with Stanford faculty<br>University of California, San Diego | 2003-present |
| Faculty Secondary Team Coordinator<br>Education Studies, University of California, San Diego | 2002- present |
| M.A. Advisor, Teaching and Learning<br>University of California, San Diego | 2002-present |
| Mentor Teacher<br>The Preuss School | 2002-2003 |
| Advisory Board, Science Education<br>University of California, San Diego | 2001-2003 |
| Genre Studies Methodologies Instructor, Professional Development for UCSD Interns<br>Institute Support and Professional Development, San Diego City Schools | 2001 |

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| Participant: District Genre Studies Trainings<br>San Diego City Schools | 1999-2001 |
| Participant: California Professional Development Institute Workshops<br>University of California, San Diego | 2000 |
| “Foundations in Mentoring” - CFASST model training<br>Marina Village, San Diego, California | 2000 |
| Featured Guest: KUSI Television Series with Susan Farrell<br>“Cultural Diversity in San Diego Schools” | February 2000 |
| Facilitator: CREATE/SDAWP/SDUSD Partnership Program<br>School site coordinator, *Temper Magazine*<br>Crawford High School | 1999-2000 |
| English Department Chair, Instructional Council, Senior Exhibition Advisor<br>Crawford High School | 1999-2000 |
| Washington D.C. chaperone, Hiking Club Advisor<br>Challenger Middle School | 1996-1998 |
| Participant: 8th grade restructuring program (based on Caught in the Middle)<br>Co-Facilitator, Science Fair<br>Participant in development of Middle Level Science Content Standards<br>Navy Volunteer Partnership Program | 1993-1996 |
| Member: Technology Team | 1995-1996 |
| San Diego Math Enhancement Program (with San Diego State University) | 1995-1996 |
| Math Club Advisor | 1995-1996 |
| Member: San Diego Cluster Science Articulation Committee<br>Memorial for International Baccalaureate Preparation | 1995-1996 |
| Participant: BioRAP Teacher Inservice<br>Research Symposium on Cancer, AIDS, skin testing, brain research<br>University of California, San Diego | 1996 |
| Participant: San Diego Area Writing Project, Invitational Institute<br>University of California, San Diego<br>Presentation: “Writing in Science Classrooms” | 1995 |
| Participant: “Dialogue on Diversity”<br>San Diego Area Writing Project<br>University of California, San Diego | 1995 |
| Participant: BTSA (Beginning Teacher Support and Assessment Program)<br>San Diego City Schools | 1994-1995 |
| Presenter: New Teacher Portfolio Conference for West Ed. Laboratories<br>San Francisco, California | 1995 |
| Participant: San Diego Area Writing Project, Open Program<br>University of California, San Diego | 1994 |
| Participant: A.V.I.D. Summer Institute<br>San Diego, California | 1994 |

**PROFESSIONAL PRESENTATIONS**

Presenter: Education Studies Winter Methodology Conference — 2008
"Refining Design: An Iterative Process of Theoretical Application and Discovery"
University of California, San Diego

Presenter: American Chemical Society, Student Chapter — 2005
"Aspects of Teaching Secondary Science"
University of California, San Diego

Co-Presenter: "The Ice Man Lives!" — 1996
*Interdisciplinary unit:science, math, language arts
17th Annual California League of Middle Schools (CLMS) Conference
San Francisco, California

Presenter: "Fall Festival of Writing," Desert Area Writing Project — 1995
"Writing in the Science Classroom"
El Centro, California

Presenter: "Writing in Science: The Real Voyage is in Having New Eyes" — 1995
Science Writing Teacher Consultant for San Diego Area Writing Project

Presenter: "Possible Crossings," Building Literacy Bridges — 1995
University of California, San Diego

**PRE-SERVICE TEACHING**

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Biology 1, 9th grade English — 1990-1991
Piloted new 10th grade science curriculum in 9th grade class
Co-facilitator, "Invent America"
Roosevelt Junior High School, San Diego, California

Advanced Biology 2 — 1990
Ecology Club
Hoover High School, San Diego, California

**PROFESSIONAL ORGANIZATIONS, AWARDS**

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American Educational Research Association
National Science Teachers Association
California Teachers' Association
California Department of Fish and Game
National Education Association
San Diego Area Writing Project
California Reading and Literature Project
Leland Stanford Junior Memorial Scholarship
Stanford University Teaching Award, Biology Department, 1987
"California Distinguished Teacher Award, 1996" from the Commission of California Educators

ABSTRACT OF THE DISSERTATION

Optimizing the Orchestration of Resemiotization with Teacher "Talk Moves":
A Model of Guided-Inquiry Instruction in Middle School Science

by

Rachel Diana Millstone

Doctor of Education in Teaching and Learning

University of California, San Diego, 2010

Professor Hugh Mehan, Chair

The current conceptualization of science set forth by the National Research Council (2008) is one of science as a social activity, rather than a view of science as a fixed body of knowledge. This requires teachers to consider how communication, processing, and meaning-making contribute to science learning. It also requires teachers to think deeply about what constitutes knowledge and understanding in science, and what types of instruction are most conducive to preparing students to participate meaningfully in the society of tomorrow. Because argumentation is the prominent form of productive talk leading to the building of new scientific knowledge, one indicator of successful inquiry lies in students' abilities to communicate their scientific understandings in scientific argumentation structures.

The overarching goal of this study is to identify factors that promote effective inquiry-based instruction in middle school science classrooms, as evidenced in students' abilities to engage in quality argumentation with their peers. Three specific research questions were investigated: 1) What factors do teachers identify in their practice as significant to the teaching and learning of science? 2) What factors do students identify as significant to their learning of science? and 3) What factors affect students' opportunities and abilities to achieve sophisticated levels of argumentation in the classroom? Two teachers and forty students participated in this study. Four principle sources of data were collected over a three-month period of time. These included individual teacher interviews, student focus group interviews, fieldnotes, and approximately 85 hours of classroom videotape. From this sample, four pathways for guided-inquiry instruction are identified. Opportunities for student talk were influenced by a combination of factors located in the domains of "teacher practice," "classroom systems," and "physical structures." Combinations of elements from these three dimensions also affected the quality of student argumentation, as measured on a five-point rubric developed for analysis. Of the four pathways, one in particular is identified as a model of "best practice," leading to the highest levels of argumentation resulting from opportunities for student resemiotization mediated by teacher "talk moves."

## Chapter 1- Introduction

*Introduction: Striving for Consensus on "Best Practices" in Science*

In the fall of 2009, San Diego Unified School District (SDUSD) Board members Richard Barrera and John Lee Evans initiated a local Blue Ribbon Task Force (BRTF) to evaluate science education in SDUSD's schools. The goal was to develop a report on the current state of local science education and to provide the board with recommendations to improve science education and measurable outcomes. A consortium of fifteen members was convened, representing a broad range of expertise and perspectives, including K-12 educators, administrators, representatives from academia and the research community, parents, students, business leaders, nonprofit organizations and members from under-served schools and communities. I was one of the fifteen. Six meeting agendas were designed to address the current state of science education and delivery in the San Diego Unified Schools, K-12, followed by themes of how children best learn science, articulation with university and college preparation, and alignment with the real world job market.

At a recent meeting of the BRTF, Dr. Fred Goldberg of San Diego State University was asked to provide the group with a succinct overview of what we know about how children learn science. Dr. Goldberg reminded the BRTF that Albert Einstein had already captured and articulated the essence of science learning in 1936. Einstein's words were scrawled across a black plasma screen facing the fifteen of us: "The whole of science is nothing more than a refinement of everyday thinking." Dr. Goldberg used these words to frame his presentation on the findings and implications of research on how students learn science, and to provide a vision for science education, whose foundation rests on scientific inquiry. He claimed that inquiry is too often taught in the service of learning content, but that scientists do inquiry in and of itself to discover new knowledge; it is this generation of new knowledge that must be privileged, especially as we prepare the next generation of minds to solve real and difficult problems that will require ingenuity and creativity.

And we *need* new leaders to solve real problems. Global warming is an actuality; but it is only one environmental threat to global climate change. A quick google search of the phrase “environmental issues” uncovers a plethora of alarming issues plaguing a new generation of youth. Browse the topic of your choice: global warming, renewable energy, green living and design, recycling, conservation, pollution, alternative and fossil fuels, environmental law and policy. The environment is in need of a new generation dedicated to the stewardship of a green world. The jobs today’s children will meet in the labor market twenty years from now are not yet even in existence. Is the knowledge and skills these children will need to solve real world problems reflected in the science educational programs of today’s schools?

Though the majority of the group consisted of staunch constructivists who share a vision of scientific inquiry, one vocal individual presented a very different view of science education- one resting on a foundation of factual knowledge, memorization, and direct instruction. He said that facts are good. We need to know facts. We need to be able to repeat facts. He made direct reference to the failure of such inquiry curricula as *Active Physics*, a district adopted physics curriculum imposed on ninth grade students and their teachers system-wide. He also spoke about the failures of another district-wide inquiry-based curricula, *Living By Chemistry*, also imposed on high school teachers with little professional development to accompany its arrival and expectations. He further claimed that inquiry approaches, in general, lacked content rigor and were loosely structured, resulting in large amounts of wasted time and "wrong answers" thrown out by students with the danger of their uptake by others as "scientific truth." In essence, he claimed, this was a civil rights issue. Schools situated in particular geographic locations get one method of what he considers "superior instruction," while many others receive what he called "the opposite approach," resulting in an inferior education, in his opinion. For this individual, "direct instruction," also known as "lecture-style teaching" was the "superior instruction," while inquiry-based approaches under all it guises- discovery –based learning, exploratory learning, problem-based learning, experiential learning, constructivist learning- was "the opposite approach."

*Dissenting Views on What Constitutes "Inquiry"*

As I listened to the heated discussion that followed, I realized there was no clear consensus on what constitutes "inquiry-based" instruction, even among this group of knowledgeable science educators. I heard several of the constructivists in the group attempt to argue what inquiry was and what it was not. In particular, one high school teacher in the group advocated strongly for the inquiry approach, claiming it teaches students *to think*. He went on to say that he routinely asks parents whether they want their children to be able to repeat facts, or whether they want them to be able to think critically and apply skills to new topics that they perhaps haven't seen before but can reason through, because inquiry-based instruction has afforded them both the skill and the opportunity to reason and think critically.

There was a cacophony of opinion in the room, despite the fact that inquiry is touted in the research literature as the premier method of teaching science. I could not help but think that this was, in part, due to a lack of explicit pedagogical models of how to conduct inquiry in classroom settings. I heard a defensive stance that inquiry is not discovery learning- not an approach where students are set loose to discover whatever they may.  I heard that there is inductive inquiry and there is deductive inquiry.  I heard that inquiry exists along a continuum, and I heard that it is the teacher asking good questions, as well as the students.  I heard that good scientific inquiry did indeed still involve a certain amount of direct instruction, but that it too, reserved space for the original ownership of abstract ideas arrived at through discourse.  Direct instruction, within the context of inquiry, provided the essential knowledge about the relationship among facts to arrive at concepts.

After much more discussion, we decided it was easier to say what inquiry was not, rather than to attempt to define it outright.  Inquiry was not the teacher always standing in front of the room, disseminating facts.  By the end, the entire group reached consensus around one important point: inquiry is an important component of science learning.  The group decided that inquiry, together with learning skills such as lab techniques, and essential facts and concepts was an effective and necessary component of science learning.  The group also agreed that the amount of inquiry can vary at different grade levels and that effective science instruction can consist of varying amounts of inquiry in different classes.  Even the original dissenter agreed to this, mostly harnessing his hopes for inquiry at the elementary level.

*Lack of Consensus Among Science Practitioners on the Necessity of "Inquiry"*

As I left the meeting, I thought about the lack of professional development that gave rise to some of the opposition by teachers toward the inquiry curricula adopted by the district. I thought too, about the civil rights issue one of the members raised at our meeting. Why do some students receive a teacher-centered science experience, while others learn to practice scientific inquiry? Why do some teachers succeed at inquiry, when others fail? And, given the large consensus in support of inquiry-based learning in the broader professional field (National Research Council, 1996, 2006, 2008; American Association for the Advancement of Science, 1993), why do some secondary science teachers still believe it is a "civil rights" issue to impose inquiry curricula on students? Using a qualitative research design, this study aims to help us further understand the norms and practices that effective teachers of inquiry utilize in their classrooms, as well as the opportunities they create in their classrooms for all students to enact science in the manner of professional scientists.

*Positionality: Transparency is the New Objectivity*

As a teacher educator in the field of science, I have thought deeply about outcomes. Outcomes are everything. We know that as educators. We live it as we lesson plan, as we design assessments for our students, for ourselves. What do we want to achieve in the end? It is the seminal question of education, really. What do we want our students to know, the youth of today, the stewards of tomorrow? In the field of science we want objectivity; we crave it. We want to see our facts in neat charts, tables, diagrams, and written text. We use the very word, objectivity, as a bulwark to protect our fiefdom from others. We objectify our experiences and observations. We are very good at making the concrete abstract through what Bruno Latour and Steve Woolgar (1979) refer to as the "black-boxing" of our work into neat little packages of abstractions, facts, theories, and laws. But, very often the processes, conversations, draft-thoughts, working hypotheses, and trial experiments upon which these "black-boxed" ideas are founded are left unexposed and mysterious- erased from the final form science that constitutes the growing canon of scientific knowledge.

Is this what I want to teach my middle school and high school teachers to accomplish? Do I want to help my teachers educate students to become protectors of fiefdoms discovered long ago? Or do I want my teachers to educate students for jobs to create a green economy for tomorrow by exposing them to the thought processes that lie inside the "black-box" of scientific discoveries? Again, outcomes are everything. It is critical we are clear on what we want for our students before we design learning experiences for them.

Recently, I picked up the local newspaper. There, I read various accounts of environmental problems argued by authorities one way, then another. I was reminded that teaching our children to look to authorities on climate issues or renewable energy sources is fruitless. Too often, authorities disagree with one another. What we need is a population who understands how to think through the processes these authorities have used; we need to educate a population to read the mechanisms behind the behaviors for which "authorities" advocate. We must teach students not to memorize the rule, but to understand the thinking and the processes that precede the formulation of those rules. Transparency is the new objectivity. We must teach our students to make transparent the understanding behind the objectification we could otherwise memorize and regurgitate as truth. If we are to face the real problems of tomorrow, our children must be critical thinkers of complex issues. In the world of learning theory, Piaget writes in terms of concrete operations and formal operations (Piaget, 1967). The notion of concrete operations follows us throughout our lives. It is, in fact, what we should aspire toward. When we know something, we can make it concrete. When we understand something, we can make it transparent, and need not hide behind hard objectification. Piaget is also credited with identifying the principal goal of education as being the creation of human beings who are capable of “doing new things, not simply of repeating what other generations have done.” This is what I want for my teachers and their students.

In my attempt to locate a field of interest that might best make an impact on the work I do with new teachers, I thought about the skills they bring with them to the university teacher education program with which I am affiliated. Most are placed as intern teachers in secondary ($6^{th}$ -$8^{th}$ grade or $9^{th}$-$12^{th}$ grade) schools located in low socioeconomic urban settings, where students come from culturally, linguistically, and racially diverse backgrounds. These teacher candidates are highly competent in their science content knowledge. However, they lack the skills necessary to plan lessons which will develop interactive discourse practices to effectively enact an inquiry approach to science learning. This same lacuna has been documented internationally (Abd-El-Khalick, et. al, 2004). In my experience working with these new teachers, it has not been difficult to convince them of the importance of inquiry; rather, my challenge has been to convey the necessity of increasing their awareness of the importance that discourse practices play in the implementation of inquiry curricula.

*"Anything Can Be Deconstructed…"*

With this outcome in mind, my most recent goal as a science educator has been to enter secondary classrooms with an eye to deconstructing them. This notion was motivated by a reading of a memoir by the musician Sting, who as a child would play 33 rpm records at 45 rpm to hear the bass parts revealed. Later, when he was learning to become a musician, he came to the epiphany that anything, no matter how complex, could be deconstructed and learned, if you slowed it down enough to really hear it. If Sting could learn to write and play music by deconstructing other people's music, I could learn to identify and teach the practices and strategies that exemplified outstanding science teaching in the secondary classroom.

My role as a science educator influenced my decision to conduct this study on inquiry-based practices in science. One of the roles my job entails is the supervision of new intern teachers in their placements at middle and high schools in an urban school district in Southern California. In this capacity, I have seen many new teachers struggle with, become discouraged by, and veer away from inquiry-based instruction. But, I have also seen teachers and their students thrive with the approach.

*Study Overview: Conducting Inquiry in Middle School Science Classrooms*

Using a qualitative research design, this study aims to help us further understand what conditions and factors foster the success of inquiry-based practices at the middle school level.

Drawing upon sociocultural learning theory as well as the frameworks of distributed cognition and embodied cognition, I can create a lens through which to view the middle school classroom as a collection of multi-systems working alone and in tandem with others to create a cognitive web of distributed learning. By answering the following research questions, I will contribute to our understanding of factors that inhibit and enhance inquiry in the classroom. I will also help to expose the processes inherent in Latour's notion of the black-boxing of science. My specific inquiries into teacher and students' ideologies of science teaching and learning will help ground the study in the realities of the classrooms in which I worked.

## *Research Questions*

The overarching research question in this study is: What factors promote inquiry-based instruction in middle school science classrooms? In order to answer this question, I developed three auxillary research questions. These sub-questions are:

1) What are teacher's beliefs about science teaching and learning at the middle school level?
2) What are students' perceptions of how their teacher's practice affects they way they learn science?
3) What factors affect students' ability to achieve more sophisticated levels of argumentation in the classroom?

The first two sub-questions will provide a context of the classrooms in which to situate the findings. And the last sub-question will provide a measure for determining what success looks like in an inquiry setting. Because argumentation is the prominent form of productive talk leading to the building of new scientific knowledge, it is used in the research design as one indicator of successful inquiry.

The purpose of this study is to identify the factors that enable and constrain students' opportunities and abilities to create sophisticated argumentation. Because argumentation is the prominent form of talk in science, if we can understand how quality argumentation is fostered in science classrooms, we can in turn better understand how to guide educators in establishing effective instructional environments that embrace an inquiry approach. My background as a science teacher educator, and my interest in preparing *all* youth for meaningful participation in tomorrow's society, influenced my decision to conduct this research at an inner city charter school dedicated to serving underrepresented populations. The specific aim of this project is to identify the factors affecting student argumentation and to construct a model of inquiry instruction teachers can implement in their middle school classrooms.

# Chapter 2- Science as a Social Process: What We Know

## *Overview of Chapter*

In order to place this study within the context of extant scholarship, I begin this chapter with a conceptualization of science as a social process, which serves as a lens through which to view the research of science communication. The conceptualization of science as a social activity, rather than as a fixed body of knowledge, requires teachers to consider how communication, processing, and meaning-making contribute to science learning. It also requires teachers to think deeply about what constitutes knowledge and understanding in science, and what instructional approaches best encompass these ideas. Therefore, this chapter explores theoretical perspectives of the nature of knowledge and understanding in science. This is followed by an examination of the debate over inquiry versus traditional approaches to science instruction. I then turn to the research focusing on the types – or modes of communication used in secondary science classrooms - with an emphasis on the verbal, written, and paralinguistic. Within the discussion of the research, special attention is focused on scientific argumentation – a core practice of expert scientists necessary to conduct science as a social practice. The chapter concludes with a discussion of pretermissions in teacher pedagogy likely to lead to the development of student argumentation in secondary science classrooms. I begin with a discussion of how research regarding science as a social practice can provide a theoretical framework within which to embed this study.

*Science as a Social Process*

As related in the introductory chapter to this work, it is imperative that we prepare *all* students equitably to participate in meaningful ways in the society of tomorrow. But this goal still eludes us. Researchers, teachers, policy-makers, parents and students can all provide ways of understanding the gap in science learning and achievement that still separates low-income, ethnic minority, and linguistic minority students from their more economically privileged peers. One in every four students in California is identified as an "English Language Learner" while nearly three-quarters of all K-12 teachers self-identify as "white" (California Department of Education, 2007). The glaring mismatch between a largely homogenous, white, middle class teaching force and the increasing ethnic diversity of the students they serve is not likely to change in the near future. For many language minority students and historically underperforming students, there exists a tension between science disciplinary learning, English language development, and academic discourse development (Rosebery, Warren, & Conant, 1992). And yet, science is a way of learning and thinking in its own right; from this perspective, both first and second languages serve as important means for constructing scientific meaning. Students from all backgrounds and communities bring with them everyday sense-making practices that harbor intellectual resources for learning science. Indeed, science is a social process. As Lemke explains:

> This is true even when a scientist is physically alone. Whenever we do science, we take ways of talking, reasoning, observing, analyzing, and writing that we have learned from our community and use them to construct findings and arguments that become part of science only when they become shared in that community. Teaching science is teaching students how to *do science*. Teaching, learning and doing science are all social processes: taught, learned, and done as members of social

> communities, small (like classrooms) and large. We make those communities by communications, and we communicate complex meanings primarily through language. Ultimately, doing science is always guided and informed by talking science, to ourselves and with others." (Lemke, 1990, p. xi)

Lemke's definition of the "language of science" clearly includes more than simply a written or verbal form. It encompasses all communication that arises through action.

*Using "All the Languages of Science"*

According to Lemke (1990), science learning is seen as the acquisition of cultural tools and practices, and as learning to participate in specialized forms of human activity organized into what he terms "the languages of science" (2006). These languages include semiotic resources such as the languages of visual representation, mathematical symbolisms, and experimental operations. Lemke defines "science talk" as all the manifold ways of communicating in science, not just literally "talking," as in speaking, science. It means "doing science through the medium of language" (1990, p. ix), where "language" is construed broadly as noted above. This "doing" includes:

> observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, writing, lecturing, and teaching in and through the language of science (Lemke, 1990, p. ix).

The goal of science education is to empower all students to use *all these languages* in meaningful and appropriate ways, and above all, to be able to functionally integrate them in the context of scientific activity. Often, teachers are not explicit about these languages, and do not foster an awareness of the multiple modalities through which the communication of scientific material is accomplished. Recent research in the field of science education has focused on communication as one crucial component of developing science literacy at the secondary level.

*Appropriating Constructs from the Literature: A Clarification of Terms*

In this chapter, I appropriate Lemke's definition of "science talk" under the umbrella of what I will interchangeably call "science communication" and "multimodal interactions." This chapter will not address science communication involving the use of advanced technologies; rather, it will explore research on science talk, writing, and paralinguistic features of communication in the secondary science classroom. Special emphasis will focus on scientific argumentation as a core component of the social process of communicating science, and on the relationship between gesture and speech as a medium for appropriating and communicating scientific understandings.

In this chapter, "discourse" has two meanings. One, I refer to the ways teachers and students communicate in the classroom. This view embraces the notion of "funds of knowledge" (Moll, Velez-Ibanez, & Greenberg, 1989) that shape the oral and written texts students use to make meaning as they move from classroom to classroom, and from home group to peer group, school, and community. Secondly, I refer to the primary function of discourse in the way that Gee (2005) defines it: as supporting the performance of social activities and social identities, and to support human affiliation within cultures. Communication becomes discourse when placed within the context of the social, cultural, historical, and political dynamics that bring it about. I also draw upon the work of Mehan (1979) in my examination of the social activities and social identities at play in the classroom setting, as I examine scientific discourse in light of the notion that science is its own form of culture (Hodson 2002). The research reviewed in this chapter is examined with an eye to how discourse furthers students' participation within that culture. I begin with a view into the nature of science itself.

*What is the Nature of Science?*

In order to understand *why and how* we communicate in science, we need to first understand the nature of science as a discipline itself. Unfortunately, science too often harbors the mystique of a dogmatic, authoritarian, and impersonal enterprise. Though there exists no official definition of what science "is," there does exist a significant consensus as to what the characteristics of the nature of Western Modern Science (WMS) *should be* relevant to science education (McComas, Almazroa, & Clough, 1998; Stanley & Brickhouse, 2000; Loving, 1997; Matthews, 1994). Within the perspective of Western Modern Science, "the nature of science" (NOS) is defined as the values and assumptions inherent to science, scientific knowledge, and/or the development of scientific knowledge (Lederman, Abd-El-Khalick, Bell, and Schwartz, 2002). Lederman and his research team have established themselves as leaders in this domain over the past decade, identifying seven aspects of the nature of science that target ideas students should develop and adults should understand (see Figure 2.1). This is a crucial step toward guiding science instruction from *what* scientists know, to *how* scientists know. Moving from a view of science as a large body of immutable facts that are always derived from the "scientific method," to a view of science as a creative, collaborative enterprise that leads to durable, but tentative scientific knowledge is key to developing a culture of scientific literacy among our youth. It is also paramount to the development of the types of curricula that might best evoke these beliefs in students.

**The Science Education View of the Nature of Science**
Lederman, N., Abd-El-Khalick, F., Bell, R., and Schwartz, R (2002)

Science is…
1. subjective (theory-laden), to a degree
2. socially and culturally embedded.
3. is based on both observations and inferences.

Scientific knowledge…
4. is tentative.
5. is based on and/or derived from observations of the natural world.
6. is created from human imaginations and logical reasoning.
7. Theories and laws are different kinds of scientific knowledge.

**Figure 2.1: The Science Education View of the Nature of Science**

According to these seven tenets, learning science in a secondary classroom, should amount to participating in the particular practices endemic to a "culture of science," encompassing its own language, creeds, material practices, perception, theories, and beliefs (Roth & Lawless, 2002). This includes the fundamental ways in which newcomers to the discipline learn to perceive and talk about natural phenomena- the way they conceive of "the nature of science."

How classroom activities are structured and which activities are privileged reflects teachers' beliefs about what constitutes the scientific enterprise. To assist students in developing these institutionalized views of the nature of science, some researchers suggest an explicit approach to instruction (Abd-El-Khalick & Lederman, 2000; Moje, Collozo, Carillo, & Marx, 2001; Sandoval and Morrison, 2003; Schwartz, Lederman, Khishfe, Lederman, Matthews, & Liu, 2002). Other researchers, however, claim that students do not change their ideas about the nature of science from such explicit instructional objectives (Feldman, 2003). Rather, they need multiple opportunities to reason about science while solving scientific problems. This leads us to the question: What is the best approach to teaching science?

### *Inquiry: Providing Access to Science as a Social Process*

For the past fifty years, disputes have been ongoing as to the best way to approach science instruction. On one side of the debate are those who advocate for a minimally-guided environment, whereby students discover or construct essential information for themselves (Bruner, 1961; Papert, 1980; Steffe & Gale, 1995). On the other hand, are those who argue that learners must be provided with direct instructional guidance on the concepts and procedures dictated by the discipline of science; the latter contend students should not be left to discover those ideas and procedures on their own (Cronbach & Snow, 1977; Mayer, 2004; Shulman & Keisler, 1966; Sweller, 2003). And yet, despite this debate, during the second half of the twentieth century, “good science teaching and learning” has come to be distinctly and increasingly associated with the term “inquiry” (Abd-el-Khalick, et al., 2004), which relies on the premise that students should construct their own understandings of the world around them. Past and present science education reform initiatives in the United States use the rhetoric of “inquiry” as a central term in their writings (American Association for the Advancement of Science, 1990, 1993; National Research Council, 1996, 2000). But why “inquiry” as opposed to other instructional approaches? What elements of the inquiry-based approach make it the preferred mode of science education in the view of most experts?

*The "Call" for Inquiry*

According to Ann Rosebery (1996) of the Exploratorium Institute for Inquiry, "Inquiry is a way of being in the world. It is a stance about one's relationship to the work, to people, to one's work, to knowledge." But why is it touted as the premier instructional method in science? As Dewey (1916) notes, inquiry helps us consider our past understandings in light of what we are learning, illuminating possibilities and helping us to choose which path to venture down next. Ultimately, inquiry is the very essence of the scientific enterprise itself. The fundamental nature of science, previously explored, is embedded in inquiry-based approaches to learning.

Over the past 20 years, our understanding about how people learn has changed. A plethora of recent research suggests that students are not empty vessels waiting to be filled with the knowledge of the teacher. Instead, advances in cognitive research and developmental psychology have transformed the way we think about teaching science. Today, educators and researchers understand that most people learn best through personal experience and by connecting new information to what they already know or believe. Students need to have opportunities to progress from concrete to abstract ideas, rethink their hypotheses, and adapt and retry their investigations before cementing them into new understandings of the concrete (Jarrett, 1997). It is not enough to sit and listen to teacher lectures. Because of this new knowledge about how people learn, national and state reform measures in science education call for a place for students to take an active role in their learning; these reform measures call for inquiry.

An inquiry approach to science instruction can be a very effective mechanism for better understanding the essence of science, its technical and reasoning processes, and the attitudes that accompany these processes. According to Denise Jarrett (1997) of the Northwest Regional Education Laboratory, this is rather like using our brain to study our brain. She explains that in order to understand the neurology or physiology of our brain, we use our brain's technical and reasoning abilities as well as certain attitudes, to carry out and report our research. When we finish, we have a better understanding of our brain because we followed the rules by which it operates, using its precision and logic to build our understanding of it. It is the same when we use the process of science to study science.

Effective inquiry necessarily involves an educator who is adept at facilitating science talk in the classroom with students. Many constructivist scholars consider that dialogue, argument, and reference to evidence are essential to developing new frameworks and understandings (Driver, Leach, Millar, & Scott, 1996). According to the National Science Education Standards (NSES):

> [Inquiry] involves making observation; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (NRC, 1996, p.23).

Such inquiry includes student-centered projects, involving active engagement in meaning-construction, with teacher guidance (Krajcik, Blumengeld, Marx, & Soloway, 1994; NRC, 1996; Roth & Roychoudjury, 1993). This approach provides a learning context conducive to developing knowledge about the methods and activities through which science progresses, leading in turn to more enlightened views of the nature of science (Schwartz, R., Lederman, N. & Crawford, B, 2004). It allows for a view of science as a "verb," rather than a "noun."

*The Argument Against Inquiry*

But the constraints of our current high stakes accountability systems informed by No Child Left Behind (NCLB), pressure many secondary teachers into privileging the "telling and showing" mode of science teaching over more interactive forms of communication (Loughran, 1994). To be sure, a direct-instruction approach is a faster format for instructional delivery and "coverage" of state standards than more contemplative inquiry-based approaches that necessitate built-in time for discussion and questioning. To address this, education reform literature recommends that teachers focus on essential topics (AAAS, 1990) that are likely to provide a foundation on which to build more knowledge over a lifetime. States are also beginning to respond to this dilemma by re-examining required standards and curriculum goals.

However, the argument for a "superior" view of direct instruction approaches stems from more than just issues of time. For years, educators and researchers have debated whether it is more important to teach the products or the processes of science. Often, due to the time it takes to conduct meaning instruction of "process" science, a dichotomy is struck between the two, in favor of teaching a "products of science" approach. Those advocating for a "process-approach" have long advocated the use of laboratory activities in science classrooms as an ideal way for students to challenge naïve conceptions first-hand and develop scientific understandings (American Association for the Advancement of Science [AAAS], 1990; Singer, Hilton, & Schweingruber, 2005). However, some researchers suggest that while labs are effective for developing students' processing and reasoning skills, the ambiguity inherent in students' experiences with natural phenomena in labs can create a significant impediment to student learning when compared to knowledge that may be gleaned from lectures and textbooks, which "black-box" science through objectification into neat facts, charts, and other representations.

In fact, Kirschner, Swellwer & Clark (2006) argue that minimal guidance during instruction does not work. They site the following approaches, as all-inclusive in their definition of "minimally-guided instruction": discovery learning (Anthony, 1973; Bruner, 1961); problem-based learning (Barrows & Tamblyn, 1980; Schmidt, 1983), inquiry learning (Papert, 1980; Rutherford, 1964), experiential learning (Boud, Keogh & Walker, 1985; Kolb & Fry, 1975); and constructivist learning (Jonassen, 1991; Steffe & Gale, 1995). In their critique of the "minimally guided approach," Kirschner et al. (2006) are quick to name these as "essentially pedagogically equivalent approaches" (p. 75), which do not consider the relations between working memory and long-term memory. Specifically, Kirschner et al. (2006) claim that minimally-guided approaches do not account for the fact that long-term memory is the central, dominant structure of human cognition, and that it is from this feature of memory that experts in any area derive their skills. They use the example of chess players to illustrate their argument. And yet, their argument dissipates when we consider a domain of science, such as physical science, where students' "funds of knowledge" (Moll, 1989), rather than factual prior knowledge, can be instrumental in the learning process. Their claim is that "the aim of all instruction is to alter long-term memory," (p. 77). What they fail to consider is that learning science is not about attaining factual knowledge to store in long-term memory. It is about learning to think the way that scientists think, and to become socialized into the habits of mind that will allow for the continuation of doing and talking science, the way Lemke refers to science.

Kirschner et al. (2006) further argue that inquiry approaches rely too much on working memory; in so doing, they claim that working memory is not free to contribute to long-term memory because while working memory is searching for problem-solutions, it is not available and cannot be used to learn. But, what the authors neglect to note, is that this same process must necessarily be followed in direct instruction approaches, as working memory searches for connections to current schema before becoming laid down into long-term memory.

Essentially, the argument is often summarized by opponents of inquiry that: products are taught more efficiently using expository (deductive) methods, such as lecturing and closely directing students' learning, and processes are best taught using discovery (inductive) methods, such as laboratory and field work. George E. DeBoer (1991) in *A History of Ideas in Science Education* identifies differences between product and process in science education. Product is science content, he says, the knowledge base that goes by familiar names like biology, astronomy, and chemistry. Examples of the products of science include its facts, laws, theories, and models. These are commonly found in texts and journals. Scientific process, on the other hand, might involve technical processes like using a microscope or expressing an hypothesis or prediction. Scientific processes often involve behaviors and attitudes, such as curiosity, imagination, honesty, and coping with ambiguity.

*The Predominance of Inquiry and the Challenges that Remain*

In his review of research on inquiry, Anderson (2002) assures us that inquiry approaches do indeed produce positive results with respect to outcomes in scientific literacy, science processes, vocabulary knowledge, conceptual understanding, critical thinking, and attitudes about science. However, he adds that it is not inherently obvious *how* to guide teachers in following such an approach. It seems, then, that any exploration about what the research says about inquiry instruction leads to a discussion of the ultimate objectives for science education, a topic with which I began in Chapter 1. Those who argue on behalf of direct (deductive) teaching of science content do so, largely because they consider it unlikely that students will discover for themselves the scientific knowledge that took "great minds" centuries to construct. And those who support an inquiry approach contend that lecture methods may develop students' learning of facts, such as vocabulary and classifications, but inquiry-based learning, such as guided laboratory investigations, develop students' technical and reasoning skills, as well as important scientific habits of mind. The educational reform of the 1990s and beyond proposes that scientific inquiry can address content *as well as* process.

One of the common misconceptions of inquiry approaches to science instruction is that direct instruction is not a necessary component. Nothing could be further from the truth. In fact, in order to assure that curriculum goals are met in regards to content, it is often necessary that a teacher prepare students for an inquiry activity by first teaching some basic facts and vocabulary (Jarrett, 1997, NRC, 2006). Students cannot be asked to inquire about something if they don't have a foundation on which to build (Brown & Campione, 1994; Flick, 1995). It is also true that activity alone, without guidance or connection to meaningful content, can lead to "mindless" involvement (Jarrett, 1997). Hiebert and colleagues (1996) emphasize that learning must be embedded in purposeful activity, but that activity alone does not guarantee good inquiry. In fact, the literature on inquiry-based science largely supports using guided-inquiry techniques that include "collaboration among peers, access to many written and electronic sources, and most importantly, focused conversations with science experts, teacher, and mentors for the purpose of concept construction" (Jarrett, 1997, p. 22).

This places great pedagogical demands on teachers; it also requires the establishment of a classroom climate conducive to inquiry, where students feel safe to share, without fear of ridicule or judgment. In fact, according to Caine and Caine (1991), a state of "relaxed alertness" is required for students to become ready and able to respond to subject matter, by asking questions that personally engage them. Caine and Caine (1991) assert that all learning is impacted by the state of mind of the learner and the atmosphere in a learning environment. "Relaxed alertness" consists of a combination of high challenge and high expectations with low threat in the learning community as a whole; in this state, the mind is situated in a combined state of confidence, competence, and intrinsic motivation. The core foundation for developing "relaxed alertness" is an orderly and caring community in which relationships are built on trust and respect. These are not easy conditions to implement and continuously foster in today's secondary classrooms.

Yet, aside from its critics, inquiry remains at the center of science curricula from kindergarten through college. National standards emphasize the investigative nature of science and the importance of students' active engagement in the construction of scientific ways of knowing and doing (NRC, 1996, 2008; AAAS, 1993).

### *Challenges To Teaching Inquiry*

For teachers desiring to teach according to such an approach, many challenges present themselves. One of the keys to inquiry is to enable students to interact verbally with their teacher and peers (Tobin & Fraser, 1991) by providing questions that spark high-level thinking, as opposed to literal recall questions (Jacobsen, Eggen, & Kauchak, 1993). But how does one engage every student in class discussion? How does one promote effective questioning? Another strategy often utilized in inquiry approaches is the use of a non-threatening and encouraging debating style as well as positive feedback during activities and social interactions (Tobin & Fraser, 1991). But how does one balance this with effective management? Inquiry can also place great demands on a teacher's content knowledge (Magnusson & Palinscar, 1995), since by engaging students in debate and negotiating, a teacher must rely even more heavily on expertise of subject matter in situations requiring quick thought from multiple perspectives. What, though, in fact, constitutes "knowledge" in science?

## *What Constitutes "Knowledge" in Science?*

For new secondary science teachers, leading students through exploratory lessons is not always an easy task. Just as science learners come to science classes with conceptualizations of the phenomena to be studied, new teachers enter education programs with existing conceptualizations of what constitutes scientific “knowledge” and how science is learned and ought to be taught, based on many years of their own successes in schools. In fact, researchers have documented that many pre-service teacher education students “carry around with them views of teaching which, like many in the community, revolve around the belief that teaching content is a matter of telling or showing, [and] also that learning means remembering” (McDiarmid, 1990, cited in Loughran, 1994, p. 366). A naïve view of science as a set of immutable facts in turn lends itself to a naïve view of precursors to complete knowledge and understanding as “right” or “wrong,” - as something a teacher can confirm or attempt to overcome, avoid, or eliminate (Smith, diSessa, & Roschelle, 1993, 1994).

The notion that students arrive at school with conceptions about the world that differ from scientists,’ and that these misconceptions need to be addressed through instruction, is not a new idea. What is “new,” however, is the manner in which such conceptions are viewed. Most teachers do not possess more than a rudimentary schema of the nature of students’ prior conceptions. Hammer (1996) outlines the challenges of viewing such conceptions from solely a “misconceptions” point of view, as cognitive units of knowledge to be avoided, dismantled, or overcome. He contrasts this theoretical approach with diSessa’s (1987) alternative account of phenomenological primitives, or p-prims. P-prims consist of fragmentary bits of knowledge that often represent students’ first encounters with the physical world. For example, one such p-prim is “closer means stronger.” A child might have learned that the closer his hand approaches to a flame, the hotter the feeling on his hand. This is not an incorrect assertion. However, when applied to a rationale for why the earth is hotter in summer than winter, this p-prim of “closer is stronger" is translated into "because the earth is closer to the sun in summer," an incorrect assertion.

Hammer argues that diSessa's p-prims perspective allows one to view knowledge as occurring "in pieces" of intuitive knowledge. In this model, intuitive knowledge is made up of more fragmentary structures that can become the building blocks of new learnings. To diSessa, the misconceptions perspective "confuses emergent knowledge, acts of conceiving in particular situations, for stable cognitive structures" (Hammer, 1996, p.98). The misconceptions view also contradicts constructivism, in that if students harbor fundamentally different conceptions, then from what can they construct expert understandings? A p-prim model would allow a teacher to approach instruction looking for student reasoning that can be built upon to arrive at more expert understandings. This approach does not simply label a student's final answer as correct or incorrect, but rather, is concerned with finding pieces that are in certain contexts correct, and can be used as foundations from which to build larger premises about science.

Strikingly absent from the schema of most new teachers is a sophisticated understanding of the nature of scientific knowledge and of how student "misconceptions" contribute to learning. If this phenomemological-primitives model were embraced by new teachers, they might be more likely to look for interstitial spaces within their curricula in which to situate classroom talk. Rather than checking off content outlined by state standards, teachers might be more apt to use classroom time to value and build upon student conceptions; discussions might become the privileged domain. Furthermore, if teachers understood the nuances of p-prims, they might better be able to carry out the role of "facilitator," rather than simply the arbiter of right and wrong answers. When two students, for example, articulate two incorrect notions, how a teacher facilitates further dialogue should depend on how those students arrived at their ideas (whether from a misconceptions or a p-prims perspective). How a teacher conceptualizes the tasks for instruction depends significantly on what s/he perceives in students' knowledge and reasoning. This is a key area of consideration missing from new science teachers' instruction. The teacher's role from here is to identify students' current states of understanding and then to construct situations or problems that may create the need to learn what the teacher is presenting before them. This suggests that teachers must possess deep and broad knowledge of their subject so they can recognize changes in students' ideas and developing scenarios that will create an intellectually intriguing environment. Instructional approaches that promote the development of such ideas are also grounded in evidenced-based knowledge of how students learn from the fields of psychology and cognitive science. In the section that follows, I explore what we know about learning according to theories of constructivism.

## *How People Learn Science*

### *Cognitive Theoretical Perspective on Learning*

Constructivism is a term used widely in educational research over the past 30 years and presents a variety of different meanings. I refer here to the term as a theory about how students learn that focuses on the productive role of learners' existing ideas and their interpretation of the reality they experience (Smith, diSessa, and Rochelle, 1993; Steffe and Thompson, 2000: von Glaserfeld, 1995). As such, constructivism originates from Piagetian roots. The constructivist theoretical assumptions about learning and cognition include viewing learners as active builders of knowledge, and learning as fundamentally interpretive in nature. Learning from this perspective is the reorganization of cognitive structures or "accommodation." This occurs when a new conceptual structure is formed or an existing structure is reorganized or modified to account for an experience that does not conform to previously constructed structures (Steffe and Thompson, 2000; von Glaserfeld, 1995).

From this perspective, cognition is viewed as "an instrument of adaptation, the purpose of which is the construction of viable conceptual structures" (von Glaserfeld, 1995, p. 59). When confronted with a new situation, a learner will either assimilate or accommodate the new information to maintain cognitive equilibrium. If the experience can be explained or understood within the learner's existing cognitive structure, then the learner maintains her cognitive structure, known as "assimilation." If, however, the experience contradicts the learner's cognitive structure, this results in disequilibrium, or perturbation. The desire to maintain cognitive disequilibrium drives the learner to reorganize the existing cognitive structure or generate a new one; this results in "accommodation."

Since learning from this perspective derives from a need to maintain cognitive equilibrium, many researchers suggest that instruction should provide an experiential basis for cognitive conflict such that the complex and gradual process of cognitive change can take place (Chinn & Brewer, 1993; Hammer, 1994, 1996; Minstrell, 2001; Posner, Strike, Hewson, & Gertzog, 1982; Smith, diSessa, and Roschelle, 1993). This assumption posits that if a learner's cognitive structure cannot account for analogous information, then the learner will likely modify his or her cognitive structure. To effect this cognitive change, however, the *learner* must view the information as contrasting with existing knowledge.

*Social Theoretical Perspective on Learning*

Educational researchers from a social perspective believe that learning and understanding are inherently social and cultural activities (Brown, Collins, & Duguid, 1989; Cobb & Yackel, 1996; Gilbert & Yerrick, 20010; John-Steiner & Mahn, 1996). Cognition and learning can be examined as situated in a broad social institution, a cultural setting, or through interpersonal interactions. In each of these settings, there are various ways to theorize about the relationship between the social context and the individual's knowledge construction. In this section, I briefly address one of the perspectives from this social learning approach: the sociocultural perspective.

<u>Vygotsky's Sociocultural Perspective</u>

From the sociocultural perspective, education and learning are viewed as situated in a larger social and cultural structure. Vygotksy contended that each human mind was unique and affected by "social, historical, cultural, and material processes" (John-Steiner & Mahn, 1996, p. 196). From this perspective, the link between the community and individual processes is a direct one. Ideas, thoughts, and knowledge occur first on a social plane and are then internalized into the psychological plane (Cobb & Yackel, 1996; John-Steiner & Mahn, 1996). "Any higher mental function, " Vygotsky (1978) argued, "was external and social before it was internal" (p. 197). Vygotsky used dialectics to make sense of the contradiction between individual and social processes; the individual constructs the social and, at the same time, is constructed by the social (John-Steiner & Mahn, 1996). Sociocultural research focuses on how this "co-construction of knowledge" – of social meaning and individual meanings, is internalized.

For sociocultural theorists, collaboration is an essential component for facilitating internalization because thought and speech are intertwined (John-Steiner & Mahn, 1996; Lemke, 2001). Language and thought are internal processes in a constant state of change depending on the social context. The people present, the situation, and the previous words that have been said influence one's decision to speak and the words one uses. All these factors affect what thoughts the individual generates. Within the research, there exists a dominant belief that teachers should design instructional practices that parallel the constructivist epistemology of student learning (Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1985). Yet, theories regarding the social aspects of learning must also be considered because they help to account for differences in student learning as a result of context and interpersonal interactions. Viewing learning as a process of both individual and social construction provides a conceptual framework for understanding the learning of students. This coordination of the cognitive and the social perspectives is captured well in the scientific art of "argumentation" – the language of science itself.

### *Argumentation: The Core Activity of Science*

Among all types of "talk" in which scientists engage, argumentation is considered the core activity in that it is the medium through which social construction of scientific knowledge occurs (Driver, Newton, & Osborne, 1998). A seminal contribution to the field of argumentation theory is that of Toulmin (1958) in *The Uses of Argument*. Therein, he provides a template for the description of students' arguments and a model specifying the components of reasoning as data, claims, warrants, backings, qualifiers, and rebuttals. According to this model, the basic argument structure might consist of the following chain within a sentence: because (evidence)…since (warrant)…on account of (backing)…therefore (conclusion). Toulmin's model is useful to assess the structure of arguments, although the knowledge and expertise of the science content teacher is still necessary to ascertain the correctness of these arguments. Any classroom seeking to advance education about science must assign the role of argument a high priority if it is to give a fair account of the social practice of science (Driver, Newton, Osborne, 1998). Unfortunately, most teachers lack the pedagogical skills necessary to advance progress in the area of scientific argumentation (Driver, Newton, & Osborne, 1998). Any classroom which does not provide such opportunities for students to practice the construction of argument is missing the essence of what scientists really do; such classrooms may unintentionally perpetuate the myth of the scientific enterprise as a discipline already discovered - one comprised of a set of facts to be memorized and learned from past scientific greats.

*Language: The Mortar of Discussions*

In examining the way in which argumentation and inquiry are used in science classroom settings, language is necessarily a key component of analysis. Language is the mortar of discussions and inquiry itself. As such, it is the vehicle through which changing views are communicated and established within science communities. How then to best structure opportunities for language practice in science classrooms? In the years since the release of documents intended to guide the latest round of science education reform, the most consistent message has been the call for deep conceptual knowledge in students (American Association for the Advancement of Science, 1990, 1993; National Research Council [NRC], 1996). The call for conceptual change has additionally been linked to a need for inquiry-based instruction (Mestre, 1994; NRC, 2000), discussed previously.

However, it has been pointed out that classroom inquiry models differ from authentic scientific inquiry that scientists conduct in their everyday practice (Roth, 1995). In fact, the real world of science is not typically represented in the classroom contexts of inquiry (Chinn & Malhotra, 2002; Driver, Leach, Millar, & Scott, 1996; Roth, 1995; Ryder, Leach, & Driver, 1999). With all the "talk" of inquiry, little has been done to train teachers in the pedagogy necessary to drive such inquiry in terms of assisting students in constructing their understandings through the skill of scientific argumentation (Driver, Newton, & Osborne, 1998). So what can assist teachers in creating opportunities to authentically imitate the work of expert scientists?

For teachers desiring to incorporate scientific inquiry into their classrooms, controversy persists among scholars regarding what actually constitutes inquiry, as discussed previously. One school of thought advocates "inductive" inquiry, another "deductive" inquiry. In the first, science proceeds by discovery of a phenomenon, where students explore a scientific idea they are curious about, and then propose a theory or model to account for it. In deductive inquiry, teachers provide the theory or model to be explored and solved, and students use this construct as a tool to explore phenomena. Research by Schwartz, Lederman, & Crawford (2004) with pre-service teachers supports the claim that just "doing science" in a deductive manner with students is insufficient for one to develop conceptions of the nature of science as promoted in science educational reform documents. Alternatively, when teachers engage students in inductive inquiry with the use of reflective activities in journal writing and seminar discussions, students are better able to construct genuine scientific understandings, more consistent with the work of real scientists. The instructional implications would seem to be that science educators provide students with opportunities to encounter puzzling observations over questions they create, and then attempt to explain them (Lawson, 2005). Questions and discussion provide the types of forums wherein inquiry-oriented instruction can be explored successfully. Conscious and skilled use of reasoning patterns and thoughtful modes of communication can lead to the type of scientific literacy called for by current science education reform. Yet, currently, the communicative approaches needed for effective constructivist teaching and learning are generally lacking in classroom settings (Yore, Bisanz, & Hand, 2004). In this sections that follow, I examine the research on scientific communication via verbal, written, and paralinguistic modalities. I begin with an exploration of the frameworks teachers commonly use to conduct verbal discourse in their science classrooms.

*Frameworks for Science Classroom Discourse*

Teachers utilize a variety of communicative resources to support the meaning-making process in secondary science classrooms (Kress & Van Leeuwen, 2001). These resources can include pictures, diagrams, graphics, models, gestures, and actions – all extending from the flow of verbal language. While the multimodal nature of classroom interactions is inescapable, many researchers nonetheless privilege verbal talk as the central mode of communication in the science classroom (Mortimer & Scott, 2000; Leach & Scott; 2002). From their studies in England and Brazil, Mortimer & Scott (2000) have developed a useful analytical framework for examining communication in the science classroom. Their model consists of a number of components focusing on the role of the teacher in making available to students what they term "the scientific story." Though all are essential, it is the component of "communicative approach" which is paramount to an analysis of science discourse.

**Table 2.1: Four Classes of Communicative Approach (Mortimer & Scott, 2003)**

| | INTERACTIVE | NON-INTERACTIVE |
|---|---|---|
| DIALOGIC | A. Interactive/dialogic | B. Non-interactive/dialogic |
| AUTHORITATIVE | C. Interactive/authoritative | D. Non-interactive/ authoritative |

Table 2.1 illustrates Mortimer and Scott's notion that a sequence of talk can be dialogic or authoritative in nature on the one hand, and interactive or non-interactive on the other. Each of these two distinctions can be viewed along a continuum. What constitutes talk as dialogic is the fact that more than one point of view is represented, and ideas are explored

and developed, rather than produced by a single group of people or by a solitary individual (Mortimer and Scott, 2003). In an authoritative stance, a single voice is heard, and there is no exploration of different ideas. Talk can also be interactive in the sense of allowing for the participation of other people, or non-interactive, in the sense of excluding the participation of other people. Any sequence of classroom talk can be located on a continuum between interactive and non-interactive, and between dialogic and authoritative talk. This framework provides a useful heuristic for examining and analyzing the different ways teachers can work with their students in developing ideas, although it does not tell us how each of these communicative approaches is actually achieved in the classroom, and the framework privileges the verbal domain of communication.

*Predominance of I-R-E Discourse Pattern*

Analysis of typical classroom practice in the United States suggests that most patterns of classroom discourse follow a turn-taking format characterized as the "triadic" Initiation-Response-Evaluation (I-R-E) sequence (Mehan, 1979; Cazden, 1986). Initiation (I) is normally accomplished through a question from the teacher, followed by a student response (R), and ending with an evaluation statement (E) from the teacher (sometimes replaced by an "F" for feedback). This pattern of discourse can also occur in a chain of interactions, as an I-R-F-R-F-… form, where the elaborative feedback from the teacher is followed by a further response from the students and so on. According to Mortimer and Scott (2003), teachers can use a variety of interventions to sustain student involvement in talk, and increase the typical triadic interaction pattern, but researchers have found this I-R-E pattern to be the default, if not the dominant, form of discourse in American classrooms (Mehan, 1979; Cazden, 1986 Lemke, 1990; NRC, 2008). While this type of discourse has been determined to be helpful in reviewing information, or in assessing what students know, it has not been shown to be productive in supporting the type of discourse likely to lead to complex reasoning or argumentation, critical to science learning (NRC, 2008).

*Six Productive "Talk Moves"*

The type of discourse that supports scientific argumentation looks very different from the classic I-R-E pattern. In fact, six classroom "talk moves" have been identified as productive in helping students to clarify their ideas and expand their reasoning and arguments in science classrooms. These "talk moves" are depicted in Figure 2.2 below:

| Talk Move | Example |
|---|---|
| Revoicing | "So let me see if I've got your thinking right. You're saying __________?" (with space for student to follow up) |
| Asking students to restate someone else's reasoning | "Can you repeat what he just said in your own words? |
| Asking students to apply their own reasoning to someone else's reasoning | "Do you agree or disagree and why?" |
| Prompting students for further participation | "Would someone like to add on?" |
| Asking students to explicate their reasoning | "Why do you think that?" or "What evidence helped you arrive at that answer?" or "Say more about that." |
| Using wait time | "Take your time…We'll wait." |

**Figure 2.2: Six Productive Classroom Talk Moves (Michaels et al., 2008)**

In the six examples above, we see the teacher choose from a variety of strategies that range from restating a student's idea in "revoicing," to asking for additional input from another student, to asking for clarification, to simply using "wait time." In addition to these "talk moves", Michaels et al., (2008) have found that teachers can also engage students in a variety of "talk formats" that lead to deeper engagement with the content. These "talk formats" include: partner talk, whole-group discussion, student presentations, and small-group work. These "talk moves" and "talk formats" are effective because they allow for students' prior ideas to surface, improve students' abilities to build scientific arguments, make students aware of potential discrepancies in their thinking, provide a context in which to develop reasoning skills, and potentially increase motivation by enabling students to become invested in their peers' ideas and claims (Michaels et al., 2008).

*"Position-Driven Discussion"*

Another type of useful talk format in the science classroom is called the "position-driven discussion." This is a very particular type of discussion in which a teacher poses a question for which there are generally only two to three reasonable answers. This type of discussion is particularly useful when a teacher desires to push for divergence in predictions and theories about a particular scientific phenomenon. It is often used over a demonstration. This type of discussion capitalizes on "the wide variety of life experiences and resources inherent in an ethnically and linguistically diverse group of students" (Michaels et al., 2008, p. 94).

*Modes of Communication in the Science Classroom*

> *In a science master of education class, one of us was discussing with a group of teachers the difficulties students have in learning some science concepts. One of the teachers commented that very often students "have the concept, but just can't put it into words." There was much nodding of heads from the other teachers to support this view. However, one teacher challenged the idea, arguing that understanding something means that you can articulate it and that "we don't have some kind of mysterious 'brain waves' running around inside our heads which allow us to think things…it's just words, it's just language. If you can't say it, you don't understand it!" This seemed like just the point for us to start talking (and thinking!) about Vygotsky. (Mortimer & Scott, 2003)*

*Science Talk*

Of all the literature on language and science, classroom discourse as science "talk" dominates the most recent research studies in the field. Studies in this division are mostly unimodal, focusing solely on the verbal component of discourse, without factoring in semiotic features of language. Indeed, science education research is only beginning to move from a unimodal view of communication, centered in written and oral language, to a multimodal view of communication, based on the interactions of speech, gesture, and visual representations. I have categorized the studies regarding verbal discourse into the major themes of: questioning strategies, collaborative learning, role-playing and debate, and scientific argumentation. Following these studies, I will review the research on writing and paralinguistic features of science communication.

Questioning Practices

Research on the use of questioning in science predominantly emerged during the nineties. Findings in general reveal that developing students' abilities to ask more and better questions within inquiry settings leads to deeper conceptual understanding of science content. Chin (2002) categorizes questions that students ask as basic information questions or wonderment questions, the latter of which is indicative of a deeper approach to science learning. Problem-solving activities have been shown to elicit more and a broader range of wonderment questions than teacher-directed activities (Chin, 2002). In attempting to develop scientific literacy among students, teachers must create effective learning environments in which students are given opportunities to ask not just relevant and scientifically sound questions (Penic, Crow, & Bonnsteter, 1996), but also wonderment types of questions. Usually questions asked during a lesson are those initiated by the teacher. Questions that are initiated by students do not emerge spontaneously, but need encouragement from the teacher; and even then, they are usually only informative-level questions (Dillon 1988).

In general, posing critical-type questions in the midst of specific experiments can avoid the general factual-type student questioning (Shodell, 1995). Van Zee and Minstrell (1997) have identified the "reflective toss," a particular kind of question that teachers can ask to give students responsibility for thinking. This sequence usually consists of a student statement, a teacher question, and additional student statements. The teacher question replaces the more usual evaluative comment in the traditional triadic pattern. More recently, Cuccio-Schirripa and Steiner (2000) suggest that questioning is one of the processing skills that is embedded in critical thinking, creative thinking, and problem solving. This is in alignment with the results of a study conducted by Dori and Herscovitz (1999), who found that fostering 10$^{th}$ grade students' capabilities to pose questions improved their problem-solving abilities. Similarly, students are able to develop their skills at asking more and better questions as a result of participating in inquiry-type chemistry laboratories (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005).

Using Mortimer and Scott's analytical framework, it would seem that greater use of effective questioning practices would affect the degrees of interaction between teacher/students, as well as the degree to which the questioning practices are dialogic versus authoritative in nature.

## Collaborative Learning

Studies in collaborative scientific reasoning have yielded conflicting results with respect to what works best for learning. Recent studies in peer- and teacher-guided discussions in middle school science classrooms reveal that teacher-guided discussions are a more efficient means of attaining higher levels of reasoning and higher quality explanations, but that peer discussions tend to be more generative and exploratory (Hogan, Nastasi, & Pressley, 2000). Perhaps due to issues like these, there has been a general shift of interest from studying the content of collaborative activities to a specific focus on discourse patterns within collaborating groups. Student engagement in collaborative explanation has been shown to promote scientific understanding, but questions have been raised as to whether these benefits stem from students working and talking together or from their engagement in the activities themselves.

Chan (2001) has found that peer collaboration and discourse patterns in learning from incompatible information reveal that peer collaboration must be implemented wisely, as it does not always produce effective results. Peer effects with high school students may depend upon the nature of the collaborative interactions involving problem recognition, formulation of questions, and construction of explanations. Tools such as graphical evidence mapping, tabular representations, and word processors have been shown to help assist collaborative groups in constructing scientific understandings (Suthers, & Toth, 2002). The role of prior knowledge in collaborative-discovery processes is also essential to guiding the learning process in science. Prior knowledge does influence the discovery process through dyadic conversation. Heterogeneity with respect to prior knowledge has been positively linked to the number of utterances made in the discovery process categories of "hypothesis generation" and "experimentation." However, collaboration between extremely heterogeneous dyads is difficult when the high achiever is not willing to scaffold information and work in the low achiever's zone of proximal development (Gijlers, & de Jong, 2005). Such information could be useful in designing what Hellerman, Cole, & Zuengler (2001) have termed "thinking communities." Through their analysis of two case studies from science classes, learning and achievement were accomplished through the construction of thinking communities in which the discourses practices between teacher and students varied according to the unique needs of each "community" of learners. This would seem to be a case where the framework of Mortimer and Scott (2003) could be useful in examining the way in which the four communicative approaches promote the unique demands of groups of students, rather than using a one size fits all approach in the use of discourse.

Debate/Role-playing

One purpose of science education is to train students to articulate their thoughts in a clear manner; another is to sustain and express their ideas within the exploratory stage, irrespective of whether they are "right" or "wrong." Colucci-Gray (2006) has found that debate and argumentation can be one means of achieving both purposes. Teachers in this study proved effective in exposing the students to a multitude of interests and points of view, and in developing critical attitudes toward different forms of knowledge and ways of knowing. Similarly, analysis of classroom debating strategies in the field of biotechnology has concluded that argumentation to be one key to the build-up of knowledge and a crucial aspect of democratic scientific education (Simonneaux, 2002). One documented disadvantage of the debate-approach was that the win/lose nature of some debates can be a potential obstacle to the full understanding of the issues and ethical implications of the resulting class decision (Colucci-Gray, 2006).

Role-play can be conceived of as another form of simulating public decision-making processes (Simonneaux, 2001). Such a strategy is seen to be effective with studies of global environmental and social issues in science. Weinstein calls for science educators to begin accepting that the power of science education lies precisely in the ways it is inauthentic, or, "in the ways it permits exploration of the imaginable rather than the merely is" (2004, p. 259). He suggests that through "careful…playful enactment," students can try on the ramifications of injustices as a means of exploring the possible agency of themselves and their teachers, and others in the scientific world wherein they live. This refocuses the attention on the ways that different curricula position, include, and exclude discourse (Lemke, 1990). It also shifts attention toward social relationships and away from merely seeking to ask if an answer is right. As the science education curriculum undergoes an epistemological shift toward the legitimization of a multiplicity of views on global issues, role-play and debate modules could facilitate the process of socialization of students and an adoption of scientifically literate identities.

Scientific Argumentation

Socializing young people into the norms of scientific argument has been one area in which science education has been lacking (Driver, Newton, & Osborne, 1998). Contact with hands-on science activities does not necessarily make students think more critically (Driver, Newton, Osborne, 1998). Something appears to be lacking in bridging the "doing" of science with the "talk" of science and the "critical thinking" required to solve authentic problems.

In The *Uses of Argument* (1958), Toulmin presents a useful model describing the constitutive elements of argumentation. This account has been drawn upon by many science educators to provide a template for the description of students' arguments in terms of claims, data, warrants, and backings (Driver, Newton, & Osborne, 1998). If also afforded physical manipulatives with explicit verbal instruction in such terms as "claim, data, and warrant," it is possible students could potentially be taught to construct increasingly sophisticated quality arguments, as measured on the five level rubric developed by Osborne, Erduran, & Simon (2004) using Toulmin's argument pattern (TAP). As researchers acknowledge, scientific arguments are not based solely on points made through speech, but also through "semiotic gestures, pointing at objects, nodding, etc…, especially in science where manipulable materials are used" (Driver, Newton, & Osborne, 1998, p. 294). Therefore, the deliberate use of physical objects during the construction of scientific argumentation, or in the development of mechanistic reasoning, (Russ, & Hutchinson, 2006) could only benefit the quality of students' inquiry, irrespective of whether a "right" or "wrong" answer is achieved. Good scientific inquiry does not guarantee true knowledge, after all- historically or in the classroom (Russ, & Hutchinson, 2006).

*Writing In Science*

During the late 1960s and 1970s, several British researchers began promoting closer integration of writing with education in all subject areas. Recent thinking on the interaction of language, culture, and attitude in the learning of science calls for interactive classrooms with expanded modes of communication (Garaway, 1994), including writing. One recent study in particular has shown that opportunities for students in science to choose between oral and written discourses leads to success in demonstrating competence in the science classroom (Crawford, 2005). Clearly, it is valuable for teachers to create opportunities in their classrooms for students to construct their own communicative repertoires, whether these are oral or written modalities. Constructivist theorists such as Driver (1988) emphasize the role of students' own language in learning science. Informal uses of speech and writing can clarify students' thinking, activate prior knowledge, and contribute to the learning of new subjects (Healy & Barr, 1991). Building on the research of Vygotksy (1962), Bruner (1964), Barnes (1986), Emig (1977), and Wells (1986), this focus on language for learning advocates a shift from text-and-teacher dominated classrooms to more open-ended, speculative language uses by students. Teachers need to respond sympathetically to exploratory student language, in both speaking and writing, rather than emphasizing correctness and traditional notions of accurate conceptual knowledge. In fact, there is considerable research evidence (Krashen, 1981; Smith, 1984) that prematurely forcing students' language into correct forms has a harmful effect on their learning. Although constructivist theorists have been quick to emphasize the centrality of talk for learning science, writing for learning has not been developed as fully, but would seem to hold promise for responding to the same call for students' exploration of thought processes.

Research on writing in the field of science education broadly consists of three main categories: one, "distributed scaffolding" through "learning by design" using paper –and- pencil scaffolding and design diaries (Puntambekar, & Kolodner, 2005); two, studies with concept mapping to link concepts (Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005) and to aid in conceptual change (Liu, 2004); and three, writing-to-learn studies using different genres to help students develop and extend conceptual understanding. The variety of usable genres is vast, and includes narratives, travelogues, poetry, scripts for debate and speech, concept and mind maps/diagrams, posters, scientific and verbal reports, brochures, journal writing, letters, and explanatory writing (Keys, 1999; Prain, & Hand, 1996).

But is writing a poem in a science class necessarily a good thing? A decade-long debate has existed over the use of non-scientific forms of writing to clarify conceptual understanding in science. Dissenters such as Martin (1993) claim that this approach is patronizing because it assumes that scientific writing and terminology are too difficult for secondary learners. According to this view, imaginative writing is seen as an inefficient display of understanding with the wrong purposes and wrong structures to support science learning. These writing genres are also seen by some as disempowering and encouraging of students' introduction of inaccurate understandings and personal irrelevancies (White & Welford, 1987). In support of diversifying science writing in the classroom, however, Rivard (1994) cites two research studies (Ambron, 1991; Rose, 1989) that affirm benefits to learning outcomes when students write expressively and for varied audiences. A recent meta-analysis of writing-to-learn interventions on academic achievement reveals the impact of contextual factors on learning in a variety of content areas and grade levels (Bangert-Drowns, Hurley, & Wilkinson, 2004). Learning enhancement derived from writing stems not so much from helping students find links between the content and their personal experiences, as from scaffolding metacognitive processes that lead students to self-regulation of learning strategies. Writing interventions in which students are asked to reflect on their current understandings, confusions, and learning processes yield more positive results than those which do not. Longer writing tasks yield less positive results, and, overall, writing-to-learn interventions have been found to be less effective in grades 6-8. One is tempted to speculate that there is something particular about this developmental stage, or the transition to schooling that is more differentiated by subjects, that impacts the effectiveness of this strategy.

Science teachers need to be skilled at recognizing and incorporating the many different ways in which individual students communicate science. Writing can serve as one of these modes, but is sometimes overlooked in science classrooms. New teachers, in particular, have been shown to believe strongly in the importance of finding out what students know prior to instruction. And yet, these same teachers do not use assessment tools such as concept-maps, journal writing, or other forms of writing to diagnose students' ideas and preconceptions (Morrison, & Lederman, 2003). Science teacher educators face an important need to instill a value for writing in science education that has been historically lacking.

*Figurative Language*

A growing body of literature explores questions of how to make science instruction relevant and meaningful for students of diverse backgrounds (Fradd & Lee, 1999). The incorporation of figurative language into science classroom talk and instruction is one possible avenue for addressing this issue. Claxton (1997) points out that:

> The languages of science are saturated with metaphors and symbols borrowed and adapted from the vernacular. Scientific maps, like all maps, are works of human invention, and they must borrow from the known to chart the unknown. Whether it be atoms as billiard balls, electric current as a teeming crowd of electrons, or *Homo sapiens* as a naked ape, scientific theories are closer to poetry and art than the rhetoric of science frequently admits (p.72).

Indeed the history of science can be perceived not as a history of discovery, but rather as a history of metaphor (Mashhadi, 1997). Theories in science frequently originate as metaphors, and retain their richness and ambiguity as they develop in whichever language is native to the scientist (Young, 1993). As the theory/metaphor leads to more and more established findings, individuals cease to rely on the metaphor to access the science; metaphors are replaced with new "created language." This scientific language is a social construction. Children who experience difficulties in the use of spoken or written language are likely to have additional difficulties in understanding the specialized vocabulary of science. It would seem, then, that the notion of using metaphor in science teaching is rife with possibility for English language learners, though no studies of which I am aware have specifically addressed this population of learners. Since learning abstract scientific concepts depends on children's ability to use their own language first to explore existing conceptions (Curtis & Millar, 1988), by working through figurative language such as metaphors and analogies, it would seem that students could thereby explore their emerging understandings of concepts. Metaphorical conceptualization could serve as a bridge to emerging verbal and written language modalities. According to Sutton (1992), choosing a new metaphor is in effect choosing an alternative theory, and students need to be given such opportunities for thinking in and about metaphors in their writing and speech. Because classrooms are dynamic social environments where many different minds from many different backgrounds meet and learn, the idea of using metaphor and analogy is especially inviting.

Analogy and metaphor are thought to be inherent components in the teaching of physics and chemistry, more than in other sciences (Mashhadi, 1997). When scientists use a word like "inertia," they are referring not to an object, but to a concept that is acquired from the experience of trying to move heavy things (Wellington, 1983). Words for unobservable entities such as "electrons" cannot be derived from direct experience and only have meaning in a theoretical context. Here is where analogies and metaphors possess great communicative capabilities. Harrison & De Jong (2005) have demonstrated the use of key analogical models used in teaching grade 12 students chemistry in Queensland, Australia. When teaching and learning principles of chemical equilibrium, teachers used multiple analogical models such as the "school dance," the "sugar in a teacup," the "pot of curry," and the "busy highway." The use of such models affords teachers the opportunity to reveal to students where analogies break down and to carefully negotiate the conceptual outcomes.

*The Role of Gesture and the Manipulation of Objects in Thinking and Learning*

In the wake of Thomas Kuhn's publication of *The Structure of Scientific Revolutions* (1962), many historians began to view the evolution of science as a series of sudden changes ("revolutions") in the way phenomena are described. Later philosophers, such as Rorty (1989), suggested that during such transitions as that from the Ptolemaic to the Copernican worldview, the talk of scientists was "inconclusive muddle" (Rorty, 1989, p.6). This "muddle" was a necessary bridge to allow for the development of new ideas expressed in language. The deep thinking required to challenge existing paradigms was not expressed in clear, obvious ways as previously perceived by science historians to drive revolutions. In fact, quite the opposite- language for talking about celestial phenomena that drove paradigm change consisted of this "muddled" combination of gesture mixed with verbal language (Rorty, 1989).

Gestures coupled to artifacts in the environment are pervasive in many settings. These include weather forecasts, archaeological field excavations, and academic talks, among others (Goodwin, 2000). It would seem, then, that gestures linked to the environment should constitute a large subset of the research in gesture. And yet, with but a few notable exceptions (Goodwin 2000; Goodwin 2002; Haviland 1995, 1996, 1998; Heath and Hindmarsh 200, Hutchins and Palen, 1997; LeBaron 1998; Streeck 1996) multi-modal sign complexes encompassing both gesture and the environment are largely ignored. This is certainly the case in education, where studies of discourse and communication styles in the classroom rest predominantly on a unimodal view of either talk or writing.

In recent years, studies by Gooding (1990) and Pickering (1995) have shown how experimentation is a situated form of learning that involves the manipulation of material objects in order to arrive at a co-evolution of "mutually constitutive entities that are reified in language" (Roth & Lawless, 2002). Both Gooding and Pickering provide clear indications that language emergence is deeply caught up in material practice. They argue that in addition to the emergence of observational and theoretical languages in the process of manipulating objects and equipment, a different feature of communication is observable and contributes to scientific laboratory communication; this feature is gesture.

## Types of Gestures

Within the literature, four general categories of gesture are distinguished (Ekman & Friesen, 1969; Goldin-Meadow, 2003; McNeil, 1992). First, iconic gestures are those that mimic the object being represented through the gesture, such as making back and forth "cutting" movements when talking about cutting a loaf of bread. Second, concrete deictic gestures are those appearing as one points at a referent while speaking about it, such as pointing at a painting. Third, abstract deictic gestures occur, for instance when one gestures from left to right, saying "from the beginning to the end." And finally, the fourth category of gesture is referred to as "beat movements." These are used in the rhythm of the speech or to mark importance intonational boundaries.

Gesture and the Emergence of Language

The role of gesture and manipulation in the initial emergence of language has long been recognized (Bruner, 1967). Gestures are produced by both sighted and congenitally blind speakers, as well as by people from all cultural and linguistic backgrounds (Goldin-Meadow, 1998, 2000). Even before children develop a language to communicate, they can pick up objects, present them to adults, and communicate with gestures. Communication skills progress through the manipulation of objects to increasingly mature forms of linguistic competence. Similarly, hand movements play a crucial role in the evolution of scientific ideas into descriptive and theoretical language. Without recourse to deictic (pointing), iconic (sweeping), and metaphorical gestures, scientists would find it difficult to communicate (Rorty, 1989; Roth & Lawless, 2002). Research studies in middle and high school classrooms suggests that gestures are not only an integral part in students' proto- scientific language, but that these gestures actually facilitate the emergence of scientific language and communication (Roth, 1996a, 1996b). Beginning with "muddled talk" identified by Rorty (1989), and supported by deictic and ionic gestures, learners isolate salient objects, which are increasingly represented in linguistic form. More abstract forms of communication such as writing and the use of symbols are used in a competent manner only in later emerging communicative patterns (Roth & Lawless, 2002). Studies in which high school chemistry students are afforded the opportunity to manipulate models have also shown an increase in these same students' ability to perform chemistry problems and to develop more concrete understandings of scientific concepts (Friedel, Gabel, & Samuel, 1990). This is the very idea behind actor-network theory, which explains how science and technology engage in a type of crossing back and forth between objects and representations (Sismondo, 2004). In so doing, these objects and representations create situations in which humans and non-humans affect one another. But much of the activity of science becomes encoded in elegant inscriptions; material practice is quite literally relegated to neat charts, graphs, diagrams and sheets of figures. The intermediary steps, which make such artifacts possible, are forgotten (Latour & Woolgar, 1979). Scientific knowledge, then, "appears a miracle" unless it can be systematically traced back to "local interactions via hands-on manipulation and working machines, via data, and via techniques for summarizing, grouping, and otherwise exploiting information" (Sismondo, 2004). The connection between artifacts and the construction of knowledge is a crucial understanding for students to become effectively socialized into the scientific field.

Harrison and Treagust (1996, 1998, 2000) also suggest that when students are encouraged to use multiple models, their understanding of abstract concepts, like bonding and the structure of the atom, are enhanced. One possible explanation for these findings is that students do not always learn what teachers intend from merely watching teacher demonstrations (Roth, 1997), because they are not given the opportunity to connect visual features of representations to relevant concepts, something they can increase the likelihood of doing by manipulating physical objects (Gobert & Clement, 1999). This suggests that hands-on science activities that focus on observational and theoretical language *in the presence of* the relevant phenomena and/or physical models of them might hold potential for more effective communication development for science learners. Unfortunately, most teachers guide students through investigations in the classroom and then separate the processing of those investigations in isolated assignments. They ask students to complete written laboratory reports at home, *away from* the concrete phenomenon or model used in the investigation settings.

Scientists and the Use of Gesture in Authentic Settings

Science education research is only beginning to move from a unimodal view of communication, centered in written and oral language, to a multimodal view of communication, based on the interactions of speech, gesture, and visual representations. Many scientists, however, have routinely practiced such communicative modes and require visual representations that they can point to or reference with their hands in order to make themselves understood. Ochs, Jacoby, & Gonzales (1994, 1996) have described how physicists commonly construct meaning through linguistic and graphic means. These scientists engage in collaborative interpretive activity by “transporting” themselves through talk and gesture into constructed visual representations through which they journey with their words and bodies. They make scientific narrative possible by creating visual representations, even drawing lines in space (an x and y axis in some cases) to create a physical and symbolic space for sense-making in an otherwise undifferentiated blank plane. In some cases, the absence of certain physical representations (graphs, drawings, photographs, models) has stalled communicative efforts (Amann & Knorr-Cetina, 1990; Henderson, 1991). Hence, in professional laboratory settings, it has been shown that talk is highly context-dependent and occurs in the presence of the object of talk. It involves a great deal of gesturing, such that talk is literally "handwork" (Suchman & Trigg, 1993).

The history of science also reveals many notable examples of the power of embodied thought in creativity and imagination (Gibbs, 2006). Many scientists, including Albert Einstein, Cyril Stanley Smith and Barbara McClintock, have conceded that their greatest discoveries occurred not as a result of pure analytic reasoning, but from "embodied possibilities" (Gibbs, 2006, p. 213). Einstein "pretended to be a photon moving at the speed of light" (Gibbs, 2006, p. 123), while McClintock viewed chromosomes as her "friends." Smith's research on alloys depended upon "aesthetic feeling for a balanced structure and a muscular feeling of the interfaces pulling against one another " (Smith, 1981, p. 359). Emerging literature in several areas of cognitive science explicitly demonstrate that such embodiment is directly linked to higher-order cognition (Gibbs, 2006).

In recent years, there has been an increasing interest in investigating the roles played by different semiotic modes in science classroom communication (Kress & Van Leeuwen, 2001; Kress, Ogborn, & Martins, 1998; Lemke, 1990; Marquez, Izquierdo, & Espinet, 2005). Though science discourse has been described as a "semiotic hybrid" (Lemke, 1990) in which scientific concepts are simultaneously verbal, visual, mathematical, and enactive (Lemke, 1990), there are still limited studies attempting to integrate different modes of communication in classroom studies. Most often, they are studied in isolation of one another. Some students have learned to juggle, integrate, and synthesize across multiple semiotic languages of science, but Lemke calls such students "lucky," and rare (2006). Communicative approaches to science teaching normally do not integrate *all* the languages of science.

The Gesture-speech Relationship

Research on gesture-speech relations in science has illuminated bright prospects for further research on multiple modalities. Studies by Crowder and Newman (1993) suggest that gestural modality provides predominantly redundant information and can be used to help students work through what she identifies as the "sense-making" stage of scientific understanding. A later study by Crowder (1996) suggests that the gestures students use for an audience and for themselves are different. When publicly demonstrating knowledge for an audience, student gestures are well-coordinated with speech. Yet, when a student is attempting to process information for himself, the resulting gestures are more "private" and less well-coordinated with speech. Crowder suggests that "given planning time, [students'] initially inarticulate self-explanations can be clarified in the process of explaining to others" (p. 205).

Other studies support the notion that gesture and speech are *not* always consistent, but in a manner distinct from the issue of timing. Goldin-Meadow, Alibali, and Church (1993) have studied the discrepancies between gesture and speech when children are in transitional states of their understanding. In working with children asked to complete Piagetian-type tasks, these researchers used the term "discordant" to identify children whose explanations in speech did not match the information expressed in gesture; they used the term "concordant" to describe children whose verbal explanations did match their gestures. Results indicated that children who produced discordant information between gesture and speech in their explanations of a concept tended also to display other forms of inconsistency with respect to their understanding of a concept. More importantly, the study revealed that "discordant" children showed more improvement than "concordant" children on a posttest containing the same original six Piagetian tasks, suggesting a heightened receptivity to instruction. One possible role for gesture in science education then, lies in the potential that nonverbal communication can provide insight into a speaker's mental representations during speech.

Studies by Roth and Welzel (2001) and Roth and Lawless (2002) have shown that a second role of gestural expressions lies in their ability to facilitate the appearance of new verbal expressions in secondary science classrooms. This work is reminiscent of the early seminal work described by Bruner (1967) in which the transitions of young children's communication progresses from enactive representations to iconic to symbolic representations in language. The likelihood of a word's use in the early linguistic career of the child was shown to vastly increase if the object was in hand or direct sight. In Roth and Welzel's 2001 study, high school physics students were invited to plan and execute investigations of their own interest; their discussions about their learning were videotaped and analyzed. Findings revealed that students used gesture to construct complex explanations even in the absence of appropriate academic language. With time, speech increasingly took over and there were either decreases in the delay between gesture and verbal speech, or long pauses before gesture and utterance overlapped. This suggests a promising link between hands-on activities, the gestures students develop, and the onset and emergence of science-related discourse. Gestures seem to provide a medium for constructing complex explanations by lowering the cognitive load and allowing for a slower emergence of the scientific discourse. Gestures also seem to provide what Roth and Welzel (2001) term “the material that ‘glues’ layers of perceptually accessible entities and abstract concepts” (p. 103).

Research shows that language modalities used by teachers and students is not the same in regard to semiotic modes; neither do these modalities play the same role in teaching and learning of abstract scientific concepts (Marquez, Izquierdo, & Espinet, 2005). Teachers nearly always use gesture, visual language, and written text of some sort when communicating through the use of a white board or easel. Each of these modes can be considered to be channels of communication that provide sometimes equivalent, sometimes supplemental, redundant, or even contradictory information that interact to create meaning (Marquez, Izquierdo, &Espinet, 2005). Studies of university science professors indicate that when there is a discrepancy between the professor’s talk and gestures, referred to as a decalage, students emerge with impaired understanding, for example when learning about graphs during lecture (Roth, 1999).

*Resemiotization: Extending Analysis of Discourse as Multi-semiotic Practice*

Recently, emerging research examining discourse in science classrooms, has yielded the conceptualization of discourse as multi-semiotic practice or, “resemiotization” (Iedema, 2001, 2003). This term denotes the act in which a learner draws upon semiotic resources, which are then transferred from one form to another, and across modalities; the result is the objectification of an experience into new terms that constitutes new meaning for the learner. In essence, resemiotization is the progressive re-representation of meaning with different media. Different modes of semiosis are managed over time by converting information from one mode to another, where the newer mode is often the more durable, thus creating a form that is once again, more "object-like." The language of "resemiotization" provides the analytical means for (1) tracing how semiotics are translated from one into the other as social processes unfold, and (2) for asking why these semiotics, as opposed to others, are mobilized to do certain things at certain times. In an attempt to understand the ways in which students participate in inductive inquiry, and how they make sense of their classroom experiences with scientific phenomenon, the notion of resemiotization (Iedema, 2001, 2003) is particularly useful. In order to best understand the impact of this analytical tool in the research, it is beneficial to first examine the use of another term in the literature on science discourse: objectification.

The term "objectification" (Halliday & Martin, 1993; Massoud & Kuipers, 2009) sheds light on the ways students can learn from hands-on activities, appropriate new subject matter from labs and, in turn, build on that knowledge by objectifying their perceived realities into stable linguistic forms that can then be built upon. There are many ways that students can objectify their realities into new forms, including through one process Massoud et al. (2009) refer to as "entexualization." This is the process by which we can render a verbal text into a written one that can be lifted out of its setting and applied to another. For example, entexualization occurs when signs or symbols from a scientific law become hardened over the course of a verbal interaction and become able to be decontextualized, picked up in new circumstances and recontextualized as a result of their text-like objectified forms. In the sections following, I examine the interconnections between the terms "objectification" and "resemiotization," and then turn to the most current research utilizing these conceptualizations as analytical tools to examine achievement data in science classrooms.

*Perceptual and Linguistic Objectification and their Connections to "Resemiotization"*

Halliday's (1993) theory of objectification refers to "the act of representing actions and events as if they were objects" (p.52). This occurs not just in science, but in all areas of life, as humans objectify "reality" in order to represent it in language. Perceptual objectification is the process by which students orient themselves to an activity and a set of materials in such a manner that they are able to carve out, or identify a "thing" to talk about. This is similar to Hutchins' concept of "material anchors" in which material objects are used as anchoring frameworks to which conceptual notions are tied (2005). However, unlike "material anchors," the notion of perceptual objectification refers to a negotiation of sorts in which the phenomenon being seen is agreed upon to behave in certain ways. For example, if two objects are dropped at the same time, reaching the conclusion that they arrived on the floor at the same time would constitute perceptual objectification. Reaching the conclusion that the objects arrived at the floor at different times would also constitute perceptual objectification. Both are perceptual "realities" the group agrees upon. Certainly, all students will not necessarily "see" the same things. In fact, according to Goodwin (1994) people learn to select salient characteristics of objects and/or events to make their experiences interpretable, depending on their level of experience or familiarity with the context and field. Those who have specialized training or experience view materials with what Goodwin (1994) calls "professional vision" such that what a "professional" might observe or choose to focus upon might not necessarily be the same as for those who have not received training or are new to the field. Perceptual objectification of laboratory activities, then, is the way that students attune themselves to looking for patterned behavior and, in so doing, make "reality" appear to be held still. This is an interactional achievement among students, the scientific materials, and their teacher, who embodies professional vision. It can be instantiated through vision, smell, texture, number patterns, etc… Students must be taught *how* to see the materials with which they work in the lab in a particular way, interpreting them so that their observations are meaningful to scientists, and not just to their school-aged peers. Roth (2005) and Kress et al. (2001) show that often, even when students see the same phenomenon, they may not arrive at the same accounts. Language, then, plays a key role.

Once students orient themselves to the materials, perceptual objectification is transformed from one modality to another via the aforementioned process of resemiotization (Iedeman, 2001, 2003). Ultimately, the result is a more stable linguistic representation cemented through this process of linguistic objectification. Students begin to demonstrate their incremental emerging understandings through a type of "transformative sign-making" wherein actions are verbalized and transposed into written representations, the messy opposite of the black-boxing to which Latour and Woolgar (1997) refer in their seminal work, *Laboratory Life*. Visual, tactile, and actional knowledge is transformed into linguistic representations that can then be built upon in future settings.

The process of linguistic objectification itself entails the reprocessing of naive linguistic representations, such as partial phrases. These, in turn, are negotiated with more knowledgeable others (often the teacher) to arrive at concise representations that are recognizable by the scientific community and become stable and "real" as scientific terms. Often, a great deal of interactional work is done on the part of the teacher, creating associations between the visual phenomenon and its linguistic representation in order to arrive at a final stable linguistic form. In order to achieve linguistic objectification that results in "scientific terminology," the use of certain pedagogical approaches is key. Approaches involving question and answer sequences, as well as discourse markers, play an important role in building coherence and consensus.

Thus, the notions of perceptual and linguistic objectification and resemiotization are useful in analyzing how students' talk in situated interaction is negotiated and built upon. With the assistance of more knowledgeable others (Vygotksy, 1978), students incrementally build on small details and pieces of evidence, working step by step to move from observation to interpretation, and build consensus along the way. By applying linguistic terminology to their actions and observations, students further objectify their lab experiences and resemiotize their interactions with materials. These linguistic representations, in turn, serve as mediational tools (Wertsch, 1991) in future learning situations and allow for movement from peripheral to more centralized participation (Lave & Wenger, 1991). These new linguistic representations become scientific terms that are infused with robust meanings built over time through first-hand experience and class discussions, rather than terms that are merely memorized from a lecture or textbook.

*Connections to Research*

In a recent National Science Foundation (NSF) study of a diverse middle school system in suburban Washington D.C., Lynch, Kuipers, Pyke, and Szesze (2005) found that students were able to transform subjective science lab experiences into "objective" representations through the processes of perceptual and linguistic objectification (Halliday & Martin, 1993; Massoud & Kuipers, 2009). The school was a particularly auspicious site to investigate the relationship between diversity and the use of "objectivity" in the pursuit of scientific "truth." Over 188 languages were spoken with a student body comprised of 41.6% White, 20.7% Hispanic, 14.8% Asian, and 22.9% African-American. Three different chemistry units were analyzed in which students were given various degrees of freedom to objectify their experiences using multiple modalities. Three different curricular models in chemistry were compared. The "Motion and Forces" module (MF), provided individual pathways for objectification, but these opportunities were set in non-collaborative settings. In a second module, "Real Reasons for the Seasons," (RRS) the teacher was the main gateway for information. Students needed to attain all information from the teacher. And in a third module, "Chemistry that Applies," (CTA) a variety of pathways existed for students to participate in the objectification process through a variety of modalities. Of all the modules, the RRS module exacerbated the differences in achievement between the "served" and the "underserved" populations of students, while the CTA module showed actual evidence of narrowing this achievement gap.

This study suggests great promise lies in the process of objectification. Science education is a context in which the divide between the material and the immaterial realities are breached through participation practices that recover agency and reduce passivity. The practice of objectification enables students to uncover the processes of construction whereby science is given “authority” through the “black-boxing” (Latour & Woolgar, 1979) of facts into set “truths.” In this study (Lynch et al., 2005), patterns of objectification correlated with different curriculum units. The degree and manner in which students were afforded opportunities to objectify their experiences across modalities was found to impact the achievement of students. This suggests that creating opportunities for students to resemioticize across different modalities has the potential to narrow achievement gaps.

*Summary of Chapter*

For decades, portions of the scientific and educational communities have agreed that investigative science is the way in which science should be taught in order to best access the social nature of the scientific enterprise. However, the task of implementing inquiry-based approaches in science rests squarely on the shoulders of teachers' abilities to facilitate meaningful communication in the classroom. In this chapter, I have reviewed the literature and research on inquiry-based teaching and science communication. While the collective view of the research suggests that inquiry methods can be highly effective instructional approaches to the teaching of science as a “verb,” rather than as a “noun,” helping teachers to meet the diverse learning needs of their students, remains a challenge. In today's increasingly diverse classrooms, students' cultural backgrounds, first languages, life experiences, and ways of learning vary greatly. It is imperative that teachers utilize instructional strategies that respect and build on these differences while helping all students learn important concepts and skills in science.

Teacher skill is crucial to inquiry. Jarrett et al. (1997) acknowledge that even with support, a teacher will face many dilemmas when engaged in inquiry. How can one facilitate discovery *and* provide guidance? When should a teacher intervene, and when does he stand back and allow students to make mistakes? How can a teacher facilitate student argumentation to occur over meaningful scientific claims? Models of *how* to implement effective communication in the classroom have tended to focus on either unimodal views of communication in the realms of the verbal or written modalities, or have focused on one lens of student-student talk in small group settings, without providing an overall context in which to situate the inquiry approaches, as in the examples of research documenting resemiotization noted in this chapter. We know that inquiry is an important tool teachers can use to bolster student performance in academics, critical thinking, and problem solving (Haury, 1993; Flick, 1995). What is needed is a comprehensive model of *how* to do so.

In the following chapter, I draw upon socio-cultural theory, distributed cognition, and embodied cognition as theoretical frameworks through which to develop a research design to explore probable models of inquiry-based instruction. These theoretical models are described at the beginning of Chapter 3, where I also describe a research design to explore the manner in which students are able to construct scientific argumentation in inquiry-based settings. The overarching goal of this study is to identify factors that promote effective inquiry-based instruction in middle school science classrooms, as evidenced in students' abilities to engage in quality argumentation with their peers. Three specific research questions are investigated: 1) What factors do teachers identify in their practice as significant to the teaching and learning of science? 2) What factors do students identify as significant to their learning of science? and 3) What factors affect students' opportunities and abilities to achieve sophisticated levels of argumentation in the classroom?

To answer these research questions, I conduct a qualitative research study. This study is described and explained in Chapter 3.

# Chapter 3- Research Design and Methodological Approaches

## *Overview of Chapter*

This chapter provides an overview of the qualitative research design used to conduct this study, including the general characteristics of qualitative research and the theoretical frameworks that inform it. This chapter includes a definition of the key constructs and the operationalization and integration of these concepts into the overarching research study. I discuss the setting sample, sampling procedures, and criteria for the selection of participants. I also provide a brief review of my positionality, discussing the benefits and limitations that emerge during the study as a result of my professional work at the school in which this study is contextualized. The chapter describes the particular methods used to both design and implement the data collection measures. Finally, it discusses the data reduction and analysis procedures used in answering the guiding research questions.

## *Goals of Research Study*

The purpose of this study is to explore the factors that promote inquiry-based instruction in middle school classrooms. Because argumentation is the prominent form of productive talk leading to the building of scientific knowledge, one indicator of successful inquiry lies in students' abilities to communicate their scientific understandings in argumentation structures. Unlike non-science-specific forms of argumentation, scientific argumentation is governed by shared norms of participation. It focuses on making claims that are backed by evidence. Since argumentation is the fundamental talk of science, I chose to analyze students' talk by using a five-level rubric, which will be described in a later section of this chapter. My daily presence in the research setting informed my decision to deconstruct the two classroom settings of the study into three dimensions, to explore the contributions of "teacher practice," "classroom systems," and "physical structures" to student talk. My rationale for so doing will also be discussed in this chapter.

As discussed in Chapter 2, "best practices" in science instruction call for a combination of both an understanding of facts and concepts, as well as the skills to generate new scientific evidence (National Research Council, 2008). In order to meet this dual goal, we need to better understand how to design effective inquiry-based environments in which to teach students to both learn knowledge already codified in the scientific canon, as well as to participate in shared norms of science to build and refine new models of explanation for questions not yet answered. One specific focus of this study is an exploration into the factors that effect students' opportunities and abilities to engage in such social interactions with their peers in the context of classroom investigations. Findings from this study have multiple implications for practice and pedagogy, including rethinking what is meant by the genre of science teaching known as "guided-inquiry," and providing models of effective instruction to educators interested in incorporating such an approach. Using a qualitative research design, I identify factors that enable or constrain students' opportunities and abilities to engage in argumentation.

### *Guiding Theoretical Frameworks*

The overarching theoretical framework guiding the research design of this study is sociocultural theory (Vygotsky, 1962). However, this work was also largely informed by two theoretical positions that stem from this larger perspective. These include distributed cognition (Hutchins, 1996), and embodied cognition (Gibbs, 2006).

#### *Sociocultural Theory*

Sociocultural theory (Vygotsky, 1962) is a theory of learning by which we come to understand that learning and development occur through an individual's participation in activities and practices and through tools. Sociocultural theory emphasizes the relationships between people and their contexts, actions, resources, communities, and cultural histories. I find Barbara Rogoff's perspective of this theory to be especially useful in application to the science classroom setting. Rogoff (1990, 1994) defines her overall sociocultural perspective of learning as a process of people changing participation in sociocultural activities of their community. When talking about "learning through participation," Rogoff (2003) proposes that there are three foci of analysis of sociocultural activity: the intrapersonal, the interpersonal, and the cultural-institutional. Use of these three lenses provides a view into individual development that rejects the viewing of individual contexts, but allows for a perspective of each as influential of the others. In this way, no aspect can be studied in isolation of the others. In Rogoff's words: "People contribute to the creation of cultural processes, and cultural processes contribute to the creation of people" (2003, p. 51). Rogoff's perspective contributed greatly to the research design of this study, informing my decision to conduct a small longitudinal study, whereby daily presence in the field could potentially capture students at work in the contexts of their classroom settings among the people, tools, and systems that influenced their learning and development.

My unit of analysis is a classroom comprised of adolescent middle school students and their science teachers within the context of inquiry-based science instruction. Embedded within this focus of analysis are multiple levels of interaction: student to student; teacher to student; small groups collaborating over science activity; and whole group discussions where students interact with the teacher, other students, manipulatives, and other representational media in the classroom (easels, white boards, diagrams in science notebooks, word charts, etc…). My decision for the use of these lenses of analysis is informed by my reading of Rogoff's analytical framework. In applying her three foci of analysis to my setting, I was able to capture a view of the individual students, the social context of their group formations, and the cultural context of their classrooms as inseparable entities. As the observer, I also came to realize that I was also a part of the analysis. According to Rogoff: "The distinction between what we choose to foreground or background lies in our analysis, and is not assumed to be a separate entity in reality" (Rogoff, 2003. pp. 53-61). The manner in which my role as a participant-observer impacted the analysis of the data will be considered in a later section of this chapter.

### *Distributed Cognition*

Also instrumental to the research design of this study is the framework of distributed cognition (Hutchins, 1995). Developed in the mid 1980s by Edwin Hutchins, the theory of distributed cognition draws upon sociology, cognitive science, and activity theory, and emphasizes the social aspects of cognition. In this model, cognition is expressed as the process of information that occurs from interaction with symbols in the world. It provides a framework that encompasses the coordination between individuals, artifacts, and the environment in order to provide a view of how environmental contexts influence the way people act and think. The model features three main components:

1) Information as embedded in representations of interaction.

2) Coordination of enaction among embodied agents.

3) Ecological contributions to a cognitive ecosystem.

This framework for thinking about cognition greatly influenced the design of this study, most notably in the data collection tools I chose to use. In my decision to use daily videotape, I sought to capture instances of cognition shaped by the transduction of information across individuals and representations formed as a result of student and teacher interactions with artifacts in their environment, as well as with each other. Distributed cognition proposes that human knowledge and cognition are not confined to the individual. Rather, they are distributed by placing memories, facts, and knowledge on objects, other individuals, and tools in the environment. This framework was instrumental in both the design of this study, as well as in the decisions guiding data analysis.

*Embodied Cognition*

Another perspective that influenced this work is the theory of embodied cognition, whereby language and thought are shaped by embodied action. Embodied cognition (Gibbs, 2006) encompasses a view of the human mind as an “embodied mind,” largely determined by the form of the human body itself. Scientists and researchers who are proponents of this idea argue that all aspects of cognition, including ideas, thoughts, concepts, and categories, are shaped by aspects of the body. These aspects include the perceptual system, the intuitions that underlie the ability to move, and activities and interactions with our environment. Underlying this notion is the idea that a naïve understanding of the world is actually built into the body and the brain. This framework was useful in thinking through diSessa”s notion of the phenomenological-primitives students bring with them to the classroom (described in Chapter 2), and how such ideas are potentially integrated into the learning of the overall classroom “system.”

## *Research Questions*

The overarching goal of this study was to identify factors that promote effective inquiry-based instruction in middle school classrooms, as evidenced in students’ abilities to engage in quality argumentation with their peers. Three specific research questions were investigated:

1) What factors do teachers identify as significant to the teaching and learning of science? (How do teachers talk about their practice of scientific inquiry?)

2) What factors do students identify as significant to their learning of science? (What elements of their teacher's practice do students identify as affecting their learning of science?)

3) What factors affect students' opportunities and abilities to achieve sophisticated levels of argumentation in the classroom?

*Research Setting: A Historical Perspective*

This research study was conducted in a charter school located in an urban, low socioeconomic area of San Diego, California. Approximately 1,000 students in grades six, seven, and eight attended the school at the time of the study, with nearly 85% of these students achieving below grade level, as determined by 2005 STAR standardized test scores (charter document). For approximately 30 years prior to the formation of the charter, the school, a large grade 7-12 secondary conglomerate, had suffered from an aura of failure (school website). Media reports, coupled with public reputation, consistently painted a negative portrait of the school and its surrounding community, riddled with gang violence and the prevalence of drugs, crime, and poverty. Past efforts to ameliorate the school climate included the establishment of a math and science magnet program at the site. Though this attracted many students from outside the school community, it was apparent that the ultimate outcome was the existence of two separate schools within the whole: one for the white magnet students and one for the neighborhood students, predominantly African-American at that time.

In 2003, the large conglomerate physically separated into a high school (grades 10-12) and a middle school (grades 7-9), a breakdown different from the traditional 6-

8/9-12 divide in most middle/high school delineations. The high school was governed by one principal and was housed on the east campus, while the middle school was governed by a different principal on the west campus. With the implementation of federal law, "No Child Left Behind" (NCLB), things began to change for the school. NCLB affects states and school districts in four basic ways: it calls for greater accountability for academic results; provides increased district flexibility for spending federal money; offers expanded options for parents and guardians; and places an increased emphasis on teacher quality (San Diego City Schools Fact Sheet). Under this law, the state designated some Title 1 schools as "Program Improvement" (PI) schools. These schools were those unable to make adequate yearly progress (AYP) towards improving student achievement for two or more years, based on state test scores. Schools in "PI Year Four" were schools that did not make AYP for at least five years. In accordance with NCLB and with the district accountability system, the district is required to restructure a school that has entered "PI Year Four" status (San Diego City Schools Fact Sheet). In 2004, the school in this study found itself in its final year of its Program Improvement, and was forced to choose from among five options. Of these five, only two were viable options for the community school: either become a charter school, or restructure with the large school district to which it belonged. On March 1, 2005, the District's Board of Education approved charter status for the school, in partnership with a large university in Southern California, and the title became official on July 1, 2005 (Sutton 2005). Gates opened to neighborhood students on September 7, 2005 under the new structure and leadership of seven administrators, and for the first time in the school's history, the year began with a full teaching staff ready to greet their students. A sign above the gates where the students enter reads: "Through these gates walk the greatest students in the world."

At the time of data collection, this charter school was in the midst of its third year of autonomous administration. Many changes had taken place at the leadership level. While the tireless devotion and dedication of the director remained, four of the assistant directors (A.D.) had chosen to leave the school for a variety of reasons. A new science A.D. had taken over the leadership of the science department. There were five teachers who taught eight-grade physical science for at least some portion of their day. Two of these five participated in this study. The main goals for the science department during the time of data collection were to develop common assessments based on the grade level California Content Standards, and to design lessons that were inquiry-based in nature. This latter goal was a significant draw for me in choosing this site for my study.

*Research Sample and Setting*

The participants in this study were selected from the middle grades of the charter school described above. Administrators at the site were instrumental in assisting me in gaining access to the classrooms of two eighth grade science teachers and the approximate 20 students in each of their classrooms (ages 13-14). Both classrooms shared similar populations of historically underrepresented students and similar populations of English Language Learners. These two samples constituted a purposive sampling from the larger convenience sample of a school-wide student body that was roughly 69% Latino, 21% African-American, 3% White, and 3% Asian. The school was also a Title 1 school (poverty indicator, 80%) and had a student body of which 63% were English Language Learners (ELs).

I carefully considered my choice to situate my research in this particular setting. The administrators and teachers at this charter school possess a strong commitment to supporting their students, the vast majority of whom suffer from achievement gaps. The large number of students for whom English is their second language also informed my choice of school, as my study holds promise for the academic language development in science for such students. This charter school not only embraces a college-going culture for historically underrepresented neighborhood students, but also maintains a thriving partnership with a major public university at which I also teach. As such, it is a convenience sample, a site to which I have inside access in gaining trust, and in requesting permission to conduct research in my target population of interest.

*Constraints*

Gaining access to the school site was a deceptively simple first step in the data collection process. The leadership team of this charter school was very amenable to my research goals and were accommodating in their assistance in suggesting teachers for the study. However, there were a number of constraints I did not anticipate which slowed the commencement of the data collection. The first of these was the fact that the participating teachers in the study requested that I not begin the study during the first month of school, as their classes were still experiencing shifting enrollments, and they had not yet embarked on science-based lessons. Rather, the first weeks' lessons consisted of school-wide "college-going culture lessons," the goal of which was to implement a common set of expectations for the behavior of students and staff.

The second of these constraints was the college-preparatory culture of the school itself. Part of this collective culture is a strict use of time allotted solely to instruction. Teachers are mandated by the administrative staff to use every instructional moment possible to meet their learning goals and to accomplish the school's mission: "to *accelerate* [the] academic achievement" (school website) of their students. Because of this climate, I had difficulty scheduling ten minutes of time to explain my study to the students and to pass out the institutional review board (IRB)/human subjects consent forms. In one class, I made five scheduled visits, only to have the teacher tell me after each day that they would not have time to distribute the forms. Five days of one class at this charter school can span two weeks, due to the school's alternating science A/B schedule, so this took up significant data collection time. Once I did pass out the forms, it took an average of two weeks to get students to return the forms, even with the bonus incentives of university folders, colored pencil sets, pens, and flashcards for a "yes" or "no" returned form. This may have been in part due to the every-other day nature of the science classes, and the difficulty of not having a reminder from the day before to return the forms.

Other constraints I did not anticipate were due to unscheduled "college classes" where the leadership team called a particular grade together for an impromptu meeting in the auditorium; also, the week of the 2007 California fires, the week of Thanksgiving Vacation, and the three weeks of Winter Vacation in December took away from data collection opportunities.

*Teacher Participants and Classroom Curriculum*

Both classroom settings in this study are grounded in the same interactive, inquiry-based physical science curriculum, *Interactions in Physical Science,* formerly known as *Constructing Ideas in Physical Science (CIPS).* However, this curriculum was used as a guide only. This was due to the fact that the site teachers felt the CIPS curriculum did not fully address California science content standards, did not sufficiently align with the academic needs of their students, and did not align with the pacing they needed to accommodate 105-minute instructional blocks of time. The two senior science teachers in the department co-planned lessons for all the other eighth grade science teachers, supplementing and deleting from the CIPS curriculum to accommodate the needs of their students. These two teachers were the two selected to participate in this study. I hereafter refer to them as “Dave” and “Carla.” Many of the core CIPS activities were preserved in the incarnations of the lessons. The new lessons were then e-mailed out to the other eighth grade science teachers, with the option, but not the mandate, of using them in their classrooms as well.

In the two years prior to this research study, both Dave and Carla used the former iteration of *Interactions in Physical Science*, known as *Constructing Ideas in Physical Science*, or *CIPS*. During that time, both teachers worked closely with a science administrator who guided them through professional development sessions and planned meetings at the school to utilize the curriculum with the goal of working with a Lawrence Hall of Science research-based inquiry science curriculum, and learning to implement it true to its precise written guidelines. The year this study was conducted, the school science department worked under the leadership of a newly appointed science administrator who gave the two teachers in this study the flexibility to use the former curriculum as a guide only, in creating and designing their own inquiry-based physical science lessons. The two teachers shared a common preparatory period during the time data was collected, and designed lessons jointly. They, thus, implemented identical content, though teacher instruction style, rapport with students, and use of multiple representations for instruction varied between them. It should be noted, however, that near the end of data collection, Carla attended a SPAWAR (Space and Naval Warfare Systems) workshop on a military base and was given kits to teach inquiry-based physical science, called Materials World Modules (MWM). Materials World Modules (MWM) are hands-on, inquiry and design-based units for middle and high school students. Based on materials science and nanotechnology principles, this interdisciplinary approach engages students, adds relevance to traditional curriculum, and has been shown to improve science knowledge for all students. Carla's lessons during the last month of data collection thus varied from Dave's in that the materials used were different. Dave and Carla continued to co-plan through the same standards, but since there was only one class set of MWM kits available, Dave continued to use school site equipment to teach the same concepts for which Carla used MWM kits.

The curriculum the two teachers designed continued to follow the same cyclical learning cycle they used in the two previous years, called the "5E model." This, in turn is an iteration of the Atkin/Karplus SCIS learning cycle (Bybee, 1997). The SCIS model is derived from the psychological theories of Jean Piaget, which have since undergone modification when applied to various educational settings. The 5E model is one such modified version, now considered an effective instructional model for contemporary science education. In this approach, students redefine, reorganize, elaborate and change their initial understandings of science concepts through self-reflection and interaction with their peers and their environment. The five components are not meant to necessarily flow in a linear fashion, but each phase impacts the others as students work through their understandings of science concepts. The five components of the model are described in Table 3.1 below.

**Table 3.1: The Five Components of the 5E Model of Instruction**

| Five Components Of 5E Model | Teacher Actions | Student Actions |
|---|---|---|
| Engage | Presents a situation to the students (a discrepant even, data that conflicts with the students' current thinking, or a problem to solve). Purposely designed to generate curiosity and interest and to elicit potential misconceptions. No answers to student questions should be given by the teacher in this step. | Students puzzled and/or actively motivated by the learning activity; designed to bring about "disequilibrium" in student thinking. |
| Explore | Role= facilitator; provides time for students to puzzle through problems; should ask probing questions to redirect students' investigations when necessary. No direct instruction in this phase. | All students should have a common, concrete experience from which to build concepts, processes and skills; should initiate the process of establishing "equilibrium" in thinking. Students explore objects, events, situations, and formulate questions. |
| Explain | Teacher should base initial portion of this phase on the students' explanations. Teacher-directed instruction, if needed, may occur during this phase in the form of verbal explanations, or video (to provide academic language for phenomena students have just studied). | Students should be able to explain their experiences to each other and to the teacher, replacing "everyday" language with scientific language. |
| Elaborate | Teachers should expect students to use vocabulary, definitions, or explanations provided previously in new contexts. | Students are presented with further experiences that apply, extend, or elaborate the concepts, processes, or skills of the learning segment. |
| Evaluate | Teachers provide opportunities for informal and formal assessments to evaluate student progress. They should refer students to existing data and evidence and ask them what they already know. Teachers should also look for evidence that students have changed their thinking. | Students should be allowed to assess their own learning. They should be asked questions like: Why do you think what you do now? What evidence do you have? What do you know about the problem? |

## *Positionality*

Before I describe the data collection procedures, I would like to briefly describe my positionality. Lincoln (1995) describes the importance of examining one's position or standpoint and its influence on the inherent nature of the research one is conducting. This is especially incumbent on researchers embarking on qualitative studies where people and their conversations are likened to "texts" that the researcher both creates from observation and reads from interview tapes and transcripts. In this case, it is important that I acknowledge my own experiences as a teacher and supervisor, and how these roles came to bear on the research process.

### *Middle and High School Teacher*

From 1990- 2001, I served as a middle and high school science and English teacher in a large district in Southern California. In this role, I have had the opportunity to work in a variety of public school settings, serving different socioeconomic groups and diverse cultures of students. My experiences working in one of the most linguistically diverse high schools in the state of California most notably informed the research topic in this study. During these eleven years, I actively sought out opportunities for teacher professional development related to inquiry-based instruction and best practices for English Language Learners. I also made attempts to initiate iterative cycles of lesson study through peer collaboration at the various schools sites where I worked.

*University Lecturer/Supervisor*

Currently, I work as a science lecturer/intern supervisor in a teacher education program at a major university in Southern California, where I teach science methods, health education, introductory education courses, and secondary intern practicum courses. From this setting, novel instructional practices are shared and put directly to use by today's newest teachers. I am afforded the unique opportunity to influence the teaching practice of those newest to the profession embarking on their careers working with some of the least privileged and youngest members of our budding adult population. I believe my position has brought both positive and challenging implications to the data collection. I embarked on this study with a strong foundation in science as well as a solid understanding of the pedagogical content knowledge needed to teach the subject to middle school and high school students. Of most recent emphasis in science education are the importance and relevance of constructivist- based teaching practices through such frameworks as the 5E model of teaching, with its emphasis on less teacher talk and more student talk; student exploration; and scientific argumentation.

I also understand the unique challenges and rewards of managing a diverse classroom of learners, including a large proportion of English learners and students who oppose and/or implicitly resist the structures of schooling itself. I believe that my dual experiences as middle school/high school teacher, and university intern supervisor/instructor could have presented the possibility of harboring pre-conceived notions to bear upon my data collection. However, I have made a consistent, conscious effort to remain cognizant of my positionality when I engaged in dialogue with my data, attempting at all times not to impose any preconceived notions onto the data. I have dialogued with other colleagues in the field of linguistics, sociology, education, and cognitive science throughout the process of data collection, reduction, and analysis. I believe that constant awareness of my positionality has lessened the chances of any misinterpretation of the data or a failure to see emerging theories or patterns that were not consistent with my original thesis.

For a short period of two weeks, a second university researcher accompanied me to the research site. This afforded me numerous opportunities to impose self-checks on my thinking by articulating ideas aloud and discussing them with her on the drives to and from the research setting. I have attempted to mitigated against imposing my own views upon this study by making the grounds on which I rested claims explicitly available in my writing through videotapes, transcripts of interviews and field notes from observations.

## *Data Collection Procedures*

### *Gaining Entrance to the Research Site*

In the two years prior to the inception of this study, I had developed a positive working relationship with the school's administrators through my supervision of four former science interns placed at the site. On April 26$^{th}$, 2007 I presented a proposal of my research to the Education Committee of the charter school, consisting of members of the governing board from both the university with which the school maintains a partnership, and the school itself. The committee granted permission for my research to proceed on April 27$^{th}$, 2007. In the initial weeks of the 2007-2008 academic year, I learned of the change in science department leadership and the new guidelines for flexibility concerning eighth grade curriculum development and lesson design. By mid-September, the final master schedule was complete, classes balanced, and I approached the new science administrator for assistance in selecting teachers to participate in my study. Dave and Carla were selected due to their veteran status in the department. I provided both teachers with a letter explaining my research and asked for their consent for my involvement in their classrooms during the fall semester as a participant- observer. This would involve my recording of classroom activity and talk in field notes. I also asked permission to interview both teachers for a 45-minute period following the final videotaped session in December. Carla and Dave each chose one of their classes for me to involve in the study.

I drafted a letter of consent in both English and Spanish for all students and parents in the participating classrooms, requesting permission to videotape group and whole class discussions from September through January. All students who returned the consent form, with either a "yes" or a "no" were given a university folder and colored pencil set as a thank you from the researcher for consideration of their time and decision regarding participation in the study. Those who replied with a "yes" were included in the tapes, and those who did not were marred from being viewed in the resulting tapes and were not chosen as subjects for the student focus groups. In this way, confidentiality of students was maintained for individuals who chose not to participate.

*Working with the Teachers*

One of the important norms necessary to establish in each classroom was a common use of scaffolds for student talk. It was necessary to be sure that both teachers provided students with equal access to argumentation terminology in order to study student talk in both settings. To this end, I presented common verbal scaffolds to both Dave and Carla. I reviewed the terms “claim,” “evidence,” “warrant,” and “rebuttal” with both Dave and Carla prior to data collection. The two teachers then worked jointly to prepare a three-day series of lessons to introduce these terms to the students. Both teachers agreed to guide students to use these socio-scientific norms in making a scientific argument in their classrooms. The lessons were co-developed and built upon the knowledge base their students currently held with regard to creating a scientific argument; however, the lessons explicitly included instruction in the meaning and usage of the terms “claim,” “evidence,” “warrant,” and “rebuttal.”

I next sought to involve Dave and Clara in selecting particular lessons/units they thought would potentially yield the richest possibilities for students to construct their own understandings of scientific phenomena (“scientific talk”). I had planned to use these as foci for the videotaping portion of data collection. However, because this was a year of implementing newly created lessons, the teachers did not feel they could accurately identify which lessons might be more beneficial than others for the type of interaction I hoped to document. Therefore, I opted to be present in the classrooms every day the classes met, except for Fridays, which were shortened days, and reserved for review of previously learned content and weekly quizzes. The science classes at this school met every other day, so some weeks I was present twice per week, and some weeks three times per week (see Table 3.3).

### *Selection of Student Participants*

After lessons from the two classrooms were videotaped and field notes were taken, I asked both Dave and Carla to watch clips of videotaped lessons from their own classrooms, and to select three groups of three-four students they felt included a snapshot of high, medium, and low achievement in terms of their abilities to construct scientific argumentation. I asked for a selection of three total groups from each teacher, requesting that each group also include at least one English learner. The three student focus groups chosen by each teacher were then personally invited to participate with me in focus group interviews. A letter in both Spanish and English was provided to the parents of these students and to the students themselves, requesting permission for the students to participate in thirty-minute focus group interviews. The interviews were both videotaped and audiotaped to assist with voice identification. These were held after school to eliminate time taken away from classroom instruction. Students participating in the focus group interviews were given university folders as a thank you for their contribution to the research efforts.

## *Data Sources*

I approached my study as a multi-level analysis focusing individually and simultaneously on the interactions of small student groups, individual teachers, and the classroom interactions as a whole. Drawing on Rogoff's (1994, 2003) analytical framework I employed four principal data gathering techniques to answer the research questions: observation (documented in fieldnotes); videotaped sessions of students in group work and whole class discussions; focus group interviews with four students at a time; and individual interviews with the two teachers of the classrooms studied. These data sources are summarized in Table 3.2.

**Table 3.2: Data Collection Methods/Frequencies**

| Teacher | Field Notes | Videotape Of Small And Whole Group Discussions | Teacher Interview | Student Focus Groups |
|---|---|---|---|---|
| Dave | ~ 35 visits | ~25 visits- every visit after IRB forms collected | One- (60 minutes, videotaped and audiotaped) | Three (30 minutes, groups of 3-4 students, videotaped and audiotaped). |
| Carla | ~25 visits | ~25 visits | same as above | same as above |
| Totals | ~60 classroom visits | ~50 classroom visits | Two interviews total | Six student focus groups |

In order to capture the complex multimodal aspects of the science classroom, I conducted a video ethnography. This enabled me to detail the range of modalities as well as the kinds of activities students were responding to in their environment. In order to carry out the video ethnography, students in two classrooms were videotaped throughout the entirety of a curriculum unit implementation. I spent from one to three days a week in each classroom seeking to document the portions of lessons providing the richest possibilities for student reasoning required for the construction of scientific argumentation. While many studies of classroom interaction use video as a medium, they frequently focus the camera on the teacher (Wright, 2008). This study focuses at times solely on the students in small groups, examining their actions and interactions, while at times focusing on both the teacher and the students during whole class discussions to capture how the students use resources with and without the teacher present. The video ethnography resulted in approximately 85 hours of video data. Because this was the first year the teachers were moving away from solely using the prescribed CIPS curriculum and were writing their own lessons, they did not have a semester-long sequence of units pre-planned; this meant the teachers were not able to pre-determine when discussion portions of the lesson would be most robust. For this reason, I chose to be present for every classroom session to collect meaningful data. I collected data from the inception to the end of the unit on forces and motion in the eighth grade curriculum. Once the teachers began the next major unit on chemistry, I stopped collecting data in the field and turned exclusively to data reduction and analysis.

*Fieldnotes*

Fieldnotes were kept throughout the process of data collection and data reduction to document my observations of science talk in the two classrooms. I primarily assumed the role of participant-observer from once to three times a week, from September 2007 through January 2008, in the two eighth grade science classrooms according to the sample schedule:

**Table 3.3: Sample Two-week Data Collection Timetable**

| Teacher | Monday-10/1 | Tuesday-10/2 | Wednesday-10/3 | Thursday-10/4 | Friday-10/5 |
|---|---|---|---|---|---|
| | | | | | |
| Dave | 5A (2:05-3:30pm) | 5B (2:05-3:30pm) | 5A (2:05-3:30pm) | 5B (2:05-3:30pm) | 5A (11:40-12:45pm) |
| | | | | | |
| Carla | 5A (2:05-3:30pm) | 5B (2:05-3:30pm) | 5A (2:05-3:30pm) | 5B (2:05-3:30pm) | 5A (11:40-12:45pm) |

| Teacher | Monday-10/8 | Tuesday-10//9 | Wednesday-10/10 | Thursday-10/11 | Friday-10/12 |
|---|---|---|---|---|---|
| | | | | | |
| Dave | 5B (2:05-3:30pm) | 5A (2:05-3:30pm) | 5B (2:05-3:30pm) | 5A (2:05-3:30pm) | 5B (11:40-12:45pm) |
| | | | | | |
| Carla | 5B (2:05-3:30pm) | 5A (2:05-3:30pm) | 5B (2:05-3:30pm) | 5A (2:05-3:30pm) | 5B (11:40-12:45pm) |

The above table depicts a typical rotation of A and B days at the charter school. Although students met daily in their math and English classes in the mornings, they only reported to their science classes during the afternoons, in either 4th or 5th period on an A or B day. Therefore, science classes met only every other day. Each period for science was a 105-minute period, with the exception of Fridays, which were 65-minute periods. For unstated reasons, both teachers I work with said they would prefer me to work with their 5th period classes only, not their 4th periods. I was thus able to videotape and take field notes in both Dave (A days) and Carla's (B days) classes and was on the school campus every day for four months. These time periods are highlighted in yellow in Table 3.3. In summary, I worked every A day in Dave's class, and every B day in Clara's classes from the beginning of October through December.

Although my role in the classrooms was primarily as observer, at times, when the camera was off, I rotated among small groups facilitating discussion and/or answered questions regarding directions. In this way, I functioned as a participant-observer, and not solely as an observer.

Fieldnotes taken during this time primarily sought to capture what I saw occurring among students and their teachers, as well as to document my current thinking in the moment. I consistently dialogued with these observations, by fleshing out skeletal fieldnotes into analysis memos on a daily basis. I included summaries of these in journal entries for my dissertation writing seminar on a weekly basis during data collection. The purpose of these memos was to document my thinking as I moved through the process of collecting and coding data, with an eye to the notion that writing is generative and that immediate documentation of classroom observations presented key patterns or ideas that became of larger significance farther along in the research process. My notes assisted in providing thick description of the data and in making transparent my thinking related to data analysis. Once videotaping and interviews began, my fieldnotes served as a supplementary data source to help unfold the developing story of science communication practices between and among middle school students and their teachers in these two inquiry-based classrooms. However, these same fieldnotes were also used as a primary data source in later data reduction, uncoupled from the videotapes. They were helpful in documenting my own thoughts and observations not captured by the camera lens/audio recorder. In fact, by applying Rogoff's analytical framework to these fieldnotes, I was able to develop three dimensions across which to analyze the student talk generated in the classrooms. These three dimensions were: "teacher practices," "classroom systems," and "physical structures." They are defined and described in a later section of this chapter.

*Teacher Interviews*

I interviewed the two teachers participating in this study in early December 2007, near completion of the observations and videotaping of classroom lessons in those classrooms. The rationale behind the decision to include teacher interviews was to document the teachers' perspectives of what factors impact students' abilities to construct scientific arguments after they had taught nearly a semester's worth of inquiry-based science lessons. All teacher interviews lasted approximately 60 minutes and were held in the teachers' classrooms after school. Students at this charter school were directed to leave the school premises by 4:00 pm, due to ongoing safety concerns in the neighborhood. This proved an advantage in having uninterrupted time to conduct the teacher interviews without student interruptions. Interviews were both audiotaped with a digital recorder and videotaped to capture the classroom seating arrangement and other representational media key to student learning, instruction, and discussion. This decision proved fruitful, as the physical arrangement of the rooms was important for teachers to reference during the course of the interviews. Though I used the questions I pre-prepared, I asked questions in addition to these pre-designed prompts (Appendix A) for clarification purposes, or, in some cases to gain more detail. This guided conversation approach proved more effective in pilot studies than the original semi-structured interview protocol. Audio files from the interviews were uploaded to my computer and transcribed into a word document for further analysis using DSS (Digital Start and Stop) software. The videotapes taken during the teacher interviews were used to document gestural information as well as representational media to which the teachers referred that I thought could be relevant to their answers as recorded from the audio files.

*Student Focus Groups*

Three student focus groups were initially chosen by the teachers from each classroom for a total of six student focus groups. Each focus group consisted of three to four students, according to the criteria described previously. However, when it came time to conduct the interviews, many of the students could not stay due to circumstances beyond their control, and I was left with one student focus group from each of the classrooms, distilled down from the original three groups each teacher had formed. Student Focus Group A from Carla's class was comprised of three girls and two boys. I refer to them in the data as: Sandra, Gina, Veronica, John, and Alberto. Student Focus Group B from Dave's class consisted of five boys I refer to as: Carlos, Mark, Alan, Ian, and Daniel. These two groups were interviewed in order to gain a perspective of what students believe impacts their ability to construct scientific arguments. These interviews lasted approximately thirty minutes and took place at the research site after school. Although I prepared ten prompts, I chose to interview the students together in a more informal focus group format, in order to create an opportunity for interaction within the group, which in turn, could potentially elicit more of the participants' points of view than might be evidenced in single interviews (Krueger & Casey, 2000). Video-elicitation was also incorporated into the format of the focus group (see prompt #3, Appendix D) in order to capture students negotiating meaning about an actual event. Students were asked to comment on a video clip of themselves engaged in a particular sense-making portion of the science lesson, during which time they were actively constructing scientific arguments for their emerging understandings. Their teachers chose these clips from the video data collected in each classroom. Despite the alteration of the students in the focus groups, and the reduction from three to one group per class, in each case students in the video clips used during the video elicitation were present in the actual student focus group interviewed. Originally, a cross section of the class in terms of high, medium, and low achievers was provided for each class from Dave and Carla; additionally, each teacher was also asked to choose at least one English learner to participate in each of the focus groups, if this was possible. I wanted the students to represent a range in academic performance and linguistic proficiency, and second, I wanted a mixture of ethnicities and genders. These were the original criteria I imposed on the selection of student groups. Part of the rationale for these criteria was that I wanted to see how the modalities employed during the construction of scientific argumentation varied when the English verbal modality of a student is limited, as in the case of the verbal repertoire of an English Language Learner. I also wanted to see if English learners use different modalities in communicating their understandings of science in group-settings. Tables 3.4 and 3.5 describe the participants across levels of academic performance and English language proficiency. The academic performance levels were determined by the teachers' own assessment of the students' current grades, where an "A" was "high," a "B" was "middle" and a " C or D" was "low." The English language proficiency levels were determined by California English Language Development Test (CELDT) scores, as reported to me by the teachers. CELDT is the California state test of English language proficiency that school districts in California are required to administer to newly enrolled students whose primary home language is not English and to English learners as an annual assessment (Education Code Section 313 and Title 5, California Code of Regulations, Section 11510). The exam is administered once each year to English learners as an annual assessment of their progress toward English proficiency. English Language Development Standards identify five proficiency levels through which English learners progress toward English proficiency: beginning, early intermediate, intermediate, early advanced and advanced.

**Table 3.4: Student Focus Group A (Carla's Class)**

| Student Pseudonym | Grade/Class | Academic Performance (per teacher) | Language Proficiency (per teacher) |
|---|---|---|---|
| Sandra | 8/5B | Middle | Early advanced |
| John | 8/5B | High | Proficient |
| Gina | 8/5B | Middle | Intermediate |
| Alberto | 8/5B | Low | Early Intermediate |
| Veronica | 8/5B | Middle | Early Intermediate |

**Table 3.5: Student Focus Group B (Dave's Class)**

| Student Pseudonym | Grade/Class | Academic Performance (per teacher) | Language Proficiency (per teacher) |
|---|---|---|---|
| Carlos | 8/5A | High | Early advanced |
| Mark | 8/5A | Middle | Intermediate |
| Ian | 8/5A | High | Early advanced |
| Alan | 8/5A | Low | Proficient |
| Daniel | 8/5A | High | Proficient |

Each group met the criteria I set for the student groups, with a range of academic performance and language proficiency levels.

## *Data Reduction and Analysis*

The process of coding data began as soon as I began taking fieldnotes in the classrooms. This process occurred continuously throughout the data collection period as I continued to document classroom observations and reflect upon them, as I videotaped small group and whole class discussions, and as I transcribed the interviews of the teachers and student focus groups. I scheduled four months (December 2007-March 2008) to code and analyze the data from my four sources. Data collection and analysis overlapped as categories emerged from the data. I used a cross-case, constant-comparison analysis method (Glaser & Strauss, 1967) for making meaning of the data and kept a running dialogue of my emerging thoughts and potential findings throughout the process. This dialogue occurred in the form of computer word documents and notes alongside of and within transcription of the interview data.

The videotaped small group and whole class discussions were transcribed and analyzed using an analytical framework for assessing the quality of scientific argumentation. The instrument of analysis evolved during use. I describe this evolution in the section that follows.

*Refining the Rubric of Analysis*

Originally, I planned to use the five level rubric found in the literature to analyze student argumentation (Table 3.6) documented in my transcripts.

**Table 3.6: Original Scientific Argumentation Rubric (adapted from Osborne, Erduran, & Simon, 2004)**

| | |
|---|---|
| Level 1 | Level 1 argumentation consists or arguments that are a simple claim versus a counterclaim or a claim versus claim. |
| Level 2 | Level 2 argumentation has arguments consisting of claims with either: data, warrants, or backings, but do not contain any rebuttals. |
| Level 3 | Level 3 argumentation has arguments with a series of claims or counterclaims with either data, warrants, or backings with the occasional weak rebuttal. |
| Level 4 | Level 4 argumentation has arguments with a claim with a clearly identifiable rebuttal. Such an argument may have several claims and counterclaims as well, but this is not necessary. |
| Level 5 | Level 5 argumentation displays an extended argument with more than one rebuttal. |

In this framework, the four terms “claim,” “evidence,” “warrant” and “rebuttal” were operationalized according to Toulmin’s definitions (1958).

**Table 3.7: Toulmin’s (1958) Elements of Argumentation**

| Term | Definition | Example |
|---|---|---|
| Evidence (data) | The facts that those involved in the argument appeal to in support of their claim (the “proof”). | Often prefaced by “since” or “because” |
| Claim | The conclusion whose merits are to be established. | “the car has a force acting on it” = claim; “because it is moving” = evidence. |
| Warrants | The reasons (rules, principles, etc…) that are proposed to justify the connections between the data and the knowledge claim, or conclusion. | For the claim above, the warrant might be, albeit faulty, “when an object is moving, there must be a force acting on it.” |
| Rebuttal | These specify the conditions when the claim will not be true. | For the above, “whereas the car would not have a force acting on it when it is stopped” (rebuttals can be true or false depending, in part, on the truth of the original claim. |

Toulmin actually identifies two additional features of argument that were not included in this rubric. They are "backings" (the basic assumptions that provide justification for warrants) and "qualifiers" (the limitations on the claim; the conditions specified under which the claim can be taken as true). These two were eliminated to streamline the process of using the rubric and also due to the fact that the teachers did not emphasize these terms to the extent they taught and practiced using "claim," and "evidence" in their speech.

As I began to analyze the tapes, this rubric proved an insufficient instrument to analyze the argumentation structures in my data. The grain size was too large. I noticed that at certain times in the data I was analyzing, the students articulated claims with no evidence, while at other times the evidence used to back other claims was quite sophisticated. The original rubric was not detailed enough to account for these nuances. In addition, there were instances of exceptional counterclaims backed by evidence that I did not feel the original rubric accounted for in a meaningful way. In the original rubric in Table 3.6, the skill of using a "rebuttal" is the defining break between the achievement of a two and a three level argument. There is not any other way to grant a score of three, four, or five to an argument, unless it contains a clearly identifiable rebuttal. Yet, rebuttals were not on the list of socio-scientific norms the two teachers taught their students to use in discussion format. Neither was "warrant," but I still found instances of implicit warrants used in conjunction with evidence to back claims and counterclaims. "Counterclaim" too was not an explicitly taught term. However, the heavy emphasis on use of a rebuttal in the four and five scores convinced me to modify the rubric to highlight instances where a counterclaim was inserted into the discussions. These latter arguments stood out to me as clearly distinguishable from arguments that had a series of claims where all students had the same claim, and I wanted a modified rubric to reflect the range of argumentation the students were able to achieve at different moments in time. Allowing for this range, in turn, allowed me to use a more refined lens through which to analyze what dimensions ("teacher practices," "physical structures," or "classroom systems") were dominant contributors to portions of the student discussions.

Ultimately, I chose to design my own rubric and used it (Table 3.8) as the instrument of analysis of all student talk. The modifications made to the original rubric make possible a more elegant analysis of what students were able to accomplish over time, and made it possible to differentiate the subtle differences in sophistication of argumentation that occurred between the use of a simple claim at a level one, the use of a claim with evidence at a level two, the use of a claim and counterclaim at a level three, and the addition of rebuttals at levels four and five. Another major revision to the original was the addition of a level zero which accounted for the many instances where students shared observations, but made no claims.

**Table 3.8: Revised Rubric: Instrument for Analysis of Argumentation**

| | |
|---|---|
| Level 0 | Evidence only; observations only; or, warrant only. **No claim is made**. |
| Level 1 | Level 1 argumentation consists of arguments comprised of **a claim**, a series of claims, or a claim vs. a counterclaim, **but no evidence or very weak evidence, or evidence that may be unclear.** These **may be "implicit claims"** (a yes or no answer to a teacher's question, or a hand raise to a teacher question such as "How many of you think two objects always fall at the same time?" An implicit claim does not include clarification questions regarding observations of what students "see." |
| Level 2 | Level 2 argumentation has arguments consisting of **claims with data, or a claim with warrants, or a claim with data and warrants.** |

**Table 3.8 continued**

| | |
|---|---|
| Level 3 | Level 3 argumentation has arguments with a series of **claims with either data and/or warrants as well as counterclaims with data and/or warrants,** but no rebuttals. |
| Level 4 | Level 4 argumentation has arguments with a **claim backed by evidence and a warrant and/or a counterclaim with or without evidence.** No rebuttals. Such an argument may have several claims and counterclaims, but it is not necessary. |
| Level 5 | Level 5 argumentation displays **an extended argument with claims and counterclaims both backed by evidence and/or warrants, and with one or more rebuttal.** |

As I analyzed the six videotapes, I used the following socio-scientific norms of argumentation: "claim," "evidence," "warrant," and "rebuttal" within the transcription data and then identified portions of interaction during which different levels of argumentation occurred as based on the rubric criteria. I used the same definitions for these terms as those outlined by Toulmin in Table 3.7.

After the initial analysis with the rubric by the researcher, an inter-rater reliability test was conducted with selected transcripts to assure credibility of the data. One veteran teacher who taught from the CIPS curriculum in previous years was asked to analyze four samples of transcripts using the five-level rubric in Table 3.8; the results were then cross-compared with those of the researcher for calibration.

Data from the videotapes was reduced using the process described above using the five-level rubric and inter-rater reliability, with already established codes - what has been described as a "bottom up approach" (Erikson, 2004). Once argumentation levels were determined across the transcripts, I returned to the raw video data in order to identify the modalities students relied upon in forming their arguments.

Data from all four primary collection strategies was analyzed using a constant comparative method (Glaser & Strauss, 1967). This was achieved through a constant dialogue between the researcher and the data in order to perceive patterns and generate theories. While the videotapes generated a description of the quality of students' argumentation through the rubric descriptors and associated numerical levels, the teacher interview data and student focus group data provided the perspective of the teachers' voices and the students' voices. The coding and categorization of data sources was guided both by my research questions and theoretical frameworks.

*Analysis of Interview Data*

Although I used the four components of scientific argument as codes (evidence, claim, warrant, rebuttal) for the videotaped data, I conducted my data analysis from the interviews such that "induction and deduction [were] in constant dialogue" (Sipe & Ghiso, 2004). I wanted to be wary of over-determining what I was analyzing and remain open to allow for alternative perspectives to emerge.

I analyzed the interviews using the software program, HyperRESEARCH. I used a "top down" approach and searched for my codes within the data (Erikson, 2004). I followed the coding process outlined by Strauss and Corbin (1990) involving three primary steps:

Step 1: <u>Open Coding</u>- I first named and categorized phenomena by closely examining the data. I then spent time reading and studying all pieces of data and kept a record of my thoughts on computer word documents and in excel spreadsheets. I began to find words to capture events, phenomena, people, and answers to such notions as when or how concerning the process of constructing argumentation.

Step 2: Axial Coding- Next, I made connections between the categories generated during open coding. I built a model that grounded the emerging findings into the school context, and could describe the relationships among the categories and sources of the data. This portion of the process involved a constant interplay between proposing ideas and checking them against my data and theoretical frameworks. It also required recursive and iterative passes through the data and coding structures to arrive at my findings (Sipe & Ghiso, 2004).

Step 3: Selective Coding- Finally, I reduced my number of categories and selected core categories as a basis for establishing a story-line of my research. I related all subsidiary categories to these main core categories to arrive at a final model to explain the voices of the teachers and students involved in the study. This led to adding these voices to the rubric level data collected from the classroom videotapes to arrive at an answer to my guiding research questions and to a proposition of a model for guided-inquiry instruction.

*Presentation of Visual Data*

A number of photos containing minors are used in constructing the argument of this work. These photos are essential to the analysis and to the ultimate construction of answers to my research questions. I am keenly aware of the need to preserve and protect the identity of minors in research work. To this end, I have taken the following measures: when students' faces are directly facing the camera and are recognizable, I have blurred their faces within the photo using Adobe Photoshop, so that the identity of the minors is not clear. I have left the photos unaltered in cases where students have their backs to the camera, and when students are far from the camera and not recognizable.

*Definitions of Key Constructs used in Data Reduction and Analysis*

In the next chapter, I analyze six videotape selections from the data collection period along the three dimensions of "teacher practice," "physical structures," and "classroom systems." These three dimensions were distilled from notes recorded daily in the research setting. Each day I spent in the classrooms, I began to realize that a view across these three dimensions could provide a thick description of the data. Often, it was noted that elements I identified as belonging to one of these dimensions, could also be located in another. Together, the three dimensions provide a useful analytical framework for understanding the contexts in which student argumentation was enabled or constrained in each classroom setting. In Figure 3.1, I depict the three dimensions in an overlapping Venn Diagram.

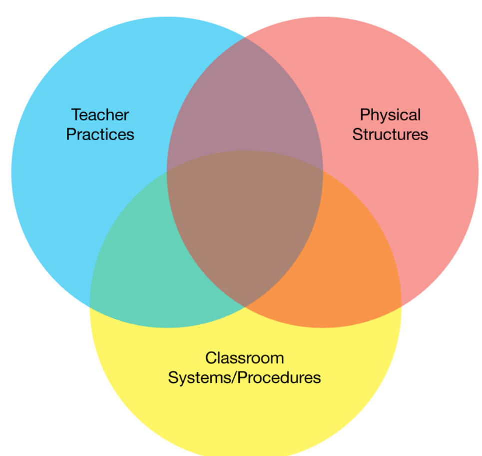



**Figure 3.1: Three Constructs of Analysis**

In the following sections, in order to eliminate confusion, and improve understanding, I define and detail the salient features of these dimensions so that these constructs become operationalized for the reader before the data is presented. These three dimensions were used to locate the contexts and conditions that either enabled or constrained opportunities for students to participate in classroom discourse.

*Definition of "Teacher Practices"*

Teacher practices in this study are defined as teacher beliefs instantiated in practice. As such, they constitute observable practices emanating directly from the teacher. I define such practices to include the teacher's discourse style with students; preferred modes of modeling- through the use of the body, manipulatives, or diagrams and charts; and purposeful opportunities created by the teacher for students to use multiple modalities to process information. When a teacher consistently uses his or her body to model aspects of instruction, I refer to this modeling as "kinesthetic modeling.

*Definition of "Physical Structures"*

The construct of "physical structures" is used to encompass all components of the physical organization of a classroom. As such, structures refer to the physical organization of the environment including the seating arrangements teachers create that influence the types of interaction that occur among classroom members. In addition, included in this category are also a variety of representational media around the classroom, which both the teacher and students draw upon in the processing and reprocessing of meaning through different modalities. These representational media can encompass a wide range of precisely located easels, whiteboards, chart paper, and LCD and overhead projectors, used to record and offload information in various phases of development, and to challenge and contemplate knowledge states throughout the process of inquiry. The social, cultural, material, and sequential structure of the environment where action occurs figures prominently into an analysis of the organization of student talk. Students' conversations are situated within a larger ecological setting where talk and action mutually inform one another and where facts ultimately become stabilized into language representing students' knowledge states; the action used to produce language in the process of drawing on the physical structures becomes erased, and invisible to the process. Such structures remains integral to the analysis, however.

*Definition of "Classroom Systems"*

Classroom systems are defined as the norms, routines and procedures of the classroom. These dictate the expectations for how things are to be accomplished in the classroom. These include school rules that pervade the classroom climate. They also include the 5E model of instruction (engage, explore, explain, elaborate, evaluate); the use of "preludes," or warm-up problems; and the use of the "G.E.S.S. system," a heuristic for solving word problems in physical science. Another element I categorize under this construct is what I refer to as "entextualization." In this study, I refer to "entextualization" as a system drawn upon by the teacher to record elements of the instruction onto the environment. This may take the form of recording information onto charts, onto the whiteboard, or onto any other representation media in the classroom. When "entextualization" is practiced consistently as a norm in the classroom, it is considered to be a “classroom system.” It can, however, traverse domains, and be considered an element of “teacher practice” as well.

*Definition of “Resemiotization”*

Across all three of these dimensions, whenever students draw upon more than one modality to process information and search for meaning, I define that practice as “resmiotization” (Iedema, 2003). This may occur when students use their verbal words in conjunction with gesture, or when students refer visually to text encoded in a chart and then begin to verbalize their ideas. In using this term, I draw upon Iedema’s (2003) work in identifying resemiotization as the progressive re-representation of meaning with different media and/or via different modalities.

## *Pilot Testing*

Before data collection commenced, I conducted several pilot tests to refine my research design. An initial pilot test of a classroom using the CIPS curriculum yielded promising observations that allowed me to make strong hypotheses about the way in which learning is distributed across multiple representational media. This reinforced the importance of using fieldnotes as a data source. One pilot study revealed that an important factor to consider in my research might be the difference in the degree of coordination between each teacher’s gestures with other representational media in their classrooms, including physical props, white boards with diagrams, and easels with chart paper prepared with sentence-predictors and definition prompts. A second pilot test confirmed my hypotheses that physical models are used as visual tools during hands-on or laboratory activities, but then discarded once students are asked to discuss and complete analysis questions about those activities and labs. Again, this reinforced the significance of recording such observations in fieldnotes.

Additional pilot tests conducted in the spring of 2007 with intern teachers participating in the Single Subject Credential Program at a major university in Southern California confirmed the decision to use a constant source of curricula as the basis for instruction. This is key since the results of asking interns for permission to observe a session in which their students would use models to "make sense" of a scientific phenomena was misinterpreted. From these latter pilot studies, I learned the importance of the role of different types of knowledge, and about the necessity of being explicit concerning the type of knowledge I wish to investigate in this study. All three of the intern teachers in the pilot used models as visual aids only in lessons centered primarily about identification and factual knowledge. This study seeks to understand the potential factors that mediate student talk in middle school science classrooms. One consideration emerging from pilot tests is role of manipulatives in serving as bridges to language emergence in the course of articulating scientific *argumentation*, rather than simply in *the recall of facts*. This is a crucial distinction. Therefore, the decision to use a uniform curriculum that centers about conceptual understanding in any classrooms used in the study was reaffirmed.

I also piloted the planned interview protocol in the spring before data collection began. Four teachers using the CIPS curriculum at local middle schools participated; two were new teachers and two veteran teachers. These interviews confirmed that 45 minutes is a suitable timeframe in which to ask the ten questions pre-prepared. These pilot tests confirmed a need to both videotape as well as audiotape. Because my study encompasses an embodied approach to learning, it would be remiss not to also include body movement, facial expressions, and gestural interactions between the teacher and the classroom environment as probable input for data collection. All teachers interviewed referred to their "word wall" (a wall bearing vocabulary words stemming from the current unit of instruction) and to seating arrangements with deictic gestures that cannot be captured on audiotape alone, underscoring the importance of considering the physical arrangement of the room when discussing instruction.

These pilot interviews were very helpful in rewording and reordering the questions in the interview protocol in order to yield the most relevant type of data necessary to answer the research questions.

In the next four chapters, I present findings for each of the research questions outlined in this chapter. In Chapter 4, I provide a rich description of each teacher's practice. In Chapter 5, I add the students' perspectives of how their learning is affected by their teacher's practice. And, finally in Chapters 6 and 7, I answer the third research question: What factors affect students' ability to achieve more sophisticated levels of argumentation in the classroom? I also use the findings from all four chapters to present a model of guided-inquiry instruction that maximizes opportunities for students to participate in quality argumentation. This proposed model answers the overarching research question: What practices enhance effective scientific inquiry in the middle school science classroom? In this study, "effective" scientific inquiry is measured by quality argumentation by students in the classroom.

## Chapter 4- Teachers' Views about Science Teaching and Learning

Teachers' knowledge of pedagogical content and beliefs about student learning significantly contribute to the context for learning in classrooms. Therefore, it is important to take into account teachers' ideologies about science learning in a study of middle school students' construction of scientific argumentation. In this chapter, I answer the first research question of this study, providing a rich description of the teaching ideologies of the two teachers in whose classrooms this study was situated. In Chapter 5, I present the students' perspectives of the teaching practices they attribute to affecting their science learning. Together, Chapters 4 and 5 lay the foundation for an understanding of the situated contexts in which the classroom discourse took place. A detailed analysis of student argumentation and the modalities contributing to the construction of those arguments is discussed in Chapters 6 and 7.

### *Introduction to the Chapter*

This chapter examines the perspective on science teaching and learning of the two teachers in this study, "Dave" and "Carla." Each provided a thorough descriptive context for their classrooms during an individual interview. Each teacher's pedagogical beliefs directly influenced the planning of lessons, the structuring of the classroom environment, and the opportunities for students to use different modalities at different times to engage in discourse about science. This is an important component to consider before addressing any findings about students' use of modalities, as it provides an understanding of the social dynamics which were a reality in each classroom, and also provides a context in which to see what types of systems were created by the teacher that might contribute to the choices students made when choosing different modalities to draw from in their construction of scientific argumentation.

Variations in classroom environment and pedagogical systems enabled the use of certain modalities, while they constrained others, as evidenced in the video data. I have determined that teachers' pedagogical beliefs and strategies, their physical room environments, and their affective teaching practices are all crucial factors for establishing and influencing the successes of an inquiry-based classroom. These three factors also influenced what students were and were not able to do, and what modalities contributed to the communication of their scientific ideas. Chapters 6 and 7 discuss these ideas in detail. In this chapter, my decision for including the teacher voice was made in an effort to provide a detailed description of each classroom in the words of the teacher him or herself, independent of what was revealed in video data. In this way, I provide a rich context, in each teacher's own voice, in which to both situate and examine students' discourse practices from both classroom settings.

*The Teachers' Perspectives on Science Teaching and Learning*

The data in this section are primarily drawn from two semi-structured interviews I held with each of the classroom teachers involved in this study. I asked the teachers to describe the primary goals for their eighth grade science students. I also asked the teachers to describe what "inquiry –based instruction" meant to them, and what it means to "think like a scientist." Teachers were also asked to describe strategies used to assist students in communicating their scientific ideas, as well as to provide their own thoughts on the major impediments to students' articulation of scientific understandings (see Appendix A for the full set of interview questions).

*Teacher Talk Matches Teacher Practice*

The way in which Dave and Carla "talk" about their practice largely matches the "actions" each take in their classrooms, with one exception in Carla's classroom. This exception will be noted and discussed in the section describing Carla's view of her role as a teacher later in this chapter. In that section, we will see that, though she states that she follows a 5E model which includes an "explain" session when students discuss their ideas from the "explore," there is rarely, if ever, time left at the end of Carla's classes for student discussion. This leaves students to work through their scientific findings alone at home, when they are given their "conclusions" to write for homework.

Aside from this one exception, there is remarkable symmetry between what Dave and Carla claim to believe and practice in our interview, and what video data reveal about their actual teaching practices during the data collection period. In the next section, I provide a summary of the ways in which Dave and Carla's views on their teaching practices were similar. I then provide a summary of the ways in which Carla and Dave's teaching ideologies differed from one another.

Although there is a great symmetry between talk and action in the data for both teachers, the ways in which Dave and Carla talk about their teaching and envision the cultural practices of inquiry "look" different in important ways. Since we know that what teachers believe about their practice influences their language and actions in the classroom, it logically follows that these beliefs and practices, in turn, enable or constrain what students are able to do, or are given the opportunity to do, in the classroom. By understanding the differences in how each teacher envisions and implements an "inquiry-based" classroom through their language, thoughts, and actions, we can better understand how students are able to act, talk, and learn in these settings.

*Language, Thought, and Action*

According to Bakhtin (1981), we come to know the world through the representations we make of it. A particular way of representing events in language influences the way we think about events, and the way we act toward them (Mehan, 1993). This is represented in Figure 4.1 below.

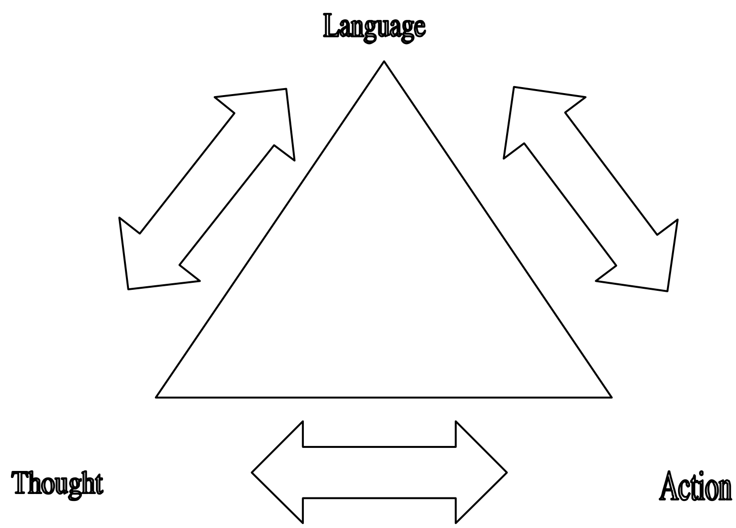



**Figure 4.1: Interaction of Language, Thought, and Action**

A main goal of this study was to highlight the components of an effective inquiry-based classroom, most especially for novice teachers and those seeking guidance in implementing an inquiry approach to teaching science. Mehan's triangle of thought, language, and action is a useful heuristic in thinking about ways teachers seeking to become effective with the inquiry model might achieve their goals. If one begins at the thought vertex, efforts can be concentrated upon to influence changes in language, and ultimately changes in action, or teacher practice, that can lead to more useful models of effective science inquiry teaching. The double-headed arrows in this figure are indicative of the mutual influence each vertex can potentially have on each of the other two vertices. In the case of teachers, it is sometimes one vertex that "leads" one, or both, of the others. Either language or thoughts or actions can lead to a transformation across any of the other vertices. In my interactions with Dave and Carla, it was clear that both teachers embody the dynamic process of thoughts affecting language, affecting actions. This process was influenced by the degree to which each teacher engaged in reflective practice, in the reading of new research and literature from the field, and by their contact with other professionals in the field. It was not my purpose to analyze which of these vertices was most influential in these two teachers' practices. Rather, I sought to discover the extent to which each educator's practice (actions), as documented in videotaped data over the course of four months, matched what they actually said about their teaching practice in my interviews with them, and then, from there, to analyze what their students were able to enact in each classroom.

*Similarities and Differences in Teaching Practices of Dave and Carla*

What follows is an account of the ways in which Dave and Carla's words from interview data matched data from the videotapes and field notes. I have categorized the data according to patterns I found concerning meaningful differences and commonalities concerning aspects of their teaching practice and beliefs. Overall, each teacher described his/her practice and pedagogical beliefs in ways that were corroborated by videotapes of actual their actual classroom teaching. Tables 4.1 and 4.2 below summarize the main similarities and differences between Carla and Dave's teaching beliefs and practices. These tables are followed by a detailed account of the ways in which the two teachers differed on significant points regarding their beliefs about teaching and learning in science.

### *Similarities in Ideologies Between Dave and Carla*

In general, Dave and Carla both shared the goals of establishing an effective inquiry-based classroom in which their students' main task is to repeatedly try and fail, as scientists in authentic settings do every day. Each teacher also clearly privileged the *process* of scientific inquiry over any type of "correct" scientific *outcome*. In fact, both teachers even celebrated the articulation of "incorrect" answers in the pursuit of the "key question" that framed each day's lesson, and viewed incorrect ideas as paving the way to final scientific truths. These similarities are summarized in Table 4.1 below.

**Table 4.1: Summary of Similarities in Teaching Beliefs and Practices**

1. Primary goal for students = inquiry, a sharing of discovery and exploration, using evidence to back claims.
2. Students' job in the science classroom = to "try and fail, try and fail."
3. Scientific process privileged over scientific outcome.

*Using Evidence to Back Claims*

Both Dave and Carla demand that students use the protocol of backing any statements, called "claims," with evidence from what they observe with their senses. This is a crucial part of what each teacher views the students' role to be in their attempts to access the content. Dave expresses this well when he says that the students know that he is not going to let anything come out of their mouths until they are able to say why they know that. "Because I'm coming right back with that question. 'Why?' "Where'd you get that?'" Dave is insistent on evidence. And he is relentless. Even if a student chooses letter "a" as an answer but then responds, "I don't know," when asked why, Dave will respond: "Well then, you don't know if it's 'a' so let's see if we can figure this out. What are you thinking? What's going on? What do you know?" (Appendix B, lines 547-549). He helps the students see that they always have something to contribute, even it if is simply starting with something that they can observe. Dave admits that many students are at first very frustrated by this. And he says that this is okay. "You take them up to that frustration level and you say, 'it's difficult, huh? Let's see if we can get somebody to help you out'" (Appendix B, lines 554-556). Two things are accomplished with this approach. The students learn that they are all valued participants in the class and that each student's thinking is equally valued with every other student's thinking. And, the students get a glimpse into Dave's unique affective style of teaching through which they learn that it is okay to be frustrated, and that it is a natural part of learning, and can actually serve to pique our curiosity and catapult us further into the process of "trying and failing" which is so obviously a part of what Dave and Carla both consider to be the main "job" of the students in their classroom.

*Differences in Ideologies and Practice between Dave and Carla*

There were many points of difference in the ideologies of the two teachers documented in the interview data. In general, I identified nine categories that condense many of the differences existing between these two teachers. These nine categories are summarized in Table 4.2 below, and then described in detail following.

**Table 4.2: Summary of Differences in Teaching Beliefs and Practices**

| | Dave | Carla |
|---|---|---|
| Goals for students | Standards with a focus on student wonder and curiosity | Standards with a focus on lack of "scientific equipment" |
| Prior Knowledge | "funds of knowledge" | Lack of exposure to scientific concepts and terminology |
| Video Clips | Used to facilitate transfer of "spontaneous concepts" to "scientific concepts." | Used to address gaps in past learning. |
| Articulation Difficulties | Stem from student difficulty explaining what they know; need to lower "affective filter." | Due to lack of "modern English." |
| Role of Teacher | "more capable peer" | "questioner, and manager of "controlled chaos. |
| Outcomes | constructed by class | constructed by individuals |
| Teacher privileges | "post-experimental meeting area" discussion | exploration |
| Inquiry | proceeds through "spiraling" | proceeds through "looping" |
| Physical Classroom Structure | serves as the student's "textbook" | consists of tables and an "elliptical meeting area" |

*Goals for Students: A Standards-based, Inquiry-based Curriculum*

I asked both teachers what their primary goals were for their eighth grade students this year. Though both teachers mentioned scientific content, they did so in very different ways. Both Carla and Dave hold inquiry as a main tenet of teaching the grade-level science content standards. Both safeguard the premise that their students should be involved in seeking knowledge through discovery and exploration. It is a constant in video data from both classrooms; there is little direct instruction in either classroom and both classrooms follow the 5E inquiry model of instruction described in Chapter 3. Beyond this, however, Carla came at the question of goals with a deficit view of her students' educational environment. Carla insisted upon high expectations, emphasizing the use of correct scientific language, with no "watering down" of the language or curriculum whatsoever. In particular, she focused on a lack of available scientific equipment as an impediment to meeting grade level standards.

<u>Carla- Impediments to Learning the Standards</u>

Carla was very succinct in her response: "My primary goals for this year are for them to learn the scientific method for an inquiry based classroom and to learn the basics of physics, chemistry, and astronomy" (Appendix C, lines 9-11). Beyond the method and specific content, she did not elaborate, other than to state some of the tools she lacks to accomplish her goals of true scientific inquiry. These included "equipment similar to what they would see in a real science lab in college or in high school or in industry, and not dumbing down the equipment…and using real scientific terms for it, not using baby terms….." (Appendix C, lines 38-42). Specific equipment mentioned included a digital balance and a "real pHmeter." Data from the field corroborates that these seem to be the goals as manifested in daily lessons in Carla's classroom.

Dave- "Thinking" through the Standards: "Imagination is More Important than Knowledge"

Dave gave a different answer, though still concerned with the content of science. His immediate answer was that "the kids walk out of the room knowing the standards," referring here to the California Science Content Standards to which the school closely aligns curriculum in all subject areas. However, he clarified that he wants his students to know all the information in the standards, "but more in tune with the idea that they can think about the information in a logical like scientific type of way" (Appendix B, lines 14-16). Even if students do not remember specific information, as long as they are able to look at a problem and extract given information and be able to reason through what they are given, what they know, and come up with their own ideas, "use their imagination," then "that would be a nice thing if everyone could walk out of the room with" (Appendix B, lines 26-27). Dave stayed with this interview topic for some time, reminiscing about when he was a child. He told me he would watch a tree fall and "I would look at it and want to know why did it do that?" He remembers that just this year, he shared with his students that when he was a child he would watch the traffic signals turn red, green, yellow and wonder, why do the left turn lanes go, and then the straight lanes go, and then the left turn lanes go, and then the straights go? Why that order?

> And then you look at certain other signals and they don't do that. And you're like, well, why is it that some signals do it and others don't? And you're like, well it's a very busy street so they want to get all these cars all out of the way so that these cars can go because until that signal turns green there's a backup (Appendix B, lines 148-152).

Dave recalls sharing childhood thoughts like this with his students and revealing how, at an early age, he was formulating hypotheses about how the world around him worked. "I was a very stubborn kid, " he admits, "I realized that being stubborn, I'm going to stick with that hypothesis or that theory on something until somebody proves it otherwise" – the natural way paradigms of science proceed, in fact. He explained the importance of his students understanding that they already come to him with an understanding of how to think like scientists. They now have to unlearn the notion that teachers will "tell" them the right answer. "I don't believe they should listen to anything I say and take it as, 'well, you said it, so it must be true'" (Appendix B, lines 180-182).

Dave's language through different stages of the 5E model is rife with a theme of wonder and curiosity. As I listened to him talk during our interview, I was reminded of Albert Einstein's famous remark: "Imagination is more important than knowledge." It is his students' wonder and curiosity that Dave equates with the only necessary prior knowledge he needs to teach them the science required by the standards. Thoughts from both Dave and Carla regarding prior knowledge are addressed in the next section.

*Differing Views in the Role of Prior Knowledge*

Although not specifically asked about student prior knowledge and its role in student learning, both teachers spoke extensively on the topic when asked this question: "When a student is struggling to articulate his or her own understanding of a scientific phenomenon, what are some of the possibilities for this struggle?" Carla's immediate answer was "lack of scientific knowledge." Her main point concerning prior knowledge is that her students lack exposure to science concepts and terminology in ways that could provide meaningful access to the curriculum she needs to teach. In contrast, Dave believes that if one approaches science from a conceptual standpoint, then prior knowledge plays a minimal role. He sees academic language as a completely different construct than prior knowledge. Carla addresses both constructs simultaneously in her view of why her students struggle with articulating their ideas in science; she sees that the two are linked and are both contributing factors to students' struggles. Past schooling preparation and English language proficiency play into her definition of "prior knowledge" in a way they do not in Dave's view.

Carla: Confounding Language Proficiency and Content Knowledge

Carla partly attributes the difficulty of student expression of ideas as stemming from what she calls their "prior knowledge" with science. In her view, her students lack enough prior knowledge of science that it makes teaching and learning the grade level standards difficult. To Carla, her students lack a sophisticated schema within which to integrate new scientific understandings. In order to make up for this, Carla often incorporates video clips in her lessons to illustrate key concepts she feels her students have lacked an exposure to at previous grade levels.

But Carla also seems to confound students' inability to express their scientific ideas in "modern English" with a "lack of scientific knowledge." In reality, lacking the English words to articulate their thinking is very different from students not possessing the scientific background to move forward in their grade level learning. We know from the research in language acquisition that these are entirely different matters. From such researchers as Cummins (1984), we know that it takes students approximately five years to attain what is known as cognitive academic language proficiency, or CALP. Though immigrant students may be able to acquire conversational fluency at a functional level in only two years of initial exposure to a second language, much longer time periods are required to acquire the academic language needed to catch up to native speakers in academic aspects of their second language.

Irrespective of her diagnosis as to why students struggle to articulate their thinking, Carla does address student difficulties. She attempts to supplement her teaching with the use of pictures and demonstrations, and encourages students to work with a partner to "try to get the words out." She claims that sometimes she hears them and tries to lead them to where the class is going.

> They really struggle because they haven't had science. And elementary school teachers don't teach science. So, they don't have that knowledge to be able to base their answers off of something prior (Appendix C, lines 165-167).

Though she states that she does not provide them with answers, but responds to questions with more questions to probe them and prod them along, she does admit that she will "write the answer in their reports," referring to their science notebooks, if they ultimately arrive at an incorrect answer to the key question of the day.

Carla also encourages students to use pictures to convey their thoughts. She performs demonstrations of science concepts, and she will purposefully partner students together according to language proficiency levels to assist them with expressing their answers. These forms of supports are readily apparent in the data from the field as well.

Students are encouraged to draw, use manipulatives to think things through, and to create visual posters to transfer knowledge from text into another learning modality.

Dave and the "Foam on Top of the Water"

In response to the same interview question, Dave has a different focus. I asked him: "When a student is struggling to articulate his or her own understanding of a scientific phenomenon, what are some of the possibilities for this struggle?" Rather than identifying a lack of scientific prior knowledge, Dave attributes potential difficulty with student expression of ideas as stemming from a simple inability to "explain what they are thinking." To him, the thoughts are there, but the verbal words are not. Unlike for Carla, his answer seems to have nothing at all to do with what the students bring with them regarding past science learning. Rather, it has everything to do with a difficulty of transferring knowledge from one modality to another: from a visual or kinesthetic "knowing" to a verbal articulation of that same knowledge. And, Dave is not necessarily concerned with why this is. Unlike Carla, he does not locate blame in a lack of English language proficiency. Also, he is not concerned with any perceived lack of scientific content knowledge, or gaps in scientific learning from previous years of schooling.

In our interview together, Dave discussed a system he has in place to scaffold the articulation of student ideas, irrespective of prior knowledge. He claims that all his students will have something to contribute; so, if they are having difficulty, he simply will ask them what they are thinking at the moment. Everyone, Dave says, has something that way.

> …that's the one thing I love about inquiry is I can look at every student in the meeting area, and you know, I say "What do you think's going on?" Then they, they have something. And that's why we do the claims, is so that it can help them have something before they say anything. But, they have something in their head…98% of the time it's because they don't know how to explain it the way that I expect them to explain it (Appendix B, lines 624-632).

Dave continues to discuss the difficulty of the terminology of science, as did Carla. However, he sees this as an easy obstacle to overcome. In the case of a lack of academic language, he will ask, "well, what did you see? Just tell me what you see and use your own words. You know, don't use my words." Student observation is seen as the component capable of leveling the playing field of science for access to all.

Interwoven in the narrative of why students struggle with articulating their ideas, Dave begins another narrative of the importance of lowering the affective filter when teaching. He is keen to identify the need for a safe and comfortable, risk-free environment as necessary for allowing students to find the words needed to express their scientific ideas. We know this to be consistent with the research about language acquisition (Krashen, 1985). A mental block, caused by affective factors can prevent input from reaching the language acquisition device. Dave also considers the creation of a positive, safe, risk-free environment to be an important component for scientific inquiry if it is to be an effective approach to teaching in general. In his words: "You can't let them feel threatened when they're struggling to articulate it [scientific ideas] because then they're not going to feel like sharing at all until they have the perfect answer" (Appendix B, lines 647-649). And, "you have to validate the wrong reasons…you have to really, immediately jump on anybody else whose snickering or laughing or making the student feel that they're not up to the task. You really have to do something about that.

And that's usually done at the beginning of the year" (Appendix B, lines 659-663). Dave writes all answers on the board, without attaching student names to the comments. He does so during the "engage" portion of the lesson to model the notion that all initial ideas are important before students explore the phenomenon under investigation in the "explore" portion of the lesson. These ideas, right or wrong, then serve as a discussion base from which to argue what students did or did not find during the exploration; this occurs during the "explain" portion of the lesson.

But perhaps most striking is what Dave says about prior knowledge when asked about his views on the tools needed to teach English learners, and whether there are strategies he feels are better for English learners when using an inquiry approach to teaching science. He answers that he has had many discussions with colleagues over these issues and the type of modifications you should or should not make for English Learners. Ultimately, he says that if you approach science with a conceptual attitude, then prior knowledge plays a minimal role.

> …you don't have to have a whole bunch of previous knowledge, other than you've lived for a certain amount of time, to walk into this room and be ready to learn. That's all. You need to have, like, walked around this area for a few days and see things move. That's it. Like I can teach you the rest. And so, since there's not a whole lot of prerequisite knowledge, then we can start from the ground up and teach all the strategies as if I was teaching a class of nothing but English language learners…good strategies are good strategies for all kids. Why would you take them away? (Appendix B, lines 738-749).

During my interview with Dave, he explains the 5E model that his science department follows. During the initial "engage" portion, the teacher should present a new situation or an intriguing event to the entire class that will elicit ideas they already have about the topic to be studied. In explaining the role of prior knowledge here, Dave likens it to some bit of pre-existing "essence" that already exists within each of his students. The literature surrounding the notion of the 5E model points to the engage piece as responsible for evoking possible misconceptions the students' might possess due to the current information state they hold (Bybee 1997). To be an effective teacher, he views it as his responsibility to find ways to shake up what his students already know and "skim off the top" what he needs to introduce the known knowledge of their world to the new scientific knowledge they are about to learn. In presenting a novel science phenomenon, Dave will ask them questions designed to jog their memories regarding previous lessons from the class, and see what they can come up with concerning the new phenomenon before being given time to explore it:

> …they just guess, guess, guess, and there's where they're bringing out their own now previous knowledge on today's lesson. So, they brought out previous knowledge from the last day's lesson [the prelude] and the previous knowledge about this new topic and so now they've got both of them sitting, like, I don't know, ***the foam on top of the water*** and so now it's like, "okay, now that I've jogged this and I've jogged this it's time to take both of these and go through this experiment, which is our explore (Appendix B, lines 831-837).

When probed to explain his metaphor about the foam on top of the water, Dave explains:

> …like when you have something in solution, it's hard to grab it, because it's all mixed in with all the other stuff. But if you can make it like the foam on top, it's really easy to just sweep it off the top and grab it. It's really easy to say, like um, this is what I need because it's sitting there floating on top. I don't have to dig for it. It's right there…And you just sweep all that information and apply it right to here [moves hands in a sweeping motion from left to right] (Appendix B, lines 874-889).

Dave views prior knowledge as something latent and endemic in all his students, perhaps buried, but nonetheless present in their minds. It is not contingent on past schooling.

Dave thinks it is imperative that he is able to design experiences in his classroom that are able to draw this every day "prior knowledge" his students possess out of their deep reserves and to the surface.

*Differing Views of the Teacher's Role*

At different times in the interviews, both Dave and Carla spoke about how they envisioned their role as "teacher" in their classrooms. Carla emphasized her role as a questioner, whereas Dave described himself as a "more capable peer," another student alongside the class.

Carla: The Questioner and Manager

During our interview, Carla talked extensively about her role in asking "good questions" of her students. She privileged teacher-student conversations in her description of assisting students who were trying to make sense of their data collected during exploratory sessions. This is consistent with what I observed in the field. Most days, Carla's written agenda on the whiteboard consisted of an "engage," an "explore," an "explain," and an "elaborate." However, in reality, rarely did the class reach the point where they were able to participate in whole class discussions, the stated purpose of the "explain" portion of the lesson. Rather, most of the class time was devoted to the explore portion, where Carla explained her role as managing a state of "controlled chaos." She sees it as a sign that they are thinking like scientists if they are "thinking outside the given questions. " She told me during the interview that she doesn't get mad at them:

> They will be falling out of the chairs and making pretty much chaos at the minimum…It is a big step. I can let it be noisy and just tell people to, you

> can be noisy sometimes, yet I have the ability to control the kids. Within three seconds have them all quiet again. Controlled chaos (Appendix C, lines 145-150).

Despite the focus on inquiry in her classroom, Carla still maintains the role of the authority figure with her students. It is important to her that she is able to turn the classroom around "on a dime," in terms of management. However, she values the times when her students "mess around with the supplies" and appear to be "off task." These are the times she says that the students often learn more from "sending stuff and [having] it hit the wall than what I would do" -what she would have directed them to do with the supplies.

I asked Carla specifically what it would look like and sound like if her students were "thinking like scientists." She told me that they would be "thinking outside the given questions…Scientists are curious, and make mistakes, tinker with things until they reach a solution" (Appendix C, lines 139-141). To Carla, thinking like a scientist means to think outside the given parameters, even in terms of what they choose to experiment, or what they choose to do with the materials she gives them. Because of this type of thinking, Carla welcomes the chaos she finds on a daily basis during the explore sessions of her class. And yet, she does not elaborate on the social interactions that play out at the tables; rather, she emphasized her own interaction with the students through her questioning of them as she rotates from table to table.

**The One Exception to the "Match" of Teacher Talk with Teacher Actions:**

Carla does not believe that all of her students come to the classroom on an even playing field. I asked her what happens if during the "explain" portion of the lesson, some students just aren't getting it, and have not successfully been able to observe what *should have* happened in the lab. We know from the literature that often, experiments conducted in the school setting do not produce the ideal results we might hope students can observe in order to "discover" this or that law or principle in science (Millar, 2004). Though laboratory activities have been espoused by the some, including the American Association for the Advancement of Science, as the ideal way for students to challenge naïve conceptions and to develop scientific understandings, others claim that students' experience with natural phenomena in laboratory activities can be more ambiguous than textbook learning, and can present significant challenges to scientific learning. Carla recognizes this latter view as true and notices that some of her students who have previous science knowledge help the others out when they get data that doesn't match scientific known principles. If the experiment doesn't "work" or the students aren't able to observe what they should have due to inadequate materials, etc…then those with prior scientific knowledge, which Carla attributes largely to past schooling experience, can help those who lack these experiences. But, for some of them she says, "I will have told them, 'yeah that is exactly what should have happened in your lab.' So they will know" (Appendix C, lines 133-134). Carla still reserves the right and possibility to "tell" students the answers they should have seen in the lab.

But in the video data, it is clear that most of the time, there is little time left after the explore portion of the lesson for students to explain their thinking to one another. When I ask Carla how students arrive at their claims, she skirts the question slightly and answers that they are graded on conceptual knowledge. While she encourages them to draw pictures of what they have seen and turn these pictures into words and paragraphs, most of the time video data reveal that there is little opportunity for students to discuss their ideas and arrive at a class consensus regarding their findings. Yet, when I ask Carla to run me through a typical day, once she reaches the "explore" portion, she says:

> Hands-on experiments can take anywhere from 30-45 minutes, sometimes they can go a little longer than that. After that we come back up to the meeting area and explain, and go over what the questions are for the lab. And what some sample answers are for them and then we have homework which is usually an extension and they evaluate their lab procedures and the conclusion (Appendix C, lines 293-298).

The video data does not match this itinerary. This is the planned agenda, but usually there is not time left to go back to the meeting area and go over the questions. I ask Carla what happens if she runs out of time. She answers that the students have to summarize what they have learned, have to answer the key question of the day, and also state what they would do differently if things didn't go as planned. Carla says that it is important that the students not answer their key questions until the very end when they go back and look at their entire experiment. She elaborates:

> If it needs explaining or if they have questions, they have their claims section. They have to provide evidence for those claims and evidence helps to explain whatever that claim is for the lab. So, they can go back over and look at the lab and what they were supposed to be learning about. Conclusion, they answer usually 3-4 questions. And I do not give them the answer, I let them get that themselves (Appendix C, lines 312-317).

I ask Carla what happens, though, if a student is writing up the claims and evidence and they are clearly on the wrong path. She admits that she will write it down for them in their notebooks if they get it wrong. When I probe further, it is clear that Carla begins to acknowledge that the key question and conclusion are actually not accomplished in the meeting area at the end of her lesson; her students do them alone, "as an individual." She is quick to add that "they sometimes do that in class, sometimes they get to do it at home" (Appendix C, line 339). Even her wording of "*get to do it* at home" seems to belie a reward of some sort for the opportunity *not to* come to the meeting area towards the end of class, and *not to* write their claims in class, which revokes the chance to learn from their peers through social interaction. But Carla describes her circular Socratic meeting area as helpful for "classroom discipline issues because they can all see each other and everyone knows if someone is messing around" (Appendix C, lines 370-371).

Carla views her role as a facilitator of questioning as well. When she says "I just ask them questions and they all answer them" (Appendix C, line 392), she emphasizes the interplay between herself and one or two students; however, in my interview with her, she did not talk about the dynamics between and among students, and admitted that "more times than not, [my students] are having to do their conclusion at home" (Appendix C, line 341). This is not seen as a negative statement to Carla, but merely a fact; she states it in a very matter of fact manner. Carla also has all her students return all manipulatives before writing their claims, since "it is just too much stuff out and it creates chaos. They have to communicate the manipulative into words" (Appendix C, lines 396-397), whether that is during class (rarely) or at home (usually). This may, in fact, be more of an issue of timing, rather than an ideological belief about the place and purpose of manipulatives. At the school where Carla and Dave work, the science classes meet only every other day. This adds pressure to the demands to cover the standards and potentially influences Carla's decision to have her students complete their claims and conclusions at home, so that when they meet again, two days later, they can begin fresh with a new activity. Carla clearly values the exploration portion of the 5E model, where her students have the freedom to try out novel ideas of their own. She privileges this exploration over the classroom discussion that should occur, time permitting, at the end of each lesson. This explains why most of the video data reveals a dearth of any type of class discussion, leaving students to articulate their ideas alone at home, individually.

Overall, Carla's role as teacher is envisioned as a facilitator of good questions within the maintenance of a room of "controlled chaos" where she can get the classroom back "within three seconds" (Appendix C, line 155). She encourages the use of pictures and words as the representations to hold students learning from their exploratory activities, and she views learning as a process that builds one new concept after another, much like a staircase progresses up a designated height, in this case up the height of progressive science content.

As documented in the previous session, she also views the student clientele differently than does Dave. To borrow from Bahktin (1981), the teachers demonstrate clear differences in "addressivity," or in the quality of addressing a student- of engaging in communication for the sake of one's interlocutor. How each constructs the notion of a student and what s/he brings with them to the classroom is quite different; this impacts how they interact with the students and what they view their roles to be as teachers. It follows then, that aside from content knowledge, a teacher needs to be keenly aware of the additional cultural knowledge necessary to provide access to the science standards for every student.

Dave: The "More Capable Peer"

Dave's view of his role as teacher is different than Carla's. During our interview, he talked about seeing himself as the more capable peer (Vygotsky, 1962) of his students. He stressed his role of "teacher as student," thinking and learning right alongside the students, and breaking down the traditional boundaries between the two roles. He will even say to reluctant students in the meeting area: "I'd like to know what you're thinking because your opinion is just as important as the teacher's opinion" (Appendix B, lines 962-963). Dave also stressed many principles of the affective domain of teaching, including providing a safe environment for students to "guess" and also valuing all answers to questions whether right or wrong, as long as the thinking of making a claim and basing it on evidence was present.

Dave's philosophy of teaching evokes Piagetian and Vygotksian principles. He describes his role as presenting ideas initially *in the world of his students*, and then slowly introducing them to the scientific concepts he wants them to know and understand. This is corroborated in the video data. At the start of one lesson, Dave showed his students a clip from a popular Harry Potter video in which Harry and his friends are playing "quidditch," a game similar to soccer but while flying on broomsticks. The students are immediately engaged in this clip and attentive. Dave asked the students to watch the way motion played out in the movement of the different balls in game- in the movement of the "snitch" and in the movement of the "bludgeons." The students were also asked to watch and make observations on the players' movement on their broomsticks. From this, a discussion ensued about such notions as speed and motion, of fast and slow- basic, superficial observations of the every day upon which Dave would ground his future lessons on forces and motion. Whatever the science to be learned is, Dave sees it as his job to find a way in which to first access that science through some sort of everyday knowledge he feels his students will identify with and be able to access culturally, linguistically, and socially. Dave explains “the idea is like, take what they know and mold it into what you want them to know” (Appendix B, lines 446-447). In Vygotsky’s work, this amounts to beginning by addressing what he calls “spontaneous concepts” and finding ways to connect these to the concepts of school, called “scientific concepts.” In Vygotsky’s view of thought and language, an idea first formulates on an interpsychological plane through social interaction between individuals. They work to understand a reality, an idea, from their own worlds of experience. Language, in turn, deepens and alters the thoughts; then, in leaving the social experience, thoughts from the interpsycholocial plane become then existant on the intrapsychological plane of the individual mind, until that individual once again comes into contact with new ideas through social interaction on the interpsychological plane. For Dave, it is important to begin at the level of the students’ own everyday experiences- Vygotsky’s “spontaneous concepts” before laying the groundwork for a transference into the more academic, scientific realm of what Vygotsky terms the “scientific concepts.”

Dave takes these ideas further, stating that it is imperative for a teacher to use what he calls “spiraling” in his lessons.

> The more I think about it, and I’m coming to learn this more and more myself, is that inquiry only works with spiraling…like going back to the same example…spiral back…build their confidence (Appendix B, lines 812-820).

Dave explained to me what he means by “spiraling,” giving the following example:

> …let's say that the day before today's lesson, you, uh, were learning about friction. And I know that by the end of the day, we're going to talk about constant force and backward motion and things like that. Well then I need to re-institute the idea in the kids' heads of what a constant force is. But I'm not going to teach constant force at the level that I taught it the day that I taught it. I'm going to probably take it at that level and just move it back a little bit so it seems easy. Something that the kids go, "oh duh, constant force. I got that." So now they're coming in –now they're finishing up the first five minutes going – re-grasp, rehashing- I can't even think of the word right now- but regrabbing the information that I need them to know before I even teach them something new all on their own….it's a confidence builder…so that's the prelude…it's the spiraling idea (Appendix B, lines 778-805).

Very purposefully, Dave designs "preludes," the school-wide version of a "warm-up" to spiral back and review previously covered material, but at a lower level than was accomplished during the previous day's lesson. This spiraling back to a lower level is essential to the progression of teaching and learning in Dave's view (see Figure 4.2).

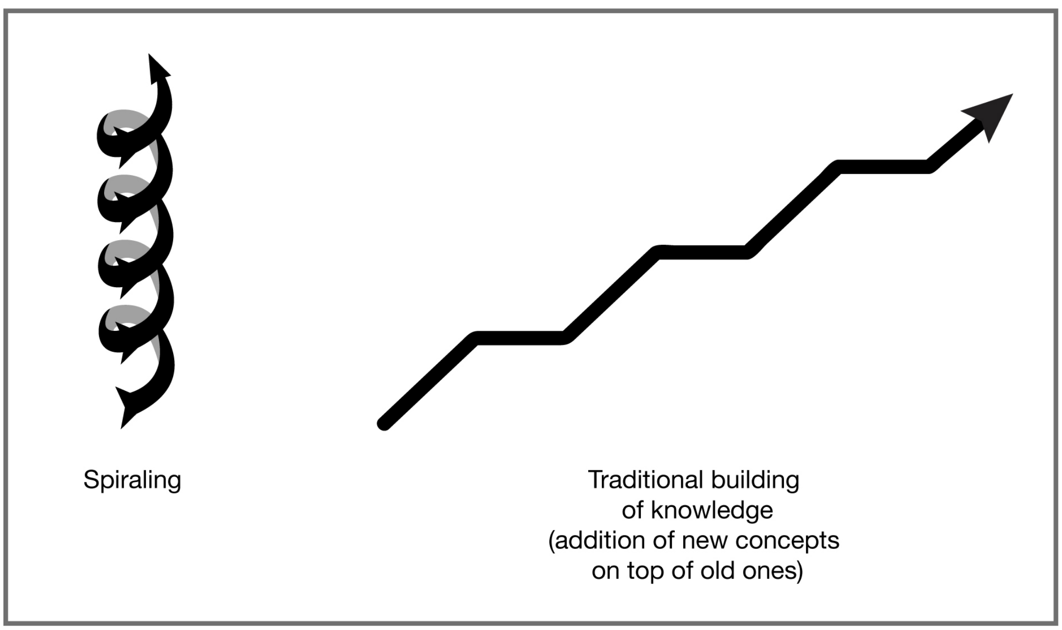



**Figure 4.2: Dave's Concept of Spiraling versus Traditional Concept of Staging**

If this spiraling back is not accomplished, then “they’re not going to feel comfortable with the information because they didn’t bring it back with them the next day. So, the question’s gotta be a little bit below their level to build their confidence and to build knowledge for the day’s lesson” (Appendix B, lines 818-821).

Dave’s emphasis on building student self-efficacy is consistent with the literature on motivation. Recent perspectives on motivation in teaching and learning consider factors such as personalization of content, student choice, and student self-efficacy to accomplish a task they consider worth doing (Bandura, 1977; Cordova & Lepper, 1996) as critical components to motivation. These factors can affect students’ intrinsic motivation and can impact their depth of engagement with content. Beginning a ninety-minute lesson with a boost to students’ self-esteem and confidence can go a long way toward creating a positive climate in which to learn. The other task Dave then faces is creating lessons consisting of tasks that his students will consider “worth doing.” This he accomplishes via his deep commitment to instilling wonder and curiosity in his students.

A second way in which Piagetian and Vygotskian principles surface in talking with Dave during the interview is when he discusses how he “chunks” lessons, activities, and words. What Dave describes is a deliberate journey through his students’ collective zone of proximal development, or ZPD (Vygotsky, 1962), as he negotiates spontaneous concepts from their worlds with scientific notions from the eighth grade curriculum. Dave explains that he intentionally breaks science content into manageable chunks, but also breaks even the academic words down into their component parts. Dave says he approaches things as if he is a thirteen-year old child himself:

> You just talk at how they probably think: "Alright, here's this really big word and I don't know what it means. But I'm expected to know what it means so let me look at this…well I know 'instant.' And so I've heard of 'instant' with 'instant coffee' and 'instant rice' and 'instant noodles' and you know, 'instant lube' for cars" (Appendix B, lines 428-436).

This example was from a lesson in which Dave was introducing the students to the difference between constant and instantaneous forces. The latter is a word Dave assumes will intimidate most of his students, so he attempts to put himself into their mind set and comes up with contexts in which the first part of the word, "instant," will be familiar to them. Hence, the examples of instant coffee, instant rice, instant noodles, and instant lube. In videotaped data, I observed a student I will call Adam, who was answering a question about a certain type of force Dave had just demonstrated. I watched as Adam's face lit up and he called out: "It's an instantaneous force like that [snaps his fingers], like that [snaps his fingers]- it happens just like that [snaps his fingers]." This is precisely the manner in which Dave taught the word to his students, with a quick snap of his fingers. After the food examples, Dave snapped his fingers and said that an instantaneous force is one which, "happens just like that," and he snapped his fingers as the words came out of his mouth.

The video data is rife with examples of Dave breaking words and scientific ideas into their component parts; the term "constant forward force" is another example. Dave "enters' his students' world" to convince them they already know what "constant" means. He takes their examples from everyday life and writes them on the board. They also already know what "forward" means. He takes their examples from everyday life and writes them on the board. And, finally he reminds them what they have arrived at and agreed upon this class definition for a force: “a push or a pull.” Putting it all together, the students feel empowered to arrive at a definition of “constant forward force” on their own.

Because of his own experiences, Dave approaches literacy in his classroom by “hammering them with both sides of the literacy,” using their own everyday definitions (such as “push or pull”) alternatively with the scientific vocabulary (such as, in this case, “force”). Dave shares that as a child he learned new vocabulary by constantly overusing the word and “making a joke of it.” All the young boys his age learned the word “masticate” because “they’d make jokes about it all the time.” The boys would use the word, laugh, and then say, “you know, man, it means ‘to chew.’” Through constant repetition of the word, Dave claims boys like he, learned new vocabulary. In fact, he recalls not being able to learn words from a dictionary. Though useful for his immediate purposes, he would soon forget the word’s meaning by the next time he was confronted with it in a new context. Here again, the Vygotskian notion of interweaving the spontaneous with the scientific becomes apparent.

> Like one time I’ll come up to them and I’ll say like- they’ll be like, “I don’t know what the force is.” “Well, what’s the push or the pull?” And then they come up and go- or I go, or next time I might go, “what is a force?” And they’ll go “a push or pull.” And I’ll say, “okay, do you see any of that?” And next time I come up I’ll say, “okay, what are the forces?” And then next time I go, “is there any pushing or pulling?” You know, you just keep mixing ‘em up, so that they see those words as being interchangeable…they do the A to B to C connection with the words and they realize that these are all equal, so I can use these interchangeably (Appendix B, lines 287-303).

Teaching literacy in Dave's view is tantamount to repetition of the new word alongside the interchangeable use of the spontaneous and scientific forms of the word concept (see Figure 4.3).

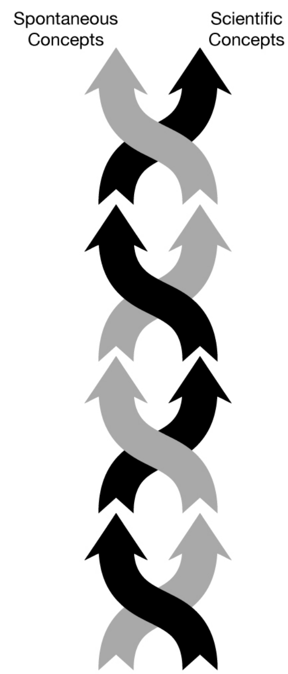



**Figure 4.3: Spontaneous and Scientific Concepts**

His evocation of the transitive property in mathematics attests to this. If A=B and B=C, then A=C. He furthermore maintains that he doesn't think many teachers do what he does; he sees his approach as unique, or at least rare. He discussed with me the idea that many teachers will teach a word like "allele" in genetics. Students may persist in using the phrase "that little letter" or "that big letter," but the teacher continues to ignore this and replace it with the correct academic vocabulary "allele," without engaging students in the back-and-forth interchanging of the spontaneous with the scientific notions, until the academic language is internalized.

Dave continues by providing another example of teaching the word “magnitude.” One time he will explain it in terms of how strong a force is; another time, he will define it as how long the arrow in his drawing is. On still another occasion, he will equate it to how big the arrow is, “going around in those circles” until it becomes second nature to the students to translate one form of the idea into another, more sophisticated form that appropriates the idea and situates it within the codified vocabulary of the scientific enterprise, both in their minds, and ultimately in their speech. Dave’s deliberate scaffolding of vocabulary using this circular process of the spontaneous realm intertwined with the scientific realm is a common theme throughout his teaching- not just of vocabulary, but of conceptual knowledge as well. This notion is captured in Figure 4.4 below with the example of interweaving the students’ use of their class definition of a “force” as “a push or a pull.”

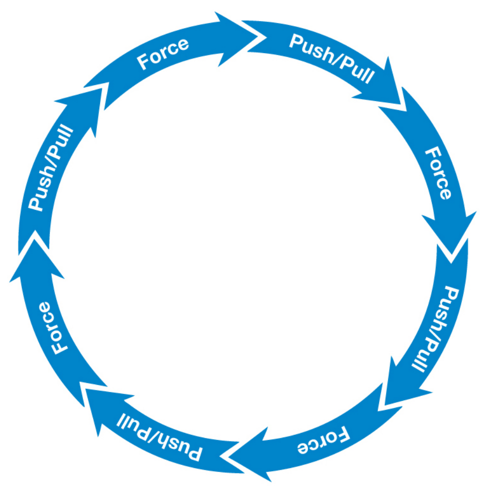



**Figure 4.4: Dave’s Use of Spontaneous Concepts Alternated with Scientific Concepts in Vocabulary Development**

He also reinforces vocabulary by approaching the same content from different perspectives- “[coming] at if from this angle, [coming] at it from this angle, [coming at it from this angle” (Appendix B, lines 334-335). One time he might do a demonstration about the concept and use the vocabulary from both the spontaneous and scientific realms, while another time he might let them do an experiment, take some notes, and “make sense of it that way.” This cycling through the visual, kinesthetic, tactile, auditory, verbal, and writing modalities is depicted in Figure 4.5. This process assures a journey through both receptive and productive modalities that enables students to weave their own personal worlds of understanding and experience in with the world of exploration and schooling that comes to be their destinations in which to situate and define scientific truths in languages shared by the larger scientific community.

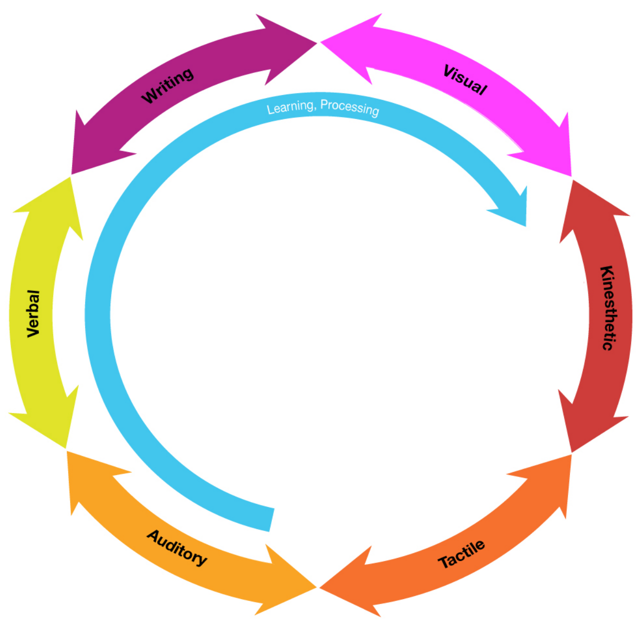



**Figure 4.5: Processing through Multiple Modalities**

Dave deems these processes associated with student vocabulary development, to be crucial skills to develop and implement as a successful teacher of inquiry.

*Differing Views on the Student's Role*

It is a student's job to try and fail, try and fail; this is the consensus from my interviews with Dave and Carla. However, even within this consensus, Carla and Dave differ on the precise mechanisms by which their students carry out this iterative "try and fail" theme. For Carla, the process of trying and failing is celebrated especially when she is witness to her students working and thinking "outside of the box." She is particularly interested when students formulate their own procedures for "trying out science." For Dave, it is the "talking it out" that is privileged, the act of working out the science on Vygotsky's interpsychological plane.

Carla: "Thinking Outside the Box"

To Carla, this is what likens her students to scientists: "To think like a scientist for me is to experiment. To try and fail" (Appendix C, line 64), she says. According to Carla, in many classrooms, science experiments are set up for students to succeed every time they conduct one. Then, often, when the results they know they should have got aren't surfacing from their lab results, "they will "fudge the numbers to try to get the right answer" (Appendix C, line 85), she says. This doesn't give one confidence to want to do science, she adds. In the real world, she explains, scientists fail more times than they succeed, something like five to one, according to Carla. Therefore, she feels it is important for her students to see why certain approaches do not work. If they come up with a “wrong answer,” she expects to see them “talking to each other, trying new things, just to try it” (Appendix C, lines108). The labs she uses in her classroom are written for them to have time to “mess around with the supplies” (Appendix C, line 109). Carla stresses the importance of students to have the freedom to experiment, to “think outside the box,” and to be able to do so on their own terms with the “guided practice” that she gives them. She also emphasizes that her students are graded on conceptual knowledge, not on effort, as they are used to from their elementary schooling experiences. However, she is quick to say that some teachers count students off for not having an “exact right answer” where “in science, there is not exact right answer [rather], many answers” (Appendix C, lines 187-188).

In order to achieve this conceptual understanding, Carla encourages and expects that students attempt to express their ideas “anyway they can” – those ways she mentions are words and pictures and touching objects, again a reference to “resemiotization” (Iedema, 2003). In fact, Carla can often be heard in the videotapes saying “write down what you just said.” Students are encouraged and praised for using the objects given to them during the “exploratory” portion of the lesson in creative ways. However, Carla collects all the manipulatives following this portion of the lesson, just prior to the discussion portion (the “explain”) because she considers them to be potential distractions. The implications of this statement are that the manipulatives are not an important part in actual problem solving, during the last stages of putting it all together. Instead, it seems Carla believes that the work of translating what the manipulatives do into language, the work of “resemiotization,” is done during the explore portion of the lesson and encoded into pictures/drawings and words in the students’ notebooks.

Dave: "Talking it Out" through Resemiotization

Dave shares Carla's view that students need to go through the same iterative process that scientists do- try something and fail, try something else and fail. He talks of it as a logical process where not the outcome, but the process, is foregrounded. Ultimately, yes, it is the outcome that is celebrated by scientists and the larger community, but it is *the process* that is the central component of being able to do the work of science. Process is what Dave and Carla privilege. They are not so much interested in the contents of Latour's "black box" (1979), or the actual content, as they are in the process that goes into its creation.

Central to the work of "process" is what Dave describes as similar to Vygotsky's intersubjectivity via work on the interpersonal and intrapersonal planes, as discussed in an earlier section of this chapter. Dave describes how certain of his students will "talk it out" – their current information states. Many of those he mentions in our interview together are seen in the videotapes using a blend of verbal language and gesture to "talk it out." Dave describes "the most important part of the lesson" as the time his students convene in what he calls the "post-experimental meeting area." This is an area in the center of his room where students arrange their chairs in a circular fashion facing Dave and an easel. On a side board of the room, the key question of the day is written along with several questions under the term "claims," where Dave has scaffolded the process he wants his students to go through in their search for a final answer to the key question of the day. In his words:

> You don't just give them the question though because that's just too much at once. You scaffold that thought process for them. And say, maybe break up that question into four little mini questions about that specific

> object….then you discuss it as a class and say, "what are your little pieces and what are your little pieces and what are your little pieces? And maybe let's put all these pieces together and now we have an idea of what happened (Appendix B, lines 855-861).

If everything has been "set up right," Dave says that the key question becomes "pretty obvious" at that point and he is able to guide the students into an understanding that by putting all of their ideas together as a whole class, they can provide a confident answer to the key question. In this way, Dave views learning as a process that is distributed over many individuals, each who in turn, are using a variety of modalities to process and think through the science. All along, he attempts to instill what is clearly evident in the video footage of his classroom: "…it's okay if you don't get it, but share it," demonstrating that he values the input of each and every student in the classroom, on par with even his own thoughts regarding the science.

And if they get stuck? How can they proceed with this formula of interpersonal crossing over into the intrapersonal? Dave says that it is his role to be constantly walking around the tables at the periphery of the classroom as students are working during the "explore" portion. From his surveillance of the groups at work, he already has an idea of which students understand the basic ideas and which do not. Here is an example of what this might look like once in the post-experimental meeting area:

> …you could look at a student who's struggling with the information and you say, "okay, why, you know- what force arrow do you think this is? And they're like, you know, "ummmmmm…." "Like, just give me one." And they're like, you know, "I don't know, friction." And say it's supposed to be gravity. You can go to the student over there – [points to the side]- or, first you say, "why did you come up with that?" And maybe

> they say, "I don't know." And you go, "okay." Now you pick a certain student that you know knows what's going on . And so you say, "what do you think?" And they say "gravity." And so you say, "why?" And then they say, "Because gravity's always pulling you down and the arrow's going down." Okay. Then you go back to that student and you say, "okay, so, did you hear what they said?" "Yeh." "What?" – if you've got enough time, and, you know, you say, "what did they say and why do you think they said that?" And then they can now- so they really grab onto that person's understanding and take it in for themselves, at least for the moment (Appendix B, lines 585-598).

The "post-experimental meeting area" is the most important aspect in Dave's opinion. This is the opportunity for students to finalize the conversations begun during the "explore" portion of the lesson. What occurs among the group is a participatory, interactive process of "objectifying" the immateriality they have all witnessed in smaller groups at their tables. At these tables, students will have worked in small groups of three to four students and will have arrived at some initial ideas concerning the scientific concepts they are studying. But this knowledge is not validated in any way and is in its nascent stages for most of them as they approach the post-experimental meeting area together with all of their classmates and their teacher. Here the discussion continues with Dave carefully calling upon certain students he has seen in the "explore" session who are more savvy about the science, or who had their particular set-up "do" what it was supposed to "do" – arrive at answers more consistent with the key scientific concept under investigation. Therefore, students are given more time, in the video data, approximately 20-25 minutes most days to continue discussing their ideas, answering the scaffolded questions from which will come their "claims," and answer the overall key question of the day. Dave believes that after these discussions, the knowledge is converted from the interpersonal plane to the intrapersonal plane- when each student "owns" the conceptual knowledge for him/herself. Videotaped data demonstrate that this is largely made possible through resemiotization of the immaterial science across multiple modalities and finally "objectified" into some sort of material "claim." This data is presented and discussed in Chapter 7.

*Resemiotization and Teacher Practice*

We know from deSaussure (1993), Giddens (1987) and Weber (1968) that as human beings, we are all suspended from our own material webs of language, which we ourselves have spun. Science, in particular, attempts to use language to conjure the materiality of things; we ask that our students use language to evoke the reality of things that appear immaterial much of the time. Dave is well aware that students need a variety of resources from which to pull in conjuring their own version of the reality before them. In videoclips from both classes, however, students can be seen using a variety of resources and modalities to construct their emerging scientific understandings. These representations include: textual representations, drawings, gesture, verbal and oral modalities, and written explanations. In fact, both classes harbor numerous, ongoing examples of what Iedema (2001, 2003) calls "resemiotization," described earlier in Chapter 2 as the transfer of ideas from one modality to another. It is in this transposition across different modalities that the scientific "truth that temporarily eludes the students, becomes more malleable. The student can rework the emerging scientific "truth" through different modalities until ready to objectify it into verbal language.

Like Dave, Carla alludes to the importance of this idea of resemiotizing science in encouraging her students to represent the concepts they are learning in "any way they can" (Appendix C, line 247). Dave, too, believes in the importance of providing multiple expressions of the same idea through different representations of the science concept the students are studying.

### *Differences in Physical Room Environment*

The way Dave and Carla talk about their physical classrooms is consistent with what I saw in the field and captured in videotape and field notes. Carla spoke about the physical arrangement of her classroom in order to address the various 5E components of her lesson design. Dave spoke about the physical arrangement of his classroom as a second "textbook" resource for his students.

#### *Carla's Classroom: Tables and a Large Ellipse*

Carla's classroom has eight tables around the periphery of its walls. Each is capable of seating four students, though in the class I worked with there were a total of nineteen students, and therefore, most tables were not full. At the center of the room there is a large navy blue rug, dubbed "the meeting area rug." A similar rug is present in every room in the school and all practice the "workshop" model of teaching, a blend of table work and "community" meeting at the rug. At the front of the classroom there is a document camera and a whiteboard where Carla daily posts the 5E components of her lesson. In her classroom, other than times when the students are at their tables exploring, Carla's students sit in what she describes as "a Socratic form, in a circle," thought in reality it appears that students face their chairs inward in more of an elliptical shape. She states that she doesn't like them sitting in rows and that the reason the tables are arranged around the room in a circular format is that this helps the students see what other groups are doing. She says it also helps with disciplinary issues, as “everyone knows when someone is messing around.”

I did not specifically ask Carla to comment on the room arrangement, and she did not offer any other information beyond mentioning that she creates charts in different colors to represent the students’ learning from different lessons. Over the course of the fourth months I observed, I saw only two charts hanging on the side windows of the classroom. One depicted the definition of “speed” and the other, the definition of “velocity.” I also observed that the meeting area in Carla’s room consisted mostly of students sitting in a large ellipse, often with many of them sitting with the backs of their chairs directly touching the tables where they sit during the “explore” sessions. It is a relatively wide meeting area in comparison to Dave’s close-knit meeting circle. Carla’s classroom also harbors a neat location of bins where the objects and manipulatives used during exploration are stored and to which they are returned immediately after the exploration.

*Dave’s Classroom: The Students’ “Textbook”*

At the start of the data collection period, the physical features of Dave’s classroom were similar to the physical design elements of Carla’s classroom; however, over the course of data collection, Dave’s classroom transformed significantly. Originally, eight tables were arranged along the periphery of the classroom. There was a large navy blue rug in the center of the classroom; and there was a whiteboard and a document camera at the front. The 5E agenda greeted the students every day as they entered the classroom.

Over time, I observed a complete transformation of the classroom into what Dave describes as the students' "textbook." This transformation was accomplished partly by virtue of three different seating arrangements in Dave's classroom. First, there are the tables where, as in Carla's classroom, the students conduct their scientific explorations. Second, there are two very different meeting area formations. The first Dave calls "the lecture style meeting area." This meeting area consists of rows of students clustered very closely together facing the front white board. Dave says that when students are in this formation they know they are about to either receive instructions from him for a task they are to accomplish at their tables; or, they are participating in the initial "engage" portion of the lesson. The second meeting area Dave calls "the post-experimental meeting area." Students bring their chairs around the blue rug in the center of the classroom, facing inward. They know that when in this formation they will be expected to participate in a discussion about the experiment they have just explored at their tables in groups; they will arrive at a class consensus of an answer to the key question of the day by providing claims backed by evidence.

As we talk during the interview, Dave reminds me of the fact that I had asked him for a dictionary earlier in the day at lunch. "I mean, it makes me think," he says. "I don't have a dictionary. I don't have encyclopedias. I don't even have a science textbook available to the kids. It's hidden in the cupboards. This [panning the classroom with his right hand] is their textbook" (Appendix B, lines 1190-1196). He repeats it twice, pausing in between each utterance. "The classroom is their textbook. This is their reference tool" (Appendix B, lines 1198-1200).

In fact, Dave claims that this type of physical environment is key to facilitating inquiry. Over time, a series of charts have appeared hanging on a line of string traversing the length of the classroom from one end to the other. These charts represent the student learning over the course of the time I have worked with this group of students. The physical environment in Dave's classroom is a manifestation of the students' conceptual development over time. I asked Dave if he realized that he had co-created, with the students, well-established patterns of communication that had become routinized into what amounts to be cultural practices of inquiry. His response was that he had not considered the overall bird's eye view of the classroom systems working like fine-tuned machinery towards some end; but he certainly had deliberately created each system almost in isolation of one another. This response is evocative of Barbara Rogoff's theoretical approach (2003). By using her notion of the three foci of analysis, I was able to see that Dave understands the necessity of looking at the individual in social interaction with social peers and the environment. He just had not realized the extent to which the systems he created in his classroom were transformative of the learning that his students were able to achieve. The lens through which he viewed his classroom was more focused on one system at a time, developed to ameliorate a particular need that arose for learning.

Videotape data reveals that students' ongoing learning was sedimented into, and came from, a great many semiotic systems in the classroom (easels, charts, white board, exploratory lab set-up, television, computer monitor, and charts along the back wall of the classroom) to form interactive communication fields of sorts. These fields in turn allowed students to participate and communicate differently with one another and with the teacher at different stages during the "5E model of learning" (engage, explore, explain, elaborate, evaluate). These interactive communication fields inform the manner in which students learn to participate in normative discussion; they help to define the "participation structures" students learn to navigate in the classroom. We know from the work of Erickson and Mohatt (1977) and Philips (1972, 1976) that participation structures may be organized differently depending on cultural influences. Specifically, in Philips' work, interaction in Native American community settings was found to be structured on a voluntary, cooperative basis, while in Anglo settings, participation was found to be organized to emphasize individual, rather than group effort. In Dave's classroom, participation structures are derived from interactive communication fields such that students interact not simply individually or with a group, but with many semiotic systems as well as other individuals and their teacher. Just as Dave considers his classroom to be the textbook itself for his students, so this notion certainly seemed to be a large contributor to one very effective model of a science inquiry classroom. The re-creation of this component of an inquiry classroom would necessitate the careful set up of semiotic systems capable of providing for the ongoing dynamics of social interaction that can, in turn, become sedimented into physical artifacts representing new learning to be drawn upon to solve future scientific questions. The constant re-use and reshaping of knowledge from these semiotics and artifacts through resemiotization, may then allow for the transfer of knowledge into new frames of meaning and analysis. In a sense, it is a similar iterative process to the way in which the "messiness" of science of which Bruno

Latour writes, gets neatly codified into charts, graphs, and tables in scientific journals and publications.

### *Summary of Chapter*

Teachers' language, thoughts, and actions exist in dynamic flow. In the case of Dave and Carla, their words closely matched the practices seen in the data collected through videotape on a daily basis in their classrooms, with the one exception of Carla's perception of how her classroom lessons ended- absenting the component of classroom discussion.

Both teachers stated independently that students should be active participants in the science classroom, with their chief role as initiators of the trial and error process that scientists also undergo in authentic research settings. It is deemed important that students try and fail over and over again and understand that this is the way science proceeds- through the process of making mistakes and trying something new to solve real problems that affect society, making meaningful contributions to the world at large. Teachers' primarily goal for students is to learn science through an inquiry model of instruction during which they have ample opportunity to explore and discover ideas on their own.

There is disagreement between the two teachers in this study in terms of their viewpoints of students. One teacher approaches her role as teacher from a deficit view of what the students bring to her classroom, and the steps she must take to address their gaps in learning. The other teacher approaches inquiry instruction from an asset/strengths model, by looking foremost at what his students bring with them to the classroom in terms of their funds of knowledge and attitudes toward science and learning in general.

These opposing perspectives generate disparate ideas regarding the role of prior knowledge; what materials are necessary to successfully teach the science content standards; the ideal physical classroom environment; the extent to which scaffolding is used to assist with language and reasoning; the role of the teacher; and the approaches to inquiry instruction itself.

In general, Dave is a strong proponent of inquiry and sees "talking" as a major vehicle through which his students express their thinking. Because of this, he privileges the "explain" portion of the 5E model lesson, teaching his students to think of this time as "the most important part of the lesson." He also strongly believes in the component of wonder and curiosity and views his students as already possessing all they need to know to be in a state of readiness to discover the science that awaits them in his classroom. Dave intentionally plans lessons that draw upon his students' spontaneous concepts and interweaves these with the scientific concepts embedded in the grade level standards for which he is responsible. Dave takes responsibility for designing portions of the lesson that will allow his students' experiential prior knowledge to rise to the top, like "foam on top of water." When his students experience difficulties in articulating their understandings, Dave encourages the use of many different types of modalities for the students to think through the science. The physical environment of Dave's classroom he likens to their "textbook." However, he was not aware of what video data revealed - that his classroom actually consists of a set of interactional systems of representational media, co-constructed with his students lesson by lesson, unit by unit, over time. This will be discussed in further detail in Chapter 6.

Carla is also a proponent of an inquiry-based approach to teaching the grade level standards. She identifies a lack of access to authentic scientific equipment as one impediment to reaching her goals for her students. Unlike Dave, she privileges the "explore" portion of the 5E lesson model, and often lacks time at the end of the classes to conduct the class discussion of the "claims" during what should be an ending "explain" portion to the lesson. Carla also cites a lack of prior scientific knowledge and a lack of proficiency in the English language as two obstacles that present students with difficulty when they attempt to articulate their understandings about science. Like Dave, she encourages her students to work through the science using different modalities; but she does not provide a space for the sharing of their verbal articulations in the "explain," as does Dave.

This view into the two teacher's pedagogical beliefs and practices serves to provide a rich context in which to analyze the discourse that transpired in each classroom as students sought to construct their own scientific understandings. Taking into account teaching styles and practices is an important consideration before attempting to draw conclusions about how student argumentation might be enabled or constrained, by the environments their teachers create in their respective classrooms.

In the following chapter, the students' voices add to their teachers' perspectives, providing another dimension to the context for learning in each classroom. This will provide a more complete view into the context of each classroom from both the teacher and students' perspectives. I will then introduce and analyze student talk from the videotapes in Chapters 6 and 7.

## Chapter 5- The Students' Perspectives on Science Teaching and Learning

### *Overview of Chapter*

In the last chapter, I described the context for learning in Dave and Carla's classrooms by analyzing each teacher's epistemological beliefs regarding science, along with their pedagogical content knowledge and beliefs about student learning. I found that both teachers strongly advocated for inquiry-based settings and constructed environments wherein lessons were designed around the 5E model of instruction. Both teachers also identified multiple modalities and multiple representations as key to successful student processing of scientific information. In this chapter, I add student voice to these teacher perspectives in order to give a more comprehensive view into the settings in which learning took place.

This chapter presents findings from two student focus groups and provides insight into one of the research questions informing this study- how do students talk about their learning of science, and how do students perceive their teacher's practice as affecting the way they learn science? Taken together, the teachers' and students' voices provide a complete view of the set of practices, ideologies, and environments in which student discourse took place during the data collection period. The additional dimension of the student perspective provides a more complete picture of the similarities and differences affecting teaching and learning within Dave and Carla's classrooms, and allows us to better identify factors that enable or constrain student talk in each classroom. I draw on the sociocultural framework of Barbara Rogoff, using multiple lenses to capture the classroom reality.  In so doing, Chapters 4 and 5 together lay the foundation for a detailed analysis of student talk, which is detailed in Chapters 6 and 7.

The sections that follow begin with a description of the group interview and an introduction of the focal participants.   Following the introduction of student participants, I describe the similarities and differences between the two focus groups' ideas about learning science.  And finally, I present an analysis of the students' views in comparison with their respective teacher's views of what factors enable or constrain students' abilities to communicate their scientific ideas.  I refine my analysis by also referring to my field notes, examining the nexus of teacher pedagogy, physical environment, and student agency that play out in each classroom setting.

### *The Interview Setting and Participants*

Two focus group interviews were conducted in an attempt to capture the ideas and perspectives the students held in regard to the factors impacting their learning of science. Each focus group consisted of five students.  Student focus group A included three girls and two boys from Carla's class: Sandra, Gina, Veronica, John, and Alberto.  Student focus group B, from Dave's class, was comprised of five boys: Carlos, Mark, Alan, Ian, and Daniel.  As explained in Chapter 3, I selected these students from among the two classes, primarily through consultation with their teachers.  I asked the teachers to help form groups, which would consist of students from a range of academic, social, and linguistic proficiencies, with at least one English learner in each group.   I also asked that the groups be representative of a mixture of ethnicities and genders.  Chapter 3, Tables 3.4 and 3.5 describe the make-up of each focus group.  As described in Chapter 3, students were asked a series of nine questions in a semi-structured interview setting after school. The interview protocol included questions about how students viewed their own work compared with the work of authentic scientists; what helps them to think through scientific data to arrive at conclusions; and what strategies they have learned from their teachers to assist them in talking about science. Students were also shown a video of at least two of the members interacting, discussing, and attempting to make sense of scientific phenomena; the group was then asked to talk about the video clip and discuss what they were doing and thinking at the time.

*Similarities: Focus Groups A and B*

Three main themes emerged in both focus group interviews as being critical to the learning of science. These are summarized in Table 5.1 below.

**Table 5.1: Common Themes in Student Comments (Focus Groups A and B)**

| |
|---|
| 1. "Try and fail" theme is important to "doing science." |
| 2. Students need time to share and talk about ideas. |
| 3. Pictures, drawings, objects necessary to arrive at an individual understanding of science. |
| 4. Video is not seen as an effective way to learn science. |

Both groups identified the same "try and fail" theme as being an essential component to "doing science." This theme was also referred to, by both Dave and Carla, in their respective teacher interviews. Both groups also highlighted the social nature of science learning, and the necessity of sharing and talking through results. The use of pictures, drawings, and objects was also mentioned by both groups as allowing students to "do your own things"" (focus group B, Appendix F, line 87) in science, and to "build, really build what you're saying" (focus group A, Appendix E, line 285), as opposed to simply repeating what a teacher does.  This building of understanding through multiple representations is seen by both groups as a necessary step to bringing written text and verbal ideas to full cognition and, ultimately, to individual understandings of the science. This idea was prevalent throughout each interview, and is paralleled in Dave and Carla's teacher interviews as well, evoking the notion of processing through multiple modalities as depicted in Figure 4.5 from Chapter 4 (illustrated again below). Though this figure appears circular, the process by which the development of ideas occurs is iterative; students cycle through these different modalities prior to arriving at final claims about science.

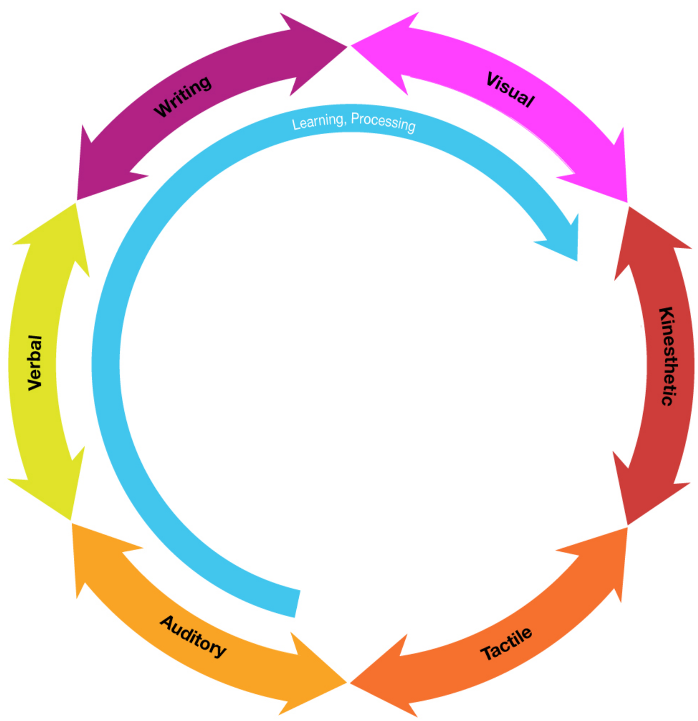



**Figure 5.1: Processing through Multiple Modalities**

Interestingly, both groups also stated that they did not feel that videos were necessarily an effective tool to learn science, because videos did not allow for this use of multiple modalities and multiple representations to work through their understandings of the science. They specifically referenced videos that were used as demonstrations to teach content. Their views are described in the section that follows.

*Videos as Static Representations of Science*

Focus group B had the most to say about using representational media, and were the most vocal about videos as an insufficient tool to unpacking scientific ideas. Before engaging them in questioning, I reminded the students that I had been present in their classroom for several months and had seen them gather at the "post-experimental meeting area" and discuss what they had been learning. I told them I heard their teacher ask such questions as "*why* do you think that?" or "*how* do you know that?" and that I also noticed the students were not permitted to say just anything, but needed to let the teacher and the community of learners know why they thought what they did. All agreed. My question to them was exactly *how* they went about trying to answer those questions. The answer emerged in a symphony of voices, each contributing a crucial component to spark the next student on with his remarks. Ian first articulated the word "evidence," followed by Alan who followed with "claim" and the need to have "objects" to conduct experiments. Mark added that if you didn't have objects but only a video to learn from, "you wouldn't learn it just as individuals…because you're actually thinking, you're doing your own things like this and that, and on the video they just told you what they do" (Appendix F, lines 85-88).

Ian immediately and proudly proclaims that they “get hands-on learning unlike watching, you know, the video. We actually *know*,” he says, “ and can actually fix it if we think it’s wrong and do it differently to get different results” (Appendix F, lines 91-93). Here, the video, while truly a fluid medium of movement, sound, and text, is considered by the students to be a static representation of science. As in Bruno Latour’s notion of the “black box,” it is not clear how the contents of that black box come to be, just as it is not always clear to the students what is occurring in the videos they have seen in science classes. The video, or black-box version of their science, cannot be “fixed” or “done again differently” as Ian points out. Carlos agrees and adds that this makes them rise to the level of true scientists who “have their own way of doing it, just like we have our own way of doing it” (Appendix F, lines 95-96). Carlos further claims that were he and his classmates to only watch videos, they would just be doing what other people say, and that is not what scientists do. These students have internalized Dave’s own vision for them – to not have his students simply do what he says, but to “think things through…[and] it’s okay if you don’t get it, but share it” (Appendix B, lines 960-961). To elaborate, Dave states:

> D: You know, *why* are you not getting, *why* don’t you believe what I believe? I’d like to know. I’d like to know what you’re thinking because you’re opinion is just as important as the teacher’s opinion. We’re all seeing the same thing. You know, like, it’s not that I have all the answers and you’re just going to get the answers from me and you’re going to walk away. Like, why are you thinking what you’re thinking, just like you should have to ask me, why am I thinking what I’m thinking. The only difference is that being and adult, I may be able to articulate my thinking better. But that’s it. They can, they know the answer. They see all this stuff happen all the time, and you really just have to tap into their real life experiences. Uh, and that comes with knowing the kids and knowing the neighborhood and things like that (Appendix B, lines 961-971).

For students in focus group B, videos were regarded as the static work of someone else's tinkering with science. They have internalized their teacher's caution to not taking on another's opinion without understanding the "why" of it. They understand that what they bring with them to the classroom is valuable; their funds of knowledge, or "their real life experiences," as Dave refers to them above, are important tools to draw upon in unpacking science. Students understand that videos use *someone else's* funds of knowledge to walk through *someone else's* steps of understanding, and this is exactly what their teacher, Dave, has so strongly disabused them of.

For focus group A students, videos were also seen as an incomplete tool to learning science. Though they were deemed helpful in providing "clues," for their learning, students still felt that "we have to do it with our own stuff" (Appendix E, line 495). When I explicitly asked whether it could be sufficient to learn from videos alone, students answered, "No, I don't think so," and again," …not if we were to have to write it or something, we have to do it with our own stuff" (Appendix E, lines 494-495). Students in focus group A are keenly aware of the benefit of working through multiple modalities and "owning" their scientific understandings by creating representations of it in different media. "Doing" the science with their own "stuff" is one such modality. The visual and auditory modalities afforded by the videos are not deemed sufficient by either focus group A nor B to lead them to understandings of science that they would be able to translate into "writing." In order to arrive at this ownership of the science *in a written form,* the students are clearly aware that they need to process the science in ways other than just the passive intake of visual or auditory information. They need to act on the science to own it. They need resemiotization in their classrooms. Both groups strongly concur on this issue.

*Differences: Focus Groups A and B*

Aside from the social nature of science, the necessity of trying and failing, and the necessity of using multiple modalities to process science, the groups' ideas differed in important ways in regard to common practices used by their teachers. These differences are summarized in Table 5.2 below.

**Table 5.2: Differences in Student Views of Instructional Practices that Promote the Learning of Science (Focus Groups A and B)**

1. When to use objects in the process of inquiry.
2. The role of pictures and "charting" in the classroom.
3. The rationale for using a science notebook.
4. The impact of teacher's pedagogical practices on their own learning of science.

In the sections that follow, I discuss these four differing viewpoints, and examine how each student group envisioned these factors as promoting their learning of science from their unique experiences with either Dave or Carla.

*Using Objects to "Decode" Text Versus to "Argue" Claims*

The notion of using representational media to explore science concepts was not one of the nine direct questions asked of the students in the focus groups (see Appendix D). Rather, the categories of pictures, charting, video, and objects emerged spontaneously in both groups. Both described these categories as tools that mediated their learning of science. They perceived their learning as directly supported by these tools. What differed was their views on *how* these representations were useful to them, and to what extent. Focus group A believed the objects to be important for decoding written text, while focus group B attributed the use of objects to furthering their argumentation of emerging student hypotheses.

Perhaps the most notable difference in their views of the efficacy of representational media was rooted in whether or not they thought the objects were useful to their learning during the "explore" portion of the lesson and/or during the "explain" portion of the lesson. *When* the objects were used during the lesson was an important consideration in order to determine *what* the objects were used for during the learning. For example, if the objects were used during the "explore" portion, it was observed and recorded in field notes, that students were attempting to directly translate written text into action, as they explored different scenarios through object manipulation. Yet, when the objects were used in the "explain" portion, the reintroduction of the objects during class discussion time served the purpose of providing a transformable context for testing out ideas and "thinking through" student hypotheses.

According to field notes, during the "explore," then, students used the objects to literally "decode" meaning from one modality into another. Sometimes, object manipulation was also used to stimulate a possible rationale for the scientific phenomena observed; whereas, during the "explain," students used the objects to work through possible hypotheses for the scientific phenomenon they observed. The objects became a tool through which to prove or disprove others' claims.

Focus group A saw no purpose for continuing to use the objects after the exploration phase. This makes sense in light of field notes, which confirm that focus group A students had little experience with the "explain" portion of the lesson, and therefore would have had little experience in talking through arguments to prove or disprove their ideas. However, focus group B felt strongly that the objects were a necessary component to the work that transpired during the "explain" discussion in the post-experimental meeting area, with their classmates and their teacher. This also makes sense in light of field notes that document the repeated privileging of class time for focus group B students during the "explain" portion of the lesson.

When questioned further, it was clear that focus group B students attributed *the teacher's* careful manipulation of the objects as critical to their learning, not necessarily their *own* manipulation of the objects. Once exploration was finished, focus group B deemed it to be the teacher's use of the objects in rehearsing student hypotheses, that enhanced and furthered student learning. Mark claimed that his teacher sometimes used the objects to work through the students' ideas: "he sometimes uses the objects to, um, teach us, um, what happens if this happens…because sometimes we, like, put the wrong answer…if we're wrong, we change the answer and we know what happens" (Appendix F, lines 214-215). As Mark talks, he uses iconic gestures, suggesting the movement of a "parachute man" moving along a parabolic pathway across his chest; the parachute men were objects used in many previous lessons regarding gravity, forces, and motion. Mark's claim is corroborated by video data in which Dave *does* bring the same objects students used at their small group tables to the post-experimental meeting area, where he uses them to test out the different hypotheses students propose to explain the scientific phenomena under study. Dave uses an iterative pattern of polling the students; using the objects to test out their ideas; eliciting student input on the result; clarifying student ideas;

using objects to test out a new hypothesis; and again eliciting student input on the results. This pattern cycles through as many iterations as necessary for the class to reach both a consensus and a result that aligns with known scientific principles. This discourse pattern in analyzed from video data and discussed in detail in Chapter 6.

Dave does not inhibit students from bringing their objects to the meeting area, but few choose to do so. Video data reveal that there are three students, in particular, who regularly bring their objects with them to the post-experimental meeting area without prompting from the teacher. One of them is Carlos, and the other is Daniel, both participants in focus group B. During our discussion of the use of objects, Carlos injects that he personally uses objects in the meeting area "in different ways, just to see, just to find out what will happen or how it will happen…I like to work with it all at the same time" (points to notebook and an imaginary object he is holding in his hand) (Appendix F, lines 236-241). Videotape data reveals that Carlos sometimes uses objects as he claims he does, but more often is seen using them in what seems to be a distracting manner to himself, and others around him. Another student in the focus group, Daniel, often rolls the objects around in his hands, as he contemplates questions posed by the teacher during the discussion, though it is not clear whether this contributes to his ability to articulate his understanding of the science concepts on hand.

During the period of data collection, I often had occasion to talk informally to both Dave and Carla. Carla expressed her beliefs that using the objects beyond the explore phase caused confusion and chaos; Dave also expressed concerns that objects could become potential management issues while engaged during the class discussion. Carlos's behavior confirms these teachers' fears. What does seem to be effective concerning object use is Dave's intentional use of them to assist students in revisiting the exploration activities to argue their hypotheses and emerging claims about the science; this is affirmed by focus group B students.

*Pictures to "Decode" Text Versus Pictures as Collective Class Memory*

Another important difference between the two student focus groups was found in their views of how pictures were used during the learning process. Focus group B held more positive views of "pictures" than videos, attributing to them the ability to "hold" class memories of prior learning on strings of charts at the back of their classroom. However, when focus group A spoke of pictures, they identified the purpose for the creation of drawings and symbols to be to decode written text in order to continue working with the science in another representation. In addition to the pictures they created on paper to decode written text, focus group A students also referred to pictures they were able to evoke *in their minds* as mental representations, when their teacher spoke or modeled activities with objects.

For Gina, in focus group A, pictures "help a lot" in terms of making sense of science. When I probe her further, she adds: "like telling, like, like, the sentence that explains what they're doing." In the previous section, I discussed how this same group of students perceived objects as also providing a way to "decode" written text. Here, we see Gina also attributes pictures to have this same utility.

There occurs a point in the interview with focus group A where the students articulate a surge of modalities when I ask them to tell me what they need in order to successfully figure out science from written text.

> Veronica: Maybe we could ask you to give us, like, different materials and then like, us, we could, like, build really, build like what you're saying.
> Gina: Make it into our own way that we can understand it.
> Alberto: Put your own mind to your hands.
> R: Put your what?
> Sandra: You can try to figure it out.
> John: Just like a picture can, like, occur in your head, like, when you're reading. So when you're reading, there are, like, even if it doesn't have pictures, pictures occur in your head, like, you know what they're talking about. But then, sometimes you don't, and that's when you need an explanation (Appendix E, lines 284-298).

All five of the students contribute to a view of resemiotization – the same view their teacher Carla holds as pivotal to their ability to process and learn the science. Pictures are referred to here as a mechanism for decoding, "like when you're reading." It is clear, however, that students from focus group A still privilege the use of objects in the process of understanding science. They tell me there is "no action" in pictures, and that using objects actually helps them "have more pictures" in their minds and to make the science in "your own way." Alberto, Gina, Veronica, and Sandra had the following exchange with me about objects and pictures. Ultimately, Gina emphatically privileges objects over pictures, demanding: "Do it with objects. Not just with pictures."

> Alberto: You have to learn to be moving it [the object] and how you're doing it and stuff.
> R: Oh. Why does that help, [student name redacted]? Do you guys think that helps?
> Sandra: Because when you draw a picture it's going to be harder because you don't really know how-
> Gina: There's no action on it.
> Veronica: It's your own way, like, you get it because it's your own way.
> Sandra: And other people are going to think about it, um, differently because you don't – it doesn't do what you think it does.
> R: Ah, so a lot of science classes, the teacher just gets up there and writes stuff on the whiteboard, and she draws pictures, but she doesn't give you any objects. So, do you guys like that?
> All: Yes.

> R: You like getting the objects? Why? Can you talk to me about why you like that? What is it – why does it help you understand and be able to say what you think, to have the objects?
> Veronica: Because it helps us to have more pictures in our mind, just – maybe if the teacher just goes up there and writes stuff, maybe it'll give us, like, a little bit of clues, but, like, we won't do it exactly like we would if, um, there was an object. So, um, I think if we had an object, for an experiment, I think that we're going to get it more and have more explanations and more answers to it.
> R: Um-hm. Um-hm.
> Gina: And we're going to get it more. Like, it's easier to-
> Veronica: We're not just going to-
> Gina: Do it with objects. Not just with pictures (Appendix E, lines 328-364).

So, while pictures were seen as decoding devices, objects are viewed as the media that allows the students to explore the science. It is the objects that lead to understanding and allow them, according to Veronica "to get it more and have more explanations and more answers to it." As John states: "So when you're reading, there are, like, even if it doesn't have pictures, pictures occur in your head, like, you know what they're talking about. But then, sometimes you don't and that's when you need an explanation" (Appendix E, lines 296-298).

To this group, pictures can assist in transforming written text, but they don't always suffice. When pictures fail, objects enable students to appropriate the science through a process of "story-telling" and action that pictures cannot. This story-telling is discussed later as "sense-making" in Chapters 6 and 7.

Students in focus group B viewed the pictures and charts they created with their teacher to be beneficial as a resource to draw upon for future learning. Alan indicates that drawings of force arrows, in particular, help the students to understand and record how an object is moving. Even though a video also captures the movement of objects, the pictures they create with their teacher are viewed as superior, since it is the students who are creating the movement with the objects, and then in turn, capturing this movement in drawings and pictures on large pieces of poster paper. This process is known in the teaching profession as “charting.” This “charting” helps students encode their thinking in a formal and uniform manner so that they can refer back to it when asked why or how they know something to be true. Alan adds that these are “always at the back of the class on the posters” (Appendix F, line 261), and points to the charts hanging at the back of the classroom. “So, if we ever have a chance, we can just look up at them and then we don’t have to forget,” (Appendix F, lines 261-262) he adds. In a sense, the wall to wall line of charts serve as a type of collective class memory that becomes encoded from a set of carefully guided social interactions mediated between teacher-using-objects and students, and between students and students on a daily basis. Daniel adds that when they are in the post-experimental meeting area and having difficulty remembering what they want to say, they can “just look up there and it reminds us” (Appendix F, lines 270-271). Specifically, each chart consists of pictures, symbols, and short phrases or vocabulary words that together transform the academic language to be learned into a larger set of alternative representations that enable students to “make it their way,” to unpack the meaning and the connections of “force” or “speed” or “acceleration.”

*The Purpose of the “Science Notebook”*

Another point of difference between the two student groups centered around the use of science notebooks. In focus group B, the “science notebook” was considered to be an important artifact for recording observations during the "explore" portion of the lessons. Interestingly, the topic of the notebooks arose in response to my question as to how "talking about science" is different from "talking about math" or "talking about English." Alan answered that talking about science was like both of the others, because it ultimately involves writing as well as equations from math, "because sometimes you have to write, and you are going to have to have the writing skills, and sometimes you might have to do equations to find out….the speed or the distance" (Appendix F, lines 154-157). Later during the interview, Ian added that it was definitely important to have the notebook with them during the post-experimental meeting area, as "we record every single thing we've done and then we compare it with everyone else" (Appendix F, lines 199-200). The notebook is clearly a placeholder for the evidence collected at their tables in their explorative groups. And, according to Ian, "if you have your notebook, you'll hardly ever gonna make a mistake" (Appendix F, lines 205-206).

In focus group A, science notebooks did not emerge as a topic of discussion. Most of interview centered around the importance of being given the opportunities to manipulate and explore with objects to learn science, but the topic of the notebook did not come up. Video data reveal that these students also kept science notebooks to record data during the "explore." It is possible that they did not mention it because they do not use it to "talk about science" as did focus group B students.

*Perceptions of the Quality of Pedagogy on Student Learning*

At the end of each interview, I asked students if there was anything else in particular they felt their teachers did to help them learn science. Carla's students noted that it was her use of objects in modeling the activities of the curriculum that assisted them in forming "pictures" of the science in their minds. Again it was clear that access to multiple modalities and representations was important to these students and their learning. Dave's students attributed much of their learning to their teacher's manner of "making everything simple" (Appendix F, line 291), a direct reference to his tapping into the spontaneous concepts and funds of knowledge the students bring with them daily. Dave's students also noted his use of charting, as important artifacts that "hold" student learning, and his scaffolds for the argumentation process that enable them to "make their claims," during the last portion of daily lessons.

These pedagogical practices are discussed in greater detail in Chapter 6 as factors that influenced the amount and quality of student discourse in each classroom.

*Summary of Similarities and Differences Between Focus Groups*

In the preceding sections, I have examined the similarities and differences between focus groups A and B regarding their ideas about how the work in their classrooms compares with the work of real scientists, and about the factors they identify as impacting their ability to process, understand and communicate their ideas about science. In general, both groups identify science as a social process that requires the sharing of ideas and the luxury of a setting that allows for the "trying and failing" of ideas students originate through the use of tinkering with objects, referring to pictures, drawings, and making the science "in their own way." Both groups concur strongly that videos are not sufficient to learn science, but rather, identify the need for opportunities to "do it with our own stuff," a reference to the need for opportunities to resemiotize the science in forms other than passive visual and auditory modalities.

Student groups differed most in their perspectives of *when* objects are most critical in the process of thinking about science, and in who uses them at these different times. Up until this point, it is clear that both teachers and students agree strongly on the necessity of using multiple modalities and multiple representations in the work of processing, understanding, and communicating scientific ideas. Focus group A views these modalities to be crucial in decoding static written text to representations more conducive to processing and learning. Focus group B views different modalities to be critical to "thinking" about the science, and the representations to be crucial place holders for collective class memory and learning.

In the next sections, I examine the intersection of the students' viewpoints with those their teachers hold, as discussed in Chapter 4. I found that each student focus group has learned to internalize many of the beliefs their teachers hold. However, in addition, the students also identify different factors as facilitating their learning and communication of science. Points of intersection are described first, followed by points of difference for each group of students and their respective teacher.

### *Salient Themes in Interview Data: Carla and Her Students*

Overall, there were several common themes that emerged in the interview with Carla and in the interview with her students. Within these themes, there were points of consensus and points of difference expressed. Table 5.3 summarizes the main points of intersection between Carla's statements in her interview and the students' statements during their focus group interview.

**Table 5.3: Salient Themes in Interview Data, (Carla and her Students)**

| Carla states… | Students state… |
|---|---|
| Students **lack sophisticated scientific materials** necessary to do the work of science. | They **lack the necessary scientific materials** in their own classroom to do the work that scientists do. |
| Students who "think like scientists" in the class "think outside the box" and work outside of set procedures given to them. | Things are "planned out for them"- they have limited opportunity to truly explore and feel confined by planned procedures. |
| The **social nature of science** is important during "explore" portion of lesson. | **Social nature of science** seen in the "accountable talk" students credit as assisting their uncovering of the curriculum. |
| **Trying and failing is important** in the inquiry process. | They are dependent **on trying and failing** to discover science. |
| Students are encouraged to use **multiple modalities** of their own choosing to assist in understanding science. | What helps them learn science = the use of pre-planned procedures, drawings, objects, questions, videos, input from experts (**multiple modalities**) (Scientists and students need to "build what the words say" through transposition into alternative representations). |
| She **believes objects are only needed in the explore portion of the lesson and are a distraction in the meeting area.** | They **do not need to use objects in the meeting area,** only during the explore portion of the lesson. |

There were striking similarities between what Carla expressed about her teaching beliefs and practices, and what her students identified as important factors to learning science. In general, Carla's students agreed with her on several points. Teacher and students remarked on their lack of necessary scientific materials in their own classroom to do the work that real scientists do. Both also commented on the social aspect of science, and the importance of working together, as well as on the use of multiple modalities and multiple representations to appropriate science knowledge for themselves. And finally, both teacher and students concurred that while objects were important for learning, they were only necessary during the exploration phase of the lesson, and were not important to the discussion of learning beyond that experience. However, there was also one main point of difference in how the students perceived their roles as student scientists playing out in the classroom. In the sections below, I begin with a description of the perspectives shared by Carla and her students, followed by a description of their differing ideas.

## *Points of Consensus Between Carla and Her Students*

### *Science as a Social Process*

Both Carla and her students agree that science is a social enterprise. Carla's students are keen to recognize the social nature of the scientific process, both for themselves and for scientists outside the classroom. Not only scientists, but these students themselves need "ideas from other people…a little group, so you can know, like what you're doing." This novice explanation of the sociocultural aspect of learning science seems to have become internalized through the experiences these students have had with their groups during the exploration portions of their daily lessons. They even put the name "accountable talk" onto the system of practices they credit as assisting their uncovering of the curriculum. When I ask the group what they do when the teacher asks them what they think and they truly don't know, there is a mixture of responses:

> Veronica: Sometimes I just like answer some question that we think it is, and then everybody is like, "noooo" so that's the only thing- [talking together]
> Alberto: Just think what the answer is like.
> John: There's agreeing and disagreeing all around the meeting area.
> Sandra: Sometimes you can say, "I'm confused and I didn't actually get it."

> John: And at the beginning of the year [teacher name redacted] was talking about, like, the accountable talk.
> R: What's that?
> John: Like, "I agree with," "I disagree with."
> R: Uh-huh. And how does that help you if you're in the meeting area?
> John: Yeah, like adding on support to help others.
> R: And so, let's say you're confused, or you say something, and I say, "na-uh, that's wrong. I disagree with you because blah blah blah." Then, does that help you change and think of something else?
> John: Yeah, it helps me change my thinking. It's like support either way. Agreeing or disagreeing (Appendix E, lines 125-152).

Carla's students here credit "accountable talk" as a critical vehicle for discussing science, giving it this "social" aspect. They explained that "accountable talk" existed when students practiced using sentence stems to discuss their emerging scientific understandings. They spoke of this "accountable talk" as learning to "agree with" or "disagree with" their peers, but that this was something they did at the beginning of the year. Video data reveal that during the data collection period, there was little, if any, time reserved for the "explain" portion of the lesson in Carla's class when such discussion would take place. It may have been something that was started in the early weeks and then did not continue due to time constraints. Interestingly, however, it is something the students remember and note as a factor affecting their ability to learn science. The lack of time safeguarded for student talk is discussed in Chapter 6 as a factor constraining the amount of argumentation students were able to develop in daily lessons.

*Alternative Representations: "Making it into Our Own Way"*

Carla's students were able to identify numerous factors they felt contributed to their ability to help them learn science. These were the same factors Carla also identified. In particular, the following were mentioned: the use of procedures, drawings, objects, questions, videos, and input from experts. One main difference was found to be that students did not seem to have the conscious awareness of the extent to which objects played out in their learning of the science, until prompted by the memory of their teacher herself using objects to model the science activities in their curriculum. They also seemed to have difficulty articulating what was clearly their use of resemiotization during the process of learning. Ultimately, the interview served as a generative forum for metacognitively reflecting on their learning of science. Ultimately, students concurred with their teacher that multiple modalities and multiple representations were critical to their learning of the science.

When faced with a novel problem, students said that they would try to do what real scientists do- that is, "build what the words say," by transferring them into alternative representations. The use of pictures, and especially arrows, helps them make meaning from the given problem. When I asked them what helps most when they are asked to explain something with their group, the replies focus on asking more questions and following procedures. This is curious since these same students previously identified having a procedure to follow as limiting the process of exploration, something they claimed "real scientists" do not face. I asked them this question over and over in many different ways: "How do you go about making sense of things when you have to share in that big group?" and again, "what helps you answer?" (Appendix E, lines 99-102) and "What do you do in the meeting area if [teacher name redacted] says, 'well, what do you think?' and you don't know. What do you do in that very moment?" (Appendix E, lines

120-122). Curiously, students stuck with their answers of using a procedure and continuing to "try" at it over and over.

However, it wasn't clear they could identify what "trying at it" actually meant, until I made the question more concrete and asked what students would do *when given a piece of paper with just words on it*. After this clarification, student answers began to center around the use of multiple representations, including "little drawings" and numerous references to utilizing objects to enact the words on the paper. This ultimately catalyzed a deluge of talk about modalities. In particular, Sandra stated that you have to "separate it apart" referring to the procedures given in words. The students then collectively revisited an actual activity they did when studying energy, sources, and receivers. John stated that "you need more than just paper…you need an expert's point of view." Veronica added that they would need "different materials" along the same lines of what their group claimed was necessary to allow them to do the true work of scientists. With these materials, she stated that they could then "build- really build like what you're saying." Here, Veronica is identifying that students can approach a problem that is not already scaffolded for them, like scientists would; she returns to her original stance that scientists use "different materials" and that they too could do this and "build" what the words on the paper say. Gina agrees with Veronica, underscoring the importance of "[making] it into our own way that we can understand it." The group concurs strongly over this issue, talking over one another and articulating the necessity of transferring words on paper into other representational forms.

However, the students have difficulty expressing exactly what these alternative representations might be. In video data, it is clear that students often resemioticize the scientific concepts from text to gesture to drawings to objects, etc…John comes close to an explanation of this resemiotization when he states: "when you're reading, there, like, even if it doesn't have pictures, pictures occur in your head, like you know what they're talking about." However, he is not always metacognitively aware of the process, adding that, "sometimes you don't [know what they're talking about] and that's when you need an explanation." He follows the trajectory of resemiotization from written text to pictures; but, the when pictures prove insufficient, he is not able to recall other modalities across which he transposes scientific concepts as seen in video data. And yet, in practice, John and the other students do indeed continue to resemiotize. Even though he is not consciously aware of it, video data reveal that gestures and objects are often involved alongside of the drawings, arrows, and questions that students identify as important factors in making the learning their own.

Although they are not always aware of their own use of objects, when I ask the students about what their teacher does that helps them understand science better, they are able to identify her use of objects as crucial to their learning. Gina, Sandra, and Veronica are quick to identify objects as a crucial aspect in Carla's teaching:

> Gina: She gives an example with objects.
> Sandra: She uses an example with things and she explains …how we're going to do everything…
> Veronica: What I like about her is that she doesn't just say what we have to do….She does like part of it… (Appendix E, lines 305-315).

The students go on to describe how some of the mystery is left to the students to solve. This ties into what we know from the research on motivation and the way in which self-efficacy plays into accomplishing a task that is worth doing and that students are curious about (Bandura, 1977).

Neither Carla nor her students ever talk about the use of gestures as contributing to science learning. It seems this may be a practice so innate, that is it difficult to consciously identify as a factor affecting science learning. But once prompted with the memory of their teacher's use of objects, the students begin to talk openly about their own use of objects to learn as well. Gina explains that using objects is even easier than having just drawing because "you've got them right there and you can redo it how much times however you want," whereas the pictures – "there's no action" and this limits the efficacy of the pictures. Veronica agrees that the objects allow the students to explore in their own way: "It's your own way, like, you get it because it's your own way." Again the objects seem to allow the students more freedom to do things their "own way" – and yet students only deem the objects as important tools during the exploration process, not during any type of explanation process. Could it be they have not had the experience of arguing their claims with others? The students also expressed that using the objects in turn allows them to "have more pictures in our mind." When speaking of objects and pictures, they are better able to articulate the process of resemiotization, clearly seen in the video data; however, they are only able to arrive at this epiphany when I ask them about what their teacher does to help them learn science.

Overall, Carla's students are not aware that the objects, and the gestures used over those objects, play an important role in their abilities to process science text and to create other representations of the science concepts presented to them on paper. They do, however, identify pictures as crucial to decoding text. It seems that the use of objects and gestures are an innate, transparent part of the process of learning science that goes unnoticed by these students, unless directly asked about objects in particular. These are overlooked, almost an afterthought, to the process they routinely use to convert text to conceptual understanding. In Chapters 6 and 7 I discuss the critical role of both objects and gestures to students' abilities to articulate sophisticated argumentation.

*The Role of Objects in Science Learning*

Once prompted into realizing that their teacher uses objects, and that this helps them learn, there is much continued discussion about the role of objects in the learning process. This notion of, "do it with objects, not just with pictures," as Gina says, is a generative realization that develops during the course of the interview. According to the students in the focus group, these objects are useful to the students only during the explorative portion of the experiments, and not during the portion of the lesson when they come to the meeting area to discuss their claims. Veronica states that the objects are needed "when you actually have to solve something or give an answer. But when we're up in the meeting area, we had already tried it with objects, so it's more easier for us to answer the questions that she's asking us" Appendix E, lines 446-448). During the interview, I repeat this claim back to Veronica for clarification: "So you don't need the objects anymore when you're in the meeting area?" Veronica, together with the other four students all agree no, they do not.

This makes sense given the fact that this group of students rarely experience a meeting area where they are asked to reach a class consensus about scientific claims. In fact, Carla herself states in her interview with me that most times the students complete their analyses and claims individually at home in their science notebooks and not collaboratively as a class. Therefore, students have experience using the objects to explore and explain emerging thoughts to one another at their tables, but are not able to associate the objects with the meeting area, because they are rarely, if ever, in that formation at the end of class time.

When I return to my original questions of what helps them learn science best, students revert to their original answers "with pictures," – but this time they add that they mean not just actual drawings, but also pictures that she puts in their minds when the teacher is working with objects. They also add videos this time, claiming that videos help them see experts "doing something." When probed, students again arrive at the importance of "doing science" themselves. When I ask them if it is sufficient to see the teacher or an expert "do the science" on a video, they all agree that it is not. Veronica says: "We get what she's saying, but not if we were to have to write it or something. We have to do it with our own stuff." Here it seems Veronica is aware that she can only superficially understand what is happening scientifically if she watches her teacher or someone on video. She articulates that students still need to do it "with our own stuff" if they are to write it- or, to own it, and be able to re-articulate it in their own words in a different representation – as, in written text. So it seems, from the students' perspective, that the process of resemiotization is a necessary process for them to experience if they are to truly understand the science concepts that are the goal of their lessons. I end the interview by asking: "So you don't think you could be able to just watch a video and get a paper with questions?" Gina is adamant in her tone as she replies: "No, I don't think so." Though they are not able to express why, on some level, the students understand the importance of the resemiotization process in which their teacher engages them every day.

### *Points of Difference Between Carla and Her Students*

In general, Carla's students held different ideas concerning their roles as student scientists in the classroom, as well as the degree of freedom they possess to explore, the way scientists do.

#### *Perceived Freedoms in the Science Classroom*

Interestingly, the students did not view their role in the classroom as the same role that scientists have in their laboratory settings. In general, these students thought that scientists' work was "more fun and more harder." Like their teacher, they cited access to materials as a main obstacle to accomplishing the same type of work that scientists manage in authentic laboratory and field-based settings. In the students' view, scientists use different materials than the students have access to and go beyond just using paper and pencil.

However, unlike their teacher, they believe it is significant that scientists do not have everything "all planned out for them" as they feel they do in Carla's class. The students give conflicting reports on their views of being given procedures. At one point in the interview, they tell me "procedures are for us to understand" (Appendix E, line 200). At another point, they tell me "in this class, they give you the steps and everything," whereas scientists "don't have it all planned out" (Appendix E, lines 44-45).

The students note that they are deprived of this freedom to break free from the procedures, but have somehow simultaneously learned to rely on these given procedures to come to “understand” the science. Carla, however, believes she provides her students with ample opportunity to “think outside the box,” and creatively tinker with ideas beyond the planned procedures she has designed for them. Her students clearly believe otherwise. They note that scientists “work together,” but are not assigned to do particular tasks and separate duties. Veronica references “Mythbusters,” a recent video clip that the students have seen. She says:

> …they [the scientists] were trying like different things…there were different things around their head but nothing was holding it. Like, they weren’t attached to their head, it was just floating there (Appendix E, lines 78-80).

Veronica realizes the ideas scientists work on are not assigned to them, but are just things that they wonder about. She identifies the freedom to explore as something missing from what she and her peers are able to have access to in the classroom. This does not fit with what Carla seems to envision as occurring in her classroom. During our interview together, Carla stated that that those of her students, whom she considers “think like scientists,” actually *do* explore and think outside the box- outside any set of procedures she might give them for guidance. It seems then, that there is some gap between what the teacher views as a sophisticated understanding of the nature of science exploration and what behaviors the students themselves perceive they are allowed to engage in during the class period.

*Salient Themes in Interview Data: Dave and His Students*

As with Carla and her students, Dave and his students shared many perspectives regarding the teaching and learning of science; and, they also differed in important ways. Table 5.4 summarizes the main points of intersection between Dave's statements in his interview and his students' statements during their focus group interview.

**Table 5.4: Salient Themes in Interview Data (Dave and his Students)**

| Dave states… | Students state… |
|---|---|
| The importance of **"try and fail"** in the inquiry process. | **"Trying and failing"** is what scientists do and this is something they have in common with authentic scientists. |
| (does not bring up role of the objects) | Objects are critical to "thinking" about science. |
| Video clips are used to initially present ideas in the world of students and then to extrapolate to scientific concepts using academic language. This facilitates the transfer of "spontaneous concepts" to "scientific concepts" (Vygotsky). | Videos are static in their delivery and rob students of the opportunity to "get hands-on learning." They do not help with the cycle of try and fail that real scientists go through. |
| All students come with ideas and teacher needs to lower the affective filter (Kraschen) and provide a safe, risk-free environment to allow for student expression of scientific ideas. Role of teacher = the "more capable peer" and another student alongside his students. Learning is a process distributed across many individuals all using a variety of modalities to process and think through the science. Believes in teaching inquiry through "spiraling" and creating opportunities for students to cycle through visual, kinesthetic, tactile, auditory, verbal, and writing modalities to arrive at their own scientific understandings (resemiotization thought to occur throughout the 5E cycle of instruction). | What helps them learn science= teacher's organization of discourse practices; students get to act like teachers themselves; students feel free to take risks; teacher has created a community where every student is necessary for the whole class's learning; teacher makes the learning "simple." |

In general, Dave's students identified the "try and fail" theme as one they share with their teacher. The idea of scientists and students trying something and failing, trying something else, and failing again is a theme that was mentioned not only by both Dave and his students, but also by Carla and her students as well. This inquiry-based perspective is clearly one that pervades both of these classrooms. But, Dave's students also spoke about ideas that did not come up in their teacher's interview, including such notions as the role of objects and the role of their teacher's discourse style on their learning of science, as well as the establishment of a community of learners in which all students feel safe to take risks and contribute to whole class learning.

In the sections below, I describe the parallel points of consensus between Dave and his students, followed by a description of ideas that differed between them, and finally by a description of the unique topics students initiated during their interview.

## *Points of Consensus Between Dave and His Students*

### *Students and Scientists: Shared Norms of Practice*

Unlike Carla's students, Dave's students more readily equate the work they do in the classroom with the work of authentic scientists. Carla's students focused on a lack of authentic equipment to carry out the work of scientists, and did not perceive that they had the freedoms that "real" scientists do. In contrast, Dave's students take a more positive stance. They believe they share similar norms of practice with scientists. They have internalized Dave's notion that doing science amounts to trying and failing in successive iterations. These students also possess a sophisticated view of the nature of scientific progression and understand that scientific paradigms are relatively stable over time.

Daniel says there really isn't a difference between the way students in Dave's class do science, and the way "real scientists" go about their work. He claims that both:

> Just test it out. Try to, like just try to figure stuff out, um, kind of like real scientists would, like, testing out theories seeing if most of us got the same results- then that's possibly the right answer (Appendix F, lines 53-55).

While this might seem like a naïve view, and one that does not take into account experimental error and flawed experimental design, in fact, Dr. Sommerville of Scripps Institute of Oceanography would agree that Daniel is, in fact, correct. Sommerville (2008) claims that usually when a majority of scientists reach consensus on a finding, it is indeed found to be correct, and becomes a part of the scientific canon. Or, in his words, "Galileos are rare." Video data attest to the fact that these students experience daily, the satisfaction of arriving at class consensus concerning the scientific phenomena of the day. In this way, they each personally experience the satisfaction of black-boxing their science learning through finalizing claims with their classmates and teacher.

*The Importance of Discourse in the Presence of Objects*

Probing the students to think further about what they need to do the work of science, the replies largely focus around discourse and objects. Ian claims that you need to have evidence to support claims. Alan added that you also need objects and supplies to conduct the experiments to make claims. The objects are considered pivotal to the work of "thinking" about science. As discussed earlier, Mark and Ian agree that video media is static in its delivery. It is a one-way of learning science, which robs them of the ability to redo experiments and make them "right." Ian explains: "We get hands-on learning unlike just watching, you know, the video. We actually *know*, and we can actually fix it if we think it's wrong and do it differently to get different results." In fact, Carlos expresses his view that this type of learning with objects elevates his status as a student equating him with scientists, "like every time a scientist does it, they have their own way of doing it, just like we'll have our own way of doing it." This is similar to the theme Carla's students expressed when they claimed that they "make it [the text of the science] into our own way." Dave's students also very astutely reveal that if they only learned from a video, they would just assume that what they saw was right and take it at face value. But, when they learn by object manipulation, "if we do something wrong, we can learn from that and like, try and change it" – again revisiting the theme of trying and failing and trying and failing.

### *Points of Difference Between Dave and His Students*

When I asked Dave's students if there was anything specific about the way Dave teaches that makes them learn science better, their first responses dealt mainly with the affective aspects of Dave's teaching practice. This contrasted with Carla's student responses, which centered around pedagogical issues only. Interestingly, Dave's students also identified different aspects of his practice than Dave did, as being crucial to the learning of science.

#### *Teacher Style and its Impact on Learning*

Dave and his students highlighted different pedagogical practices as particularly conducive to science learning. As discussed in Chapter 4, Dave primarily spoke about learning as a process distributed across many individuals all using a variety of modalities to process and thing through the science. As also described in detail in Chapter 4, he advocates teaching inquiry through “spiraling,” and by creating opportunities for students to cycle through visual, kinesthetic, tactile, auditory, verbal, and writing modalities to arrive at their own scientific understandings. He believes all students come with ideas from their everyday life experiences and that it is the teacher’s duty to lower the affective filter (Kraschen) and provide a safe, risk-free environment to allow for student expression of scientific ideas. Dave also expressed his belief in assuming the role of a “more capable peer” –another students alongside his own students. His students concur that they feel safe to take risks in the classroom; additionally, they add that it is their teacher’s unique discourse style that furthers their learning experiences. These two ideas are discussed in the sections below.

<u>Students Feel Safe to Take Risks</u>

Students attributed a risk-free environment as greatly impacting their learning process in Dave’s classroom. This was in response to the question: what is it about Dave’s teaching that makes you learn better? Mark attributes much of his own success to the fact that they often get to act like teachers themselves:

> He, um, he let’s us do the work, like, sometimes when we are working independently, he tells us, “who wants to do the workon the board?” We do the work and then he tells the whole class, “Is this right or wrong?” and then we talk and discuss about it (Appendix F, lines 121-124).

Mark feels free to take risks and make mistakes in front of his peers; clearly Dave has lowered the affective barrier for this shy English learner. Ian attributes much of his success to the community Dave creates in his classroom. Every single student is necessary for the whole class's learning:

> Ian: The way that [teacher name redacted] does it is that he gets everyone involved. Every single student at least says something and gets to share an opinion during either an experiment, or like our conclusion or anything. And he tries to get everyone involved and more into science. Even if you might not like it. Maybe you might not like science, or he probably gets you to enjoy it because you feel like you're participating and actually doing something good, and that's the way that [teacher name redacted] likes to do it (Appendix F, lines 128-134).

Ian is articulating what we know from one strand of motivation literature which is that self-efficacy and a task worth doing are major contributors to motivation (Bandura, 1977). Alan agrees with Ian's analysis of Dave's inclusion and motivation of all students. He tells me: "Yeah, 'cause Mr. ______, he is a good teacher. Last year, I was a bad kid in my science class but this year with Mr. ___ I think I just got a little bit better" (Appendix F, lines 136-138).

As I close this student focus group and ask the students if there is anything else they would like to tell me about the way they learn science this year in their classroom, many of their answers again focus on teacher style: "It's more fun….it's more active" and "Mr.____ makes things simple" – a possible reference to the way this teacher interweaves the spontaneous concepts his students bring with them everyday with the scientific concepts (Vygotsky) to which he so brilliantly and artfully exposes them in his lesson designs each day.

Students' Views of Dave's Discourse Style

In addition to a safe environment for learning, Dave's students also identified their teacher's organization as contributing to their learning. In particular, Carlos mentioned the organized discourse practices: "…if we have questions, he'll answer them, like, in an organized way instead of everyone just yelling out." In fact, videotape data reveals that what Carlos is referring to, is a very purposeful interaction of teacher-student-student discourse pattern that is discussed in detail in Chapter 6. Through this discourse practice, Dave strives to have his students talking with one another, and leads by carefully chosen, purposeful questioning prompts. As he stated in his interview with me, and as I observed in practice, Dave will observe students during the exploration phase and call upon those he considers the "more capable peers" to drive the class discussion at the end of the day.

*Unique Perspectives of Dave's Students*

Six main topics arose during my focus group interview with Dave's students that did not emerge during my interview with Dave. These topics are summarized in Figure 5.2 below.

1. Students claim their notebooks served as a "placeholder" for offloading the observations and evidence they collect during their exploration in small groups.
2. Student notebooks became a place where students transformed their visual, auditory, kinesthetic, and tactile experiences into other representations- where they resemiotize their understandings (this is the black-boxing Latour writes of).
3. Students claimed it was crucial to their learning that the teacher bring the objects used in exploration to the post-experimental meeting area.
4. Students identified the charts at back of room as important scaffolds to their learning (serve as a type of collective class memory of past learning).
5. Students identified the method of learning to draw diagrams per teacher instruction as helpful to their learning (assist them in incorporating movement into their diagrams).
6. Students identified the post-experimental meeting area as crucial not only for their own learning but for their teacher's as well.

**Figure 5.2: Unique Perspectives of Students**

*The Use of Multiple Representations*

Dave's students put a great deal of emphasis on their science notebooks and on objects in the post-experimental meeting area. As discussed in an earlier section, the students perceive their notebooks as serving as a "placeholders" for offloading the observations and evidence they collect during their exploration in small groups. Ian tells me that students always bring their notebooks to the post-experimental meeting area "because we obviously are all going to share out" (Appendix F, line 196). The fact that he equates the necessity of sharing out with the necessity of having the science notebooks on-hand and available for the class discussions, suggests that the notebooks serve as a place where students transform their visual, auditory, kinesthetic, and tactile experiences into other representations- where they resemiotisize their understandings. Video data reveal that students record text, sounds, drawings, and "movement symbols" via arrows and other small notations in their notebooks. Ian explains that "we record every single thing we've done and then we compare it with everyone else" (Appendix F, lines 199-200). Alan adds that the notebook is necessary so "you'll never forget." During the post-experimental meeting area discussions, the notebook representations are then drawn upon in explaining students' thinking, transformed into verbal words and gestures.

When I directly ask the students if it matters if they have their notebooks with them during the class discussion, Ian answers: "I do feel that it would matter because, you know, some kids might go like this [pretends to cause a distraction] and then sometimes other kids feel like laughing, but if you have your notebook, you'll hardly ever gonna make a mistake" (Appendix F, lines 204-206). This again gives credence to the idea that the students' notebooks are the permanent record of all learning that has previously occurred during exploration and even the lecture-style meeting area learning. Curiously, Dave does not bring the subject of the science notebooks up during our interview; his students, however, are keenly aware of the power of the notebook as the "keeper of memories," and record of past learning. Dave does talk at length about the need for resemiotization, but does not address the ultimate step of codification of that work into written form. It is his students that elevate and celebrate that artifact in their learning process.

*The Role of Objects in the Meeting Area*

In regards to the objects and their role in the class discussion, Dave does not comment during our interview. However, his students are unanimous in their agreement that it matters if the objects are brought back to the post-experimental meeting area after exploration. Video data attests to the fact that Dave routinely uses the objects during this time, but the students do not. I confront the students with this fact, and the following exchange occurs:

> R: But you don't really bring those objects with you, right?
> Mark: Yes, because [teacher name redacted], he sometimes uses the objects to, um, to teach us, um, what happens if this happens. Like when we were learning about gravity with the block and the parachute man, he put them, he let them go up and we saw if the block fell before the other one (gestures with his hands).
> R: So, but [Mark], you did parachute man at your tables, right? How does it help that [teacher name redacted] also uses parachute man at the meeting area? How comes it helps when he does it again?
> Mark: Because, sometimes we, like, put the wrong answer, and he tells us, um, how this works and that, and if this, um friction, and if gravity is, um, stronger than friction, with the parachute man, and then we, if we're wrong we change the answer and we know what happens (Appendix F, lines 212-226).

Marcos refers to the objects as critical and integral to understanding the science during the discussion. However, he doesn't refer to the students' direct use of the objects, but rather, as discussed in an earlier section, he alludes to *the teacher's* use of the objects that affects student understanding. It is when *the teacher* works through different scenarios that the students have already explored at their tables, that understanding is advanced. This is corroborated by video data that is described in detail in Chapter 6. In this data, an iterative pattern emerges in the discourse in which the teacher is seen to poll students regarding a question, to then test out with the objects the original task students were given, then call for student input, test out new student ideas with the objects, receive new student input, test out new ideas, receive new student input, etc… until a class consensus in reached.

*The Role of "Charting"*

The final idea the students identify as helping them communicate their ideas about science is the series of diagrams that hang on chart paper at the back of the classroom along a single thick cord; this cord originates at one end of the room and ends at the opposite side. As the students face the front of the classroom, toward the white board in their lecture-style format, this line of charting hangs to their backs. Many often glance back to find definitions as they think through new issues or review past material. In particular, Alan explains that the way Dave teaches them to denote movement in their diagrams via arrows "helps us understand what the object is doing." These force arrow diagrams, as Dave calls them, are modeled on one of the charts at the back. These diagrams assist the students in incorporating movement into the representational realm of drawing, in turn helping students resemioticize the science content and process their learning.

Video data reveal that these charts are created jointly between the teacher and the students and serve as a type of collective class memory so that when students forget a definition or term, they can "look up there and it reminds us, we like, just remember from what we see up there" (Appendix F, lines 270-271). In particular for Mark, one of the English learners in the group, a strength of these charts is in providing access to the words he needs to articulate his understandings of science. In his words, "and so if we want to say something but we can't remember what it is, we can just see the map [points at papers along the cord] and we know what the word means and we just use it" (Appendix F, lines 280-281). In this manner, students are participating in classic process by which scientists themselves "black-box" scientific ideas, codifying and cementing them into neat chart, graphs, and tables. Though they appear to be unassailable representations of scientific "truth," in fact, they are actually arrived at through complexly mediated interactions between and across multiples representations and modalities; simply put, they are the products of complex resemiotization.

*The Role of Inscription in the Learning Process*

Ultimately, I ask the students if there is anything else that they want to tell me about in terms of strategies they use, or were taught to use, for when they want to say something about science but are having trouble articulating their ideas. The immediate responses are repeated references to the importance of the science notebooks and the charting along the back of the classroom; both are identified as two ways of offloading the community learning onto artifacts in the environment of the students.

This is a clear example of how inscription advances the learning process. In this case, inscription of past learning onto chart provides a particularly clear example of how pointing to these artifacts calls upon embodied practices that transform over and over again, the social organization of the classroom and renegotiates participant frames to include aspects of the environment as crucial participants in the learning. Students' deicitic gestures toward the charts and objects animate and elevate these same charts and object to a participant level, changing the notion of what constitutes a knowledgeable member of the class. Dave never brings this up during my interview with him, until I call his attention to it at the end our discussion, describing his classroom as a set of interactional systems students can call upon as they reach different knowledge states during the lesson. Interestingly, Dave's students identify these systems as important, though they are not able to fully articulate why they are so critical to the learning process; they do not speak of the charts and objects as participants with them in the learning, but they realize their importance.

*The Role of the "Post-experimental Meeting Area"*

Interestingly, one of Dave's students identifies the post-experimental meeting area as the crucial component not only for the students' learning, but for their teacher's learning as well. Ian explains that it matters that they come back to a circle at the end of the class for these reasons:

> Ian: I feel it does for three reasons. One, I think it will help [teacher name redacted] because I'm guessing he takes everything that he does in one class and sees which are successful, and us coming into that circle, it shows everyone was contributing something, which means they did it, or they were paying attention (Appendix F, lines 374-377).

Though he does not explicitly say so, the latter comment speaks to the sociocultural nature of students learning from one another, rather than in social isolation completing their final claims and conclusions alone, which happens much of the time in Carla's situation. Alan follows up on Ian's comments by explicitly providing examples of how the discussions in the post-experimental meeting area allow students who are not understanding the main conceptual science goals to work through their misconceptions. The "circle" provides opportunities to watch the teacher work through different "incorrect" scenarios provided by the students, and allows these students a second chance at "how you should've did it, how it should be" (Appendix F, lines 388-389). Students who go off-track during the course of the exploration phase of the lesson, then, in the post-experimental meeting area are allowed to find ways to correct their initial claims via teacher guidance and teacher use of the original objects used in the "explore" portion. Students also suggest that the post-experimental meeting area is useful as a place where their teacher scaffolds the claims process, by providing them questions to answer, which when answered with evidence, become their final claims. This is absent from Carla's class.

*Summary of Findings from Student Focus Group Interviews*

In general, students from both focus groups tended to agree with their teachers' viewpoints in regards to their roles as students and how they best learn. Carla's students underscored her point about lacking scientific equipment to do the work of "real" scientists. They also felt confined by procedures given to them by their teacher, and talked about the importance of multiple modalities, though the latter were not thought to be necessary once the "explore" portion of the lesson was completed. Dave's students highlighted the importance of their notebooks as places to offload their learning; they also highlighted the importance of the use of objects throughout their lessons; and finally, they commented on the affective teaching style of their teacher as a major contributing factor to their science learning.

Both the student and teacher voices in Chapters 4 and 5 underscore the importance of the process of resemiotization in students' attempts to process, understand, and communicate their emerging scientific understandings. In Carla's class, it is clear from both her own remarks as well as those of her students', that resemiotization is encouraged at the exploration phase of the lessons, when students are grappling with decoding written tasks of the science curriculum, and attempting to "make it our own." In Dave's class, resemiotization occurs at both the exploration and explanation portions of the lesson; it is encouraged, supported, and intentionally planned for to assist students in processing, understanding, and in arguing their respective scientific knowledge. But what does resemiotization look like? What does it sound like? How do we know when it is occurring in the classroom, and how does it influence students' abilities to process, understand, and communicate their scientific ideas? What other factors influence students' abilities to communicate their scientific understandings? The following two chapters present an investigation into these questions.

## Chapter 6- Forging Pathways to Learning: The Intersections of Teacher Practice, Physical Structures, and Classroom Systems

### *Introduction and Overview*

The previous two chapters examined the perspectives of eighth grade students and their teachers concerning science teaching and learning. Specifically, their views regarding the roles of students and teachers of science, and their ideas about the factors influencing the teaching and learning of science were investigated. In this chapter, and in the one following, I investigate the final research question: What factors affect middle school students' ability to achieve more sophisticated levels of argumentation in the classroom? I also propose a model to answer my overarching research question of: What factors promote inquiry-based instruction in middle school science classrooms?

I begin in this chapter by examining the ways in which the two classrooms in this study were physically arranged, how classroom norms were developed and used, how teachers' beliefs were instantiated in practice, and how these dimensions in turn influenced students' talk.

Six videotaped lessons were selected from the data collection period as the context in which to analyze classroom discourse. As discussed in Chapter 2, argumentation is the prominent form of productive talk leading to the building of scientific knowledge. Unlike everyday, common-sense forms of argumentation, scientific argumentation is governed by shared norms of participation. It focuses on making claims that are backed by evidence. Since argumentation is the fundamental talk of science, I chose to analyze students' talk in the six lessons, using the five-level argumentation rubric described previously in Chapter 3 (see Table 3.8). An analysis of the six transcripts from the selected lessons is detailed in Appendices H-M. Additionally, an agenda of the events planned for each class session is presented for reference in Appendix G.

Three of the six lessons come from Dave's classroom, and three of the lessons from Carla's classroom. Together these six lessons are the last documented during the data collection period. They were chosen for analysis because they represent the longest period of time over which students created and practiced shared norms with their respective teachers. Since we know that both students and teachers need time to develop a shared understanding of the norms of participation in science (National Research Council, 2005), I chose to use the last three lessons from each classroom to analyze, in order to maximize the benefits of this shared understanding.

A detailed analysis of the six lessons reveals that students' opportunities and abilities to achieve various levels of argumentation was influenced by a combination of factors stemming from three dimensions: teacher practices; physical structures of the classroom environment; and classroom systems, including routines and procedures. The degree and manner in which each of these dimensions influenced the quantity and quality of argumentation varied across the selected lessons, and is noted in the individual analysis of each lesson.

*Opportunities for Student Argumentation Influenced by Dimensions of Teacher Practice, Physical Environment, and Classroom Norms*

In Chapter 3, three domains were defined and described as harboring the practices, contexts, and conditions that could potentially create opportunities for students to participate in inductive inquiry; these were teacher practices, physical structures, and classroom systems (routines and procedures) (see Figure 6.1).

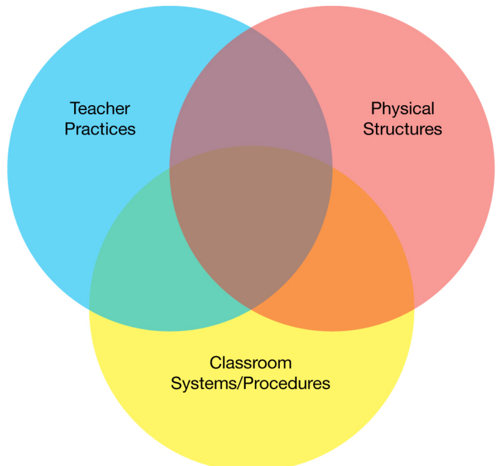



**Figure 6.1: Three Domains of Analysis Used to Examine Origin of Factors Affecting Classroom Discourse**

The features of these dimensions are described in detail in Chapter 3 with reference to the figure above. However, upon analysis of the lessons, this Venn Diagram was found to be an insufficient model to explain the complex interrelationships within and across the three dimensions. Instead, in Figure 6.2, I propose a more intricate model to explain the interaction of the three domains as observed in the six lessons. This model depicts four pathways of inquiry teaching identified from the data; each pathway leads to different outcomes of scientific learning.

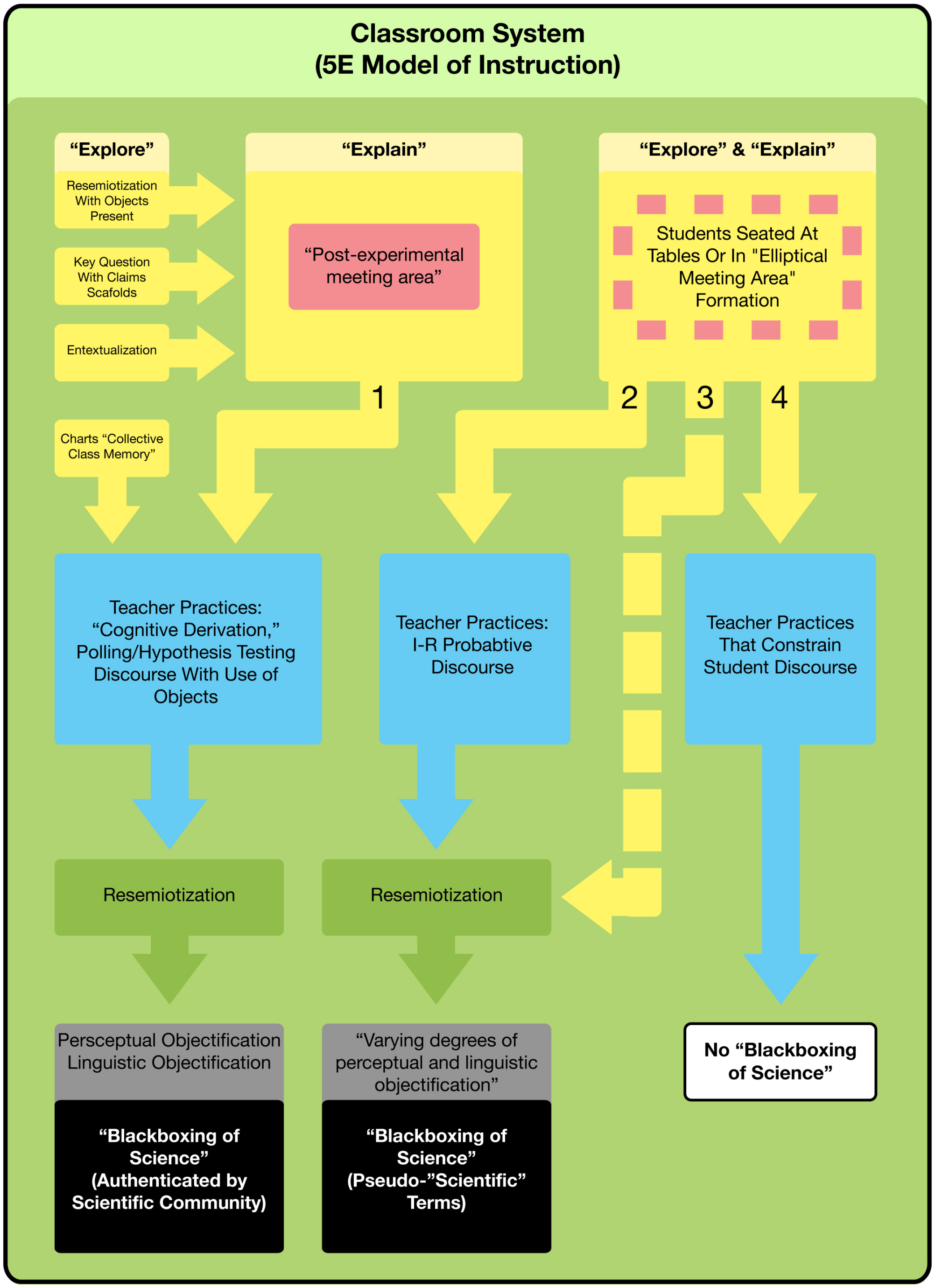



**Figure 6.2: Four Pathways to Scientific Knowledge in Inquiry-based Settings**

This model proposes an answer to my overarching research question of: What factors promote inquiry-based instruction in middle school science classrooms? Elements from the "classroom systems" domain are illustrated in yellow; elements from "teacher practices" are depicted in blue; and elements from "classroom structures" are in red. I present the model early in the chapter as a visual heuristic for the reader, without a complete explanation for the pathways. Instead, throughout this chapter, as each lesson is analyzed across the three dimensions, I will refer back to the model and explain its derivation from the analyses. While most of the model is unpacked in this chapter, some aspects, such as opportunities for resemiotization, will be explained in Chapter 7, where the model is revisited.

### *Structure of the Chapter*

In order to follow the intricate analysis of student talk presented in Chapter 7, it is necessary to first provide, in this chapter, a rich description of each classroom across the three aforementioned dimensions, followed by a detailed, more refined analysis of how these dimensions influenced talk in the six lessons selected from the data collection period.

#### *Components Across the Data Collection Period*

Therefore, I begin this chapter by first describing components in each of the three domains that were consistently used in Dave and Carla's classrooms throughout the entire data collection period. I do so in order to provide a holistic view into the practices that occurred in each classroom. These descriptions are informed by video data, as well as field notes compiled during the three months spent in each of the classrooms.

*Analyses of the Six Lessons*

After a holistic description of each classroom over the entire course of the data collection period, I present a detailed analysis of the six lessons in the areas of "teacher practice," "classroom systems," and "physical environment." It is in these analyses that we see the presence or absence of factors across the three dimensions which either enabled or constrained opportunities for students to engage in argumentation. For instance, one example of a "factor" from the dimension of "teacher practices," is the use of a particular discourse style. In each lesson, the factors identified within the three dimensions are analyzed for how they either enabled or constrained the level of argumentation students were able to achieve.

I also use the model in Figure 6.2 to explicate each lesson. The four pathways summarize the ways in which factors from the three domains converged and sedimented into varying degrees of "black-boxed" science learning. This model illustrates the manner in which students' were able to use various tools and draw upon systems to unpack science, process it, and re-create it again as "black-boxed" science in a new form. In many ways, the analysis that went into this chapter, and the writing of this chapter also followed the thinking behind this model, wherein I used many types of modalities and representations to capture and document the act of student learning. I, too, attempted to unpack the processes by which students approached black-boxed science and made it "messy" in order to ultimately reclaim it in the form of this model (Figure 6.2)

While it is possible to separate the three dimensions in text for analytical purposes, in practice these domains mutually influence one another. A specific factor affecting argumentation might be said to "belong" to one, two, or even three of the domains used in this analysis. For example, the use of "charting" can be considered an artifact of the physical environment, but also a participant of sorts, in a classroom system of communication. When such examples arise, they are noted and addressed. Additionally, it is important to emphasize that the different domains inform and enhance one another in some cases. In other cases, elements from a single domain negatively affect factors from another domain. For example, a particular teacher practice might have a negative impact on student discourse, even though it occurs within the context of a classroom system that normally enhances opportunities for student discourse. When such instances occur, they are clearly stated and explicated.

It was not a focus of my work to quantitatively nor qualitatively document which of the domains served as the leading influence in the students' argumentation. However, in some lessons there were pronounced indications that certain of the domains influenced, guided, and/or led the argumentation/discussion more than other domains. When this was evident, it is documented and described qualitatively.

In the sections immediately following, I provide a holistic description of Dave and Carla's classrooms over the entire course of the data collection period. Subsequent sections then provide detailed analyses of the six lessons in the areas of teacher practice, classroom systems, and physical environment.

*Teacher Practices Used Throughout the Data Collection Period*

Table 6.1 below summarizes the teacher practices in Dave and Carla's classrooms that either enabled or constrained student discourse throughout the duration of the data collection period. I have identified six teaching practices in Dave's classroom, and five teacher practices in Carla's classroom. Five of these categories are common to both teachers, though a category may play out differently in one classroom or another. For example, both Dave and Carla used particular affective practices in their teaching. I define affective practices to be those that influence the emotional climate of the classroom, making it either safe or intimidating to take risks during the learning process. The affective practices Dave routinely used were found to enhance student discourse, while in Carla's case they were found to constrain it. In viewing the findings, it is important to note that my analysis of factors constraining discourse is not to be interpreted as a negative view of the teacher in whose classroom these factors exist. I have chosen a certain lens through which to measure classroom discourse. This was not necessarily a priority for both teachers in the study, and should not be held against them as effective teachers. The use of various teaching practices is informed by many factors including classroom management as well as learning goals.

**Table 6.1: Categories of Teacher Practice Routinely Used in Dave and Carla's Classrooms**

| Dave | Carla |
|---|---|
| Affective teacher practices | Affective teacher practices |
| Opportunities provided for perceptual objectification | Opportunities provided for perceptual objectification |
| Opportunities for resemiotization | Opportunities for resemiotization |
| Kinesthetic modeling | Kinesthetic modeling |
| Routine use of "talk moves" | Routine use of I-R-E discourse practice |
| "Cognitive Derivation" (concrete to abstract examples used in teaching) | |

I next describe the categories in Table 6.1 and describe their effects on classroom talk.

*Dave: Discourse Style and Multiple Modalities*

Six practices are identified as consistently used in Dave's classroom. Of the six categories identified in Dave's teaching, three in particular were most prevalent during the entire data collection period. The first was his unique discourse practice, in which he would poll students for their hypotheses about a given scientific scenario; then "try out" the majority student view with objects to recreate the scenario; then, receive revised student input, and again "try out" new student ideas; receive revised input, etc… The second was his theory of teaching students, which he coined "cognitive derivation," and which was instantiated in his actions in the classroom. And the third, was his intentional creation of opportunities for students to use multiple modalities and multiple representations to process information. Each of these practices was found to facilitate student talk. These teacher practices are described in depth in the context of the first three lessons featured in this chapter.

*Carla: Discourse Style, Affective Practices, and Multiple Modalities*

In Carla's classroom, there are three constant teacher practices throughout the data collection period. The first is her reliance on a discourse style discussed earlier in Chapter 2, known as the I-R-E sequence (Cazden, 1986; Mehan, 1979). In this well-documented pattern, the teacher initiates a question, a student answers, and the teacher provides an evaluative word or phrase to end the discourse move. This practice was found to be associated with opportunities for higher-level argumentation to occur in

Carla's classroom. The second constant practice was a strict management style that also hindered students from participating in discussion when issues of management arose. This teacher practice was also found to constrain the amount of talk that was able to occur between and among students in the classroom, even in the absence of management issues. And the final teacher practice commonly occurring in Carla's classroom was the creation of opportunities for students to achieve perceptual objectification. Carla consistently reenacted events students had previously explored at their tables in groups, and allowed for students to achieve a class consensus on what the scientific phenomena they were observing. However, this practice was used without also enacting participation frames which could have facilitated student participation in classroom talk. This will be analyzed in further detail in lesson six.

### *Physical Structures Present throughout the Data Collection Period*

#### *Dave's Three Seating Arrangements: Structure Dictates Function*

Throughout the data collection period, Dave routinely used three types of seating arrangements in order to conduct the 5E lesson model. One of these seating arrangements is the group table formation. Students sit at tables during the exploration portion of the lessons. While in this formation, they are to move, talk, and explore with one another, while the teacher walks around the tables and serves as a guide when needed. In addition, there are two types of "meeting areas" used to seat the students: a "lecture style meeting area" and a "post-experimental meeting area." These seating arrangements define the participation structures in which students are to engage (Erickson & Mohatt, 1977; Philips, 1972, 1976). In "lecture style meeting area," students bring their chairs in row formation on the center carpet and face the front white board. They know that while seated in this manner, they are in "intake" mode and are to listen to the teacher and follow directions. The "post experimental meeting area" occurs at the end of a lesson. Students bring their chairs to the center carpet in a circular formation. Students understand this set up dictates that they all participate in a group discussion. Hence, the rules for participation clearly follow from the manner in which the students are seated; structure dictates function.

Dave's classroom also prominently displays easels, charts, whiteboards, and a document camera- all representational media used very purposely during specific portions of the 5E lesson. The corresponding semiotics encoded on these structures are constructed over time and are pivotal to the overall analysis of the production of classroom discourse. This will be detailed in the first three lesson analyses, which follow. The entire physical environment of Dave's classroom is created over time, intuitively on Dave's part. Interview data suggest that Dave was not aware of this temporal construction of the physical representational media, but that on a subconscious level he has internalized the theoretical basis for sociocultural theory and the underlying notion that social interaction occurs on a daily unpredictable basis, and is mediated by objects, language and sign systems (see Appendix B, lines 1117-1148).

*Carla's Two Seating Arrangements: Group Work Versus Direct Instruction*

Carla also uses two types of seating arrangements in her classroom: group tables and a "meeting area." Unlike in Dave's classroom, there were not clear established "rules" as to what each seating arrangement implied in terms of students' participation.

She referred to a "meeting area" as being a seating arrangement whereby students sat in a loose elliptical arrangement with their chairs facing inward and towards the document camera at the front of the room. This was the default seating arrangement for any type of instruction, mostly direct instruction, other than the times students worked in groups. During group work, students sat at tables of four along the periphery of the classroom exterior walls. Video data reveals that the teacher often used the "meeting area" as a punishment for times students could not handle sitting at their tables and needed more face-to-face interaction with the teacher. Unlike in Dave's class, the meeting area did not appear to signal a change in the function of the discourse, whereby students were signaled that they now controlled the discussion. In fact, the meeting area in Carla's class cued students to face forward towards the document camera and listen for instructions from the teacher. In this way, Carla's meeting area functioned much like Dave's "lecture style meeting area." In this class, structure does not necessarily dictate function.

## *Classroom Systems Used Throughout the Data Collection Period*

### *Dave: 5 E Model, G.E.S.S., and "Entextualization"*

The routines and procedures that existed in Dave's classroom largely consisted of the use of the 5E model; the G.E.S.S. system of solving problems; and the entextualization of the entire day's lesson on the front whiteboard. As students progressed through the stages of the 5E lesson, they were provided with numerous opportunities to work in different modalities, and to create various representations of the science phenomena under study. This assured that any "black-boxed" notion of the material was recreated into alternative forms the students could manipulate and contemplate, before turning them again into new forms of their own version of "black-boxed" science. During these five distinct parts to the lesson, certain information state markers became more prominent, such as gesturalized understandings and other situated acts of interactive participation; each of these contributed to a symphony of multiple modalities and multiple representations at work in constructing ultimate scientific "truth" in the classroom. This 5E model on instruction provided an over-arching structure in which to accomplish this resemiotization. For this reason, in Figure 6.2, the 5E model is represented by the overall rectangular structure in which all four identified pathways for learning are situated.

The G.E.S.S. system is one that Dave uses to solve problems from "the prelude," or the beginning "warm up" of the day. "G" stands for "given, "E" for "equation, "S" for "set-up" and the second "S" for "solve." Students are able to apply this procedural system to warm up problems simply and accurately, and thus begin their day in Dave's class on a successful note. Dave creates daily preludes he expects all students to be able to solve without assistance. He purposefully designs these preludes to exist at a difficulty level slightly lower than that at which he originally taught the information. In this way, students may achieve success at the start of the lesson, and begin engaging with new material on a note of confidence. For example, after already studying the formula speed = distance/time (s=d/t), students were given the following prelude to solve:

| |
|---|
| Prelude: Penguins swim through cold ocean water at 12 meters per second. To migrate a distance of 144,000 meters to their summer nest, how much time do they need to get there? |

**Figure 6.3: Prelude, October 17, 2007, Dave's 5A Class**

Students have learned the rationale behind the formula for speed from a previous lesson. In that lesson, they set up orange construction cones on the asphalt outside of their classroom and ran different distances, timing themselves and calculating speed. With their teacher, they learned to derive the formula for speed. Then, on October 17th, 2007, they were able to begin their lesson by confidently manipulating the formula s=d/t to calculate the answer to the penguin problem. As students do so, Dave can be heard saying: “Don’t want to take a guess? Use G.E.S.S. ,” as he points to a chart at the back of the room that bears the formula students previously derived with their teacher.

The final “system” prevalent in Dave’s classroom is one previously described in Chapter 2 as “entextualization.” Dave encodes the entire sequence of his lessons from the prelude to the “engage” to the “key question of the day,” to the “explore” to the “explain” and “claims questions” needed to scaffold their conclusions. All of this is encoded onto the whiteboards in the classroom. At all times, there is an ongoing narrative on the front whiteboard, “in text,” of what the students are learning in various modalities throughout the day. This process is co-constructed in real time together with the students. By virtue of creating it in real-time, nothing is written until it is first processed via other modalities. Only then is it encoded in written text. The implications of creating text only after this process will be discussed in the conclusion to this chapter.

*Carla: 5E Model and G.E.S.S.*

In Carla’s classroom, both the 5E model, as well as the G.E.S.S. system, are also used. However, there is no “entextualization” of the lesson onto a whiteboard. Additionally, Carla will sometimes change the order of the “Es” in the lesson to meet her goals for a particular day. This will be discussed in the sample video lessons in the following sections.

In Carla's classroom, G.E.S.S. is used as a system that students are familiar with to solve problems, but the prelude with which students begin class is not intentionally created to be at a difficulty level lower than that of the day's lesson, as in Dave's class. Nevertheless, the G.E.S.S. system does provide access to solving the prelude, just as it does in Dave's classroom. The problems Carla uses for the preludes belie her belief in the notion of "staircase" learning, rather than "spiraling." Instead of revisiting previously covered material and looping back up to add on to this learning, Carla believes in presenting challenging preludes to her students. Often, they are problems that require application of past learning to novel situations. These belief systems were discussed previously in Chapter 4 and depicted in Figure 4.2.

### *Summary of Practices and Systems Used Throughout Data Collection Period*

The previous sections exposed common teacher practices, physical structures, and classroom systems present in Dave and Carla's classrooms for the duration of the data collection period. The purpose was to provide an overview of each teacher's classroom praxis. In the sections that follow, I analyze three lessons from Dave's classroom and three from Carla's classroom. I deconstruct the six lessons with an eye to the contributing elements of "teacher practices," "physical environment," and "classroom systems" and examine how these influenced student talk in each classroom.

*Six Lessons – An In Depth Look at the Confluence of Teacher Practice, Physical Environment, and Classroom Norms*

The purpose of the next sections is to describe the confluence of the three domains in each of the six lessons, and to illustrate how each contributes to opportunities for student discourse and to the ultimate notion of an inquiry-based science classroom. I begin with a brief description of the context for each lesson, followed by a detailed account of the how each dimension played out in the lesson, and how each affected student discourse and scientific understanding, as evidenced through articulated argumentation. I end by labeling each lesson as illustrative of either pathway one, two, three, of four of those delineated in the model presented in Figure 6.2.

This chapter does not look closely at levels of argumentation, but rather at the presence or absence of discourse in general. Clips of the highest argumentation levels achieved from each of the six lessons are described and analyzed in detail in Chapter 7, for the purpose of documenting *how* students arrived at their final understandings.

*Lesson 1 – Gravity and Motion Claims, Discourse Led by Factors in "Teacher Practice" Domain*

Lesson one is a 5E lesson on gravity and motion. The key question of the day was: "What type of force is gravity and how does it affect motion?" Students completed a series of activities during the "explore" portion of the lesson (see Figure 6.4 below). They then discuss their ideas in what the teacher calls "the most important part of our experiment," the "post-experimental meeting area." This is the time during which the teacher embarks on a class discussion of the students' observations (See Appendix G for the entire agenda of the lesson).

DIRECTIONS

Paper clip and Wood Block

1) Hold the paper clip in one hand and the wood block in the other.
2) Drop both objects at the same time.
3) See which one hits the ground first or if they hit at the same time.
4) DRAW both objects falling to the ground.

Shooter Ball

1) Put the ball in the shooter angle it to the side.
2) Shoot the ball and watch the path as it goes towards the ground.
3) DRAW the shooter and the path of the ball with an arrow.

Parachute Man

1) Throw Parachute Man in the air
2) Watch the speed of the man as he moves towards the ground.
3) DRAW the Parachute Man falling to the ground.

**Figure 6.4: "Explore" Directions for Lesson One**

By the closure of this lesson, the class achieved consensus that gravity is a constant force, which speeds things up. This final claim was achieved via the co-construction of input from several students who relied predominantly on watching their teacher re-enact certain portions of the "explore" portion of the lesson. Students used their words, accompanied by gesture to articulate their emerging understandings, and built on fragments of different knowledge states of one another- all conveyed through different modalities. Dave is well aware that his students use one another's emerging understandings to build from, as they progress to closer and closer approximations to the scientific "truth." As he stated in his interview with me: "they really grab onto [one another's] understanding and take it in for themselves, at least for the moment" (Appendix B, lines 597-598). In lesson one, students are able to achieve level four argumentation at three different points in the lesson.

Though the predominant leading influence of this lesson is teacher practice, the physical structures of the classroom, with the use of the “lecture-style meeting area” and the “post-experimental meeting area,” also played into the students’ achievement of quality argumentation. Together, these two dimensions enabled the high quality of argumentation in this first lesson. Below, I detail the contributions of each of the domains of teacher practices, physical environment, and classroom systems at work in this lesson. In Chapter 7, I will thoroughly account for what modalities specifically enabled the level four argumentation to occur.

*Teacher Practices in Lesson One*

As explained in Chapter 3, teacher practices constitute observable practices emanating directly from the teacher. Of the three dimensions, teacher practices were most influential of student discourse in this lesson. They include Dave’s discourse style with his students and his preferred modes of modeling- through the use of the body, manipulatives, diagrams, and charts. These practices represent his beliefs about how children learn, as instantiated in practice (see Appendix B).

<u>Discourse Style</u>

Figure 6.5 below shows Dave engaged in a particular pedagogical approach to discussion with his students in the post-experimental meeting area after a lesson on gravity.

**Figure 6.5: "Cognitive Derivation" at Work**

In my fieldwork interactions, once the students had gone home for the day, I often had a chance to casually talk with Dave about his teaching practice. As documented in field notes, Dave described one of the mainstays of his practice as embedded in a theory of learning he has coined "cognitive derivation." According to this idea, Dave believes it to be his responsibility to create opportunities for his students to step into the science from their own worlds, such that they are able to navigate through the scientific phenomena by observing and perceiving, then deriving relationships in science "*on their own*," but also through the developmental process of "co-construction *with the class*." He defines this as the practice of intentionally beginning with the novice ideas his students bring with them from their own worlds. He attempts to evoke these ideas via pop-culture videos such as Harry Potter or online video clips from you-tube. He then intentionally interweaves these ideas with increasingly more sophisticated scientific ideas and language (see Figures 4.2 in Chapter 4).

For example, early on in the data collection period, I watched Dave introduce a lesson on the concept of calculating speed by asking his students to watch a movie clip from a scene in Harry Potter. In the scene, "Harry" and his friends are playing a game of "quidditch" in which they compete on flying broomsticks to catch a small golden ball, the "snitch." Dave begins with a simple request. He asks the students to record observations of what they currently understand to be instances of "motion" and "speed" from the movie clip. This request reflects Dave's belief in his students as learners who bring a wealth of "spontaneous" or "everyday" concepts with them to the science classroom. These concepts are grounded in concrete experiences that can be built upon over time. Interview data with Dave reveal his belief in the ability of students to become increasingly more abstract in their thinking over time (Appendix B, lines 286-293). This belief is instantiated in many instances throughout the data collection period.

Part of the process of "cognitive derivation," as seen in practice, necessitates that the teacher orchestrate the interaction between himself, the students, the objects in his hands, and the media around the classroom used to record ongoing learning (whiteboards, easels, etc…). The focus of the lens we use to view these interactions, in this case, dictates whether these interactions are attributed to "teacher practice" or "physical environment." In the Harry Potter lesson, Dave is seen to co-construct knowledge with his students over diagrams, notes, the incorporation of "story," references to "magic" with the use of a "mystical formula," and multiple references to the "magic hand" that covers parts of an equation on the whiteboard to highlight variables pertinent to the problem-solving task at hand. The "magical" scene from Harry Potter provides a context for the students in which to embed the idea of solving speed problems with distance and time, as a "magical" process of formula manipulation (s= d/t).

Cognitive Derivation and "Talk Moves"

The transcript that follows documents Dave's unique style of polling his students during lesson one. It is comprised of a consistent pattern of "talk moves," summarized in Figure 6.6 below.

| Discourse Steps by Teacher |
|---|
| 1. Polls students on original question.<br>2. Re-enacts original task in presence of students to achieve perceptual objectification.<br>3. Receives revised student(s) input.<br>4. Restates student claims ("revoicing move").<br>5. Teacher tries out a new student idea (steps 3-5 are often repetitive)<br>6. Consensus is achieved and cemented into academic language (linguistic objectification). |

**Figure 6.6: Dave's Unique Discourse Steps**

As students sit in the circular "post-experimental meeting area," Dave first polls the students regarding observations from their table groups. He then "tests" students' ideas, by re-enacting the original tasks students were given to complete during the "explore" portion of the lesson. He uses the same objects the students used, in order to achieve consensus on the facts of what they all witnessed. Once perceptual objectification is attained, Dave next seeks to address the science behind what the students observe. He asks for student input and verbally repeats what they claim to be true. Then, he tests their claims again, by reenacting the activities in front of the students; and finally, he takes additional student input to accommodate developing student hypotheses. This is an iterative process of progressive understanding that continues until class consensus is achieved. In a sense, the objects Dave uses serve as "material anchors" (as discussed in

Chapter 2) for the conceptual phenomenon they are investigating. Figure 6.7 illustrates this iterative process with the text and accompanying actions used by the teacher and students in an excerpt from lesson one.

| **Transcript** | **Commentary on complimentary co-occurring actions in the classroom** |
|---|---|
| T: So, the first thing we did is we had the wood block and we had the paperclip. | Teacher picks up the same objects students used in the "explore" session: a wood block and a paperclip. |
| T: Alright, how many people felt like the wood block hit the ground before the paperclip? | **Teacher is polling the students.** Two students raise their hands. |
| How many people felt like the paperclip hit the ground before the wood block? | Two students raise their hands. |
| How many people felt the two of them hit at the same time? | |
| Really? | Most all others raise their hands. |
| S: Isaac Newton says they do. | |
| T: Okay. Well, let's test it out. Alright, so I've got the paperclip, I've got the wood block, I let them go – | |
| | Teacher drops the paperclip and wood block. |
| S: See, so I'm right. | |
| T: Okay, did they hit at the same time? | |
| S (a few students): No. | |
| S (some others): Yes. | |

**Figure 6.7: Discourse Pattern with Co-occurring Actions**

| | |
|---|---|
| T: Okay, which one is heavier?<br><br>S (most): The wood block.<br><br>T: Then why isn't the wood block falling faster than the paperclip?<br><br>S: They're falling at the same rate.<br><br>S: That one has a surface, makes it when it's going down it's like holding it a little and the paperclip, since it's, like –<br><br>S: has holes-<br><br>S: Yeah yeah, it goes right down. [uses gesture to accompany his words]<br><br>T: But you didn't say this one went faster. You said they hit at the same time.<br><br>S: That's why. So the bigger one maybe goes fast, but since that one's smaller, it's going at the same time [uses gesture to accompany his speech].<br><br>T: So you're saying that this one's got a big surface, so the wind's pushing against it, but it overcomes that because it's heavy? And this one doesn't have much surface, but it's light, so they travel at the same speed?<br><br>S: So that one's big and the air is holding it back and that one's small and the air isn't holding it back so they level up and they fall at the same time [uses gesture to accompany his thoughts]<br><br>T: Then which one should fall faster - this box is a lot lighter than this and it's got a surface similar to this one? | [Even watching the very same event, students do not agree on their observation of the time in which the wood block and the paper clip hit the ground]. |

**Figure 6.7 continued**

| | |
|---|---|
| S: They'll both fall at the same rate [several students state this]<br><br>T: Well, no, he's saying that the surface with the wind makes a difference, so let's try it out.<br><br>S: I think 'cause it's smaller, the wood is smaller, and they're like the same as that one, the the... (doesn't finish sentence).<br><br>T: Okay, well let's try, uh - these are about the same - not really too much wind is going to get these two, alright? | Teacher drops the box and wood block. A student points at objects the teacher is holding. Teacher drops objects. |

**Figure 6.7 continued**

In this excerpt, we see the teacher engaging the students in the development of an understanding that two objects will fall at the same time despite their sizes, unless a frictional force is present. The first "talk move" in Dave's discourse style involves polling his students using the original materials the students used to explore various scientific phenomena at their tables in groups (see Figure 6.8).

**Figure 6.8: Dave Polls Class: "How many people…?"**

He begins with the wood block and paperclip, holding them up in the air. He then raises his own hand as a cue, and asks "how many people felt like the wood block hit the ground before the paperclip?" Two students raise their hands. He then asks how many thought the paperclip hit first, with one response, and finally asks how many thought they hit at the same time, to which a majority of hands go up. This is the polling portion of his deliberate discourse strategy.

| Discourse Steps by Teacher |
| --- |
| 1. Polls students on original question. |

**Figure 6.9: Discourse Step 1**

Next, Dave repeats the original task the students performed at their tables, using the same materials they had. "Alright, so I've got the paperclip, I've got the wood block, I let them go…" In this way, all students become witness to the same materialization of the scientific phenomenon without the added variables of such conditions such as the height from which the objects were dropped, the timing of the drop, etc… Theoretically, this time around, all students are witness to the same perceptual reality and can objectify it in the same manner. Establishing perceptual objectification enables Dave to achieve class consensus on the "reality" before them. This becomes the second deliberate step in Dave's pedagogical discourse pattern.

| Discourse Steps by Teacher |
| --- |
| 1. Polls students on original question.<br>2. Re-enacts original task in presence of students to achieve perceptual objectification. |

**Figure 6.10: Discourse Steps 1-2**

**Figure 6.11: Teacher Re-enactment of "Explore" Scenario**

Dave's third step involves considering various students' input. He proceeds by asking clarifying questions to further the students' thinking. He then restates what he believes are their new ideas, sometimes synthesizing their partial sentences with their gestures and deictic pointing at charts and other representations in the classroom. He uses the discourse marker "so you're saying…" to begin these restatements of student ideas. For instance, in the above example, he asks: "So you're saying that this one's got a big surface, so the wind's pushing against it, but it overcomes that because it's heavy?" In this one question, Dave fuses several students partially articulated sentences with other student's gestures to arrive at his rendition of their idea. In the literature on classroom discourse, this is often referred to as a "revoicing" move (Michaels, 2008). This brings us to steps three and four of the discourse sequence, where Dave receives revised student input and then restates the students' claims for clarification purposes:

| Discourse Steps by Teacher |
| --- |
| 1. Polls students on original question.<br>2. Re-enacts original task in presence of students to achieve perceptual objectification.<br>3. Receives revised student(s) input.<br>4. Restates student claims ("revoicing move"). |

**Figure 6.12: Discourse Steps 1-4**

Finally, the teacher tries out a new situation the students claim should work if their evolving ideas are correct. Dave often seeks out antithetical viewpoints from among the students in order make the "correct" position become clearer. Here, Dave says: "Well, no, he's saying that the surface with the wind makes a difference, so let's try it out." This completes the discourse pattern that then continues in a repetitive cyclical process from steps three through five until the more capable peer (Vygotsky, 1978), often the teacher, leads the students to consensus around ideas congruent with those already established by the scientific community at large (step six).

| Discourse Steps by Teacher |
|---|
| 1. Polls students on original question.<br>2. Re-enacts original task in presence of students to achieve perceptual objectification.<br>3. Receives revised student(s) input.<br>4. Restates student claims ("revoicing move").<br>5. Teacher tries out a new student idea (steps 3-5 are often repetitive)<br>6. Consensus is achieved and cemented into academic language (linguistic objectification). |

**Figure 6.13: Discourse Steps 1-6**

<u>Summary and Discussion of Teacher Practices in Lesson One</u>

Dave's discourse pattern is the predominant factor influencing student argumentation in lesson one. The design of this calculated discourse style is embedded in his self-proclaimed theory of "cognitive derivation." This theory, in fact, is a version of Bruner's (1967) ideas in microgenesis, wherein we find the recapitulation of learning that repeatedly takes place in the life-span of human beings in social situations. According to Bruner, the development of cognition proceeds through the life course from infancy to adolescence, from the sensori-motor through the concrete and to the symbolic (Bruner, 1967). These ideas direct the pattern of "talk moves" Dave uses in his classroom in order to lead his students from the concrete objects they use to explore science learning, through to the abstract scientific ideas that have already been black-boxed by scientists into neatly packaged facts. In this case, Dave's students are able to articulate the notion that gravity is a constant force that speeds things up. The use of this deliberate discourse pattern occurs repeatedly throughout the discussions that take place in Dave's "post-experimental meeting areas." This is but one example.

Notably, Dave does not use the well-documented I-R-E turn-taking format. This latter sequence, often characterized as "recitation" has been found to be the dominant, or at least the default, pattern of discourse in classrooms (Michaels, 2008). This pattern has been shown to work well to review prior learning, and to assess prior knowledge, but it does not work well to support complex reasoning, to elicit claims with evidence, to express a novel point, and/or to get students to justify or debate a position (Michaels, 2008). As discussed in Chapter 2, six classroom talk moves have been identified as productive in helping students to clarify their ideas and to expand their reasoning and arguments. These six are revisited in Figure 6.14 below:

| Talk Move | Example |
|---|---|
| Revoicing | "So let me see if I've got your thinking right. You're saying __________?" (with space for student to follow up) |
| Asking students to restate someone else's reasoning | "Can you repeat what he just said in your own words? |
| Asking students to apply their own reasoning to someone else's reasoning | "Do you agree or disagree and why?" |
| Prompting students for further participation | "Would someone like to add on?" |
| Asking students to explicate their reasoning | "Why do you think that?" or "What evidence helped you arrive at that answer?" or "Say more about that." |
| Using wait time | "Take your time…We'll wait." |

**Figure 6.14. Six Productive Classroom Talk Moves (Michaels et al., 2008)**

Over the period of data collection, evidence of all six of these documented "talk moves" are present in Dave's interaction with his students. In lesson one, revoicing is the predominant "talk move" that enables Dave to continue the hypothetico-deductive reasoning with his students via the continuous reenactment of *their* developing ideas with objects. In chapter 7 we will see how this revoicing move leads to spaces for resemiotization through multiple modalities leading, in turn, to high levels of argumentation.

*Physical Structures/Environment in Lesson One*

As discussed earlier, the use of physical structures in Dave's classroom includes the intentional use of three different seating arrangements that dictate what type of interaction will occur among all classroom members. Once again, these are: a "lecture-style meeting area," where students sit close together in rows; a "post-experimental meeting area," where students sit in a circle with the teacher and an easel; and tables located along the perimeter of the classroom, where students work in small groups. This dimension of "structures" together with "teacher practices" enables the discourse that occurs in lesson one.

Aside from the seating arrangements, the category of "physical structures" also includes a variety of representational media around the classroom, which both the teacher and students manipulate during the process of resemiotization – or, the progressive re-representation of meaning through different sign systems. These representational media encompass a wide range of precisely located easels, whiteboards, charts, and LCD and overhead projectors, used to record and offload knowledge in various stages of development during the process of inquiry. Figure 6.15 below illustrates the structures in Dave's classroom as they might appear at the time of the "post-experimental meeting" area in lesson one.

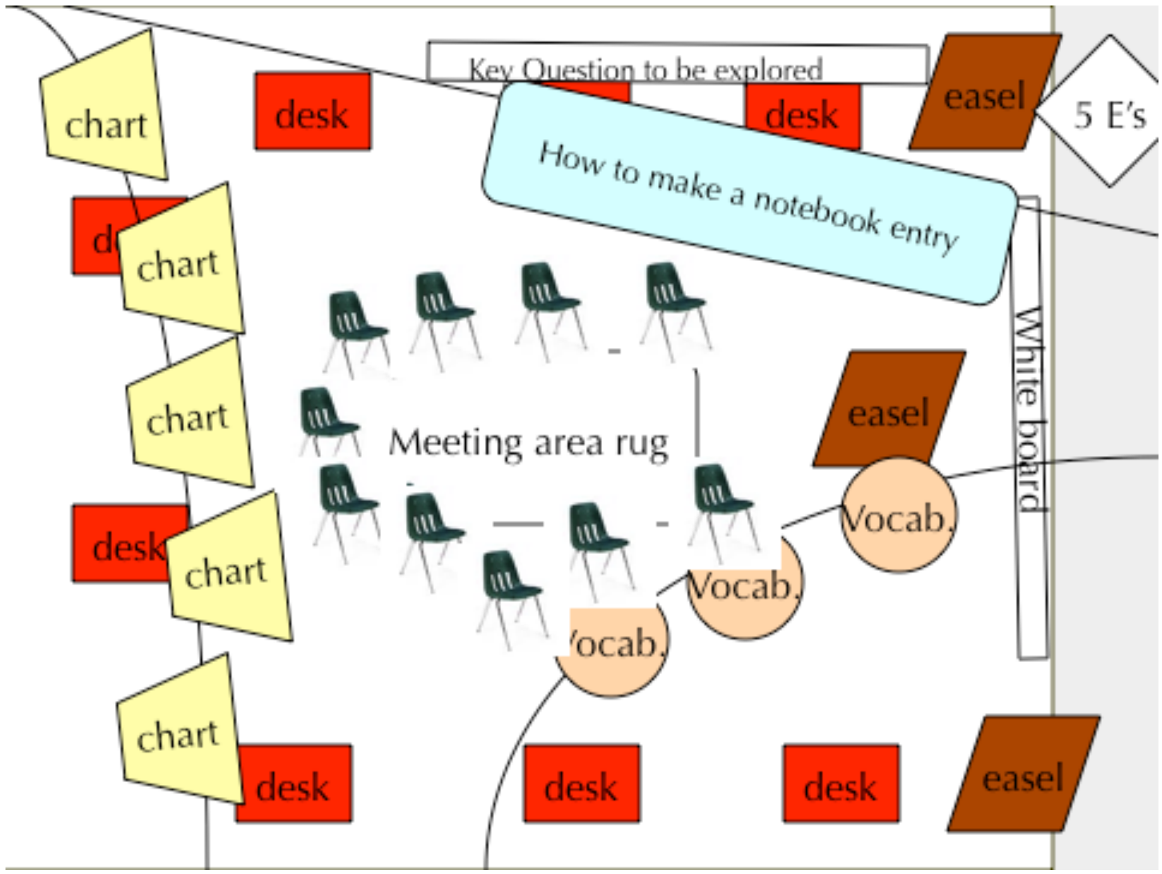



**Figure 6.15: The Physical Structure of Dave's Classroom**

Just as there often exists a match between structure and function in biology, there is a purposeful planning of function and structure in the set-up of Dave's classroom. The structure as depicted in Figure 6.15 above has been co-constructed by the students and the teacher over an extended period of time. At the far right of the illustration is a triangular symbol representing the 5E agenda that is daily written on the white board at the front of the classroom (see Figure 6.16 below).

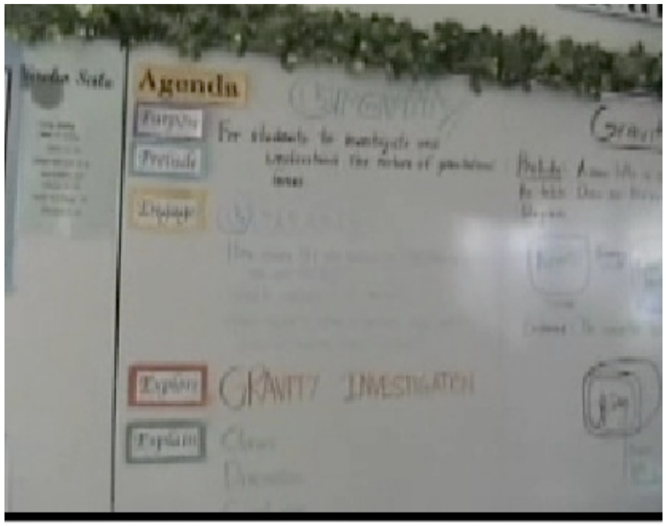



**Figure 6.16: Agenda with 5E Model**

This agenda sets the stage for the day, and assures that students rotate through the appropriate steps necessary, to consider new material in a pedagogically sound manner (Bybee, 1997). Two easels flank the sides of the front whiteboard where Dave writes the “prelude,” or warm-up of the day. The word “prelude” is used to liken the entire lesson to an orchestra event, which is fitting for this teacher, given the fact that much of what he accomplishes with his students in the classroom is seemingly “orchestrated” through purposeful discourse patterns, as discussed in the previous section of “teacher practices.” A conductor of sorts, Dave elicits partial sentences from students, and blends these with other students’ gestures, adding to the mix the deictic pointing of others, to makes things explicit. He then bestows upon this blending of partial understanding scientific names, and then checks for understanding. Dave usually has a student work the prelude on the front whiteboard and another student model the process of taking notes on the entire lesson at the side as shown in Figure 6.17 below.

**Figure 6.17: Student Modeling Notes on Overhead**

In my interview with him, Dave indicated that he chose a different student every day to do this modeling to build self-confidence; students rotate through the process of serving as the class role model. During the prelude and "engage" portions of the lesson, students are seated in what Dave calls the "lecture style meeting area," as seen above (Figure 6.17).

| Seating Arrangement |
| --- |
| 1. "Lecture style meeting" area – students seated in rows facing front. |

**Figure 6.18: Seating Arrangement 1**

Students are seated in chairs facing the front whiteboard and understand that when they are in this arrangement they are either reviewing previous information or receiving instructions for what they are about to explore on their own. Answers to the prelude and comments about the "engage" portions of the lesson are written by Dave on the front whiteboard, such that a narrative of the events of the day are left encoded in written text (Figure 6.19 below). This begins the "entextualization" process described earlier as a common system used in Dave's lessons.

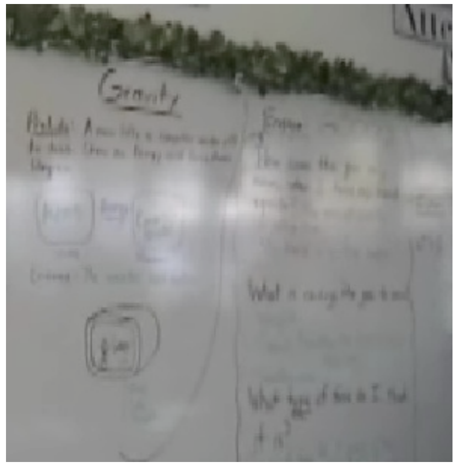


**Figure 6.19: Prelude and "Engage" as Narrative on Front Whiteboard**

On the adjacent wall to the front whiteboard is another whiteboard where Dave daily writes the "Key Question of the Day" (see Figure 6.20 below).

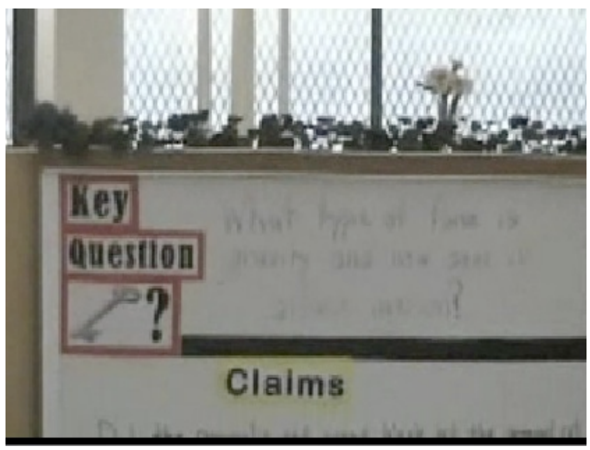



**Figure 6.20: Key Question of the Day**

This question is a frame for the entire lesson. It is the first idea students are presented with after the prelude, and after they are presented with some sort of intriguing idea during the "engage" portion of the lesson. During the "engage," Dave often initiates what is described in the literature as "position-driven discussions" (Michaels et al., 2008). Students are presented with a demonstration poised to run after students exchange predictions, arguments, and evidence about what they anticipate will occur. In such discussions, the students are usually forced to choose from two or three different but reasonable answers. Position-driven discussions are designed to push for divergence in predictions and theories, and capitalize on the everyday knowledge inherent in the group (Michaels et al., 2008). Such discussions are a powerful form of "shared inquiry," that mirrors the discourse and discipline of scientific investigation. Although it promotes talk, in Dave's classroom it signifies an introduction to the topic of the day. Generated talk usually consists of claims or observations, without evidence to back them. The physical structure of seating arrangement during the "explore" also directs this discourse as one that is still very teacher-directed and "position-driven."

In Figures 6.21 and 6.22 below, Dave is giving instructions about the "explore" portion of the lesson. Students have the identical instructions on a piece of paper they will later glue into their science notebooks.

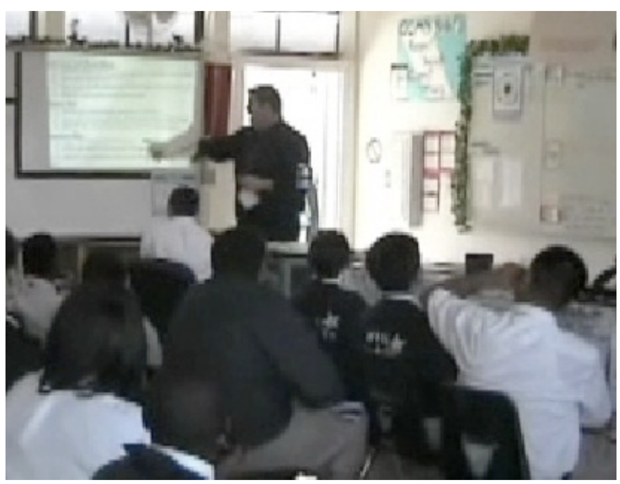


**Figure 6.21: Students in "Lecture-style Meeting Area" while Dave Points at Directions on Overhead**

During this time, Dave reviews what students are to do at their desks in groups. He shows the students the materials they will be using and models key parts that might present a challenge to the students (Figure 6.22).

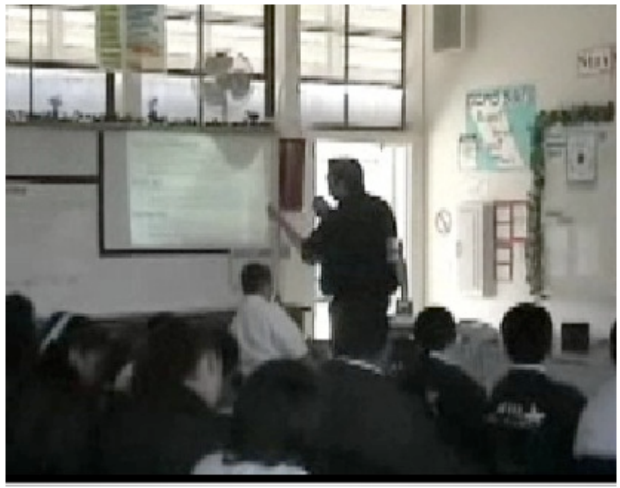


**Figure 6.22: Dave Modeling Use of Objects**

Students then proceed with the "explore" section of the lesson as seen in Figure 6.23 below.

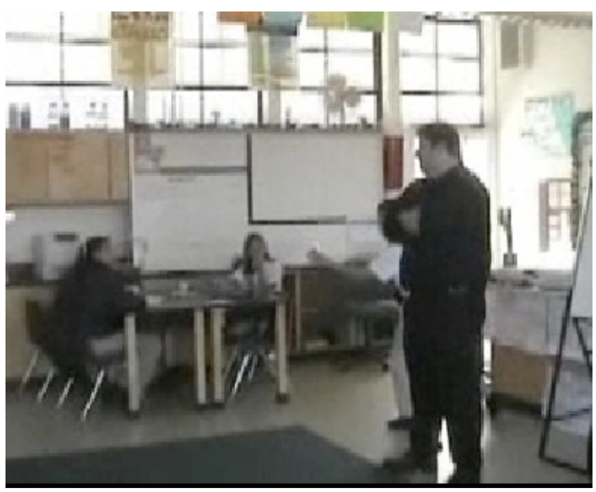


**Figure 6.23: "Explore" Seating Arrangement**

| Seating Arrangement |
| --- |
| 1. "Lecture style meeting" area – students seated in rows facing front. |
| 2. Group work at desks for "explore." |

**Figure 6.24: Seating Arrangements 1 and 2**

After students have had a chance to complete their tasks at their tables, Dave transitions the seating arrangement for a third time. Students are asked to come and form a circle with their chairs at the center meeting area rug (see Figure 6.26), which constitutes the "post-experimental meeting area."

| Seating Arrangement |
| --- |
| 1. "Lecture style meeting" area – students seated in rows facing front. |
| 2. Group work at desks for "explore" |
| 3. "Post-experimental meeting area" |

**Figure 6.25: Seating Arrangements 1, 2, and 3**

Students know that when they sit in this formation they are to share as equals. Again, structure dictates function. Front facing chairs means listen; tables mean work in groups; and circle means share. Sharing denotes articulating claims and backing those claims with evidence. It is a very different expectation than the "position-driven" talk generated during the initial "engage" portion of the lesson.

As explained earlier, Dave considers time spent in the "post-experimental meeting area" to be "the most important part of the lesson." He is deliberate about making this explicit to his students.

**Figure 6.26: Students in “Post-experimental Meeting Area”**

It is at this point that Dave calls students’ attention again to the “key question of the day.” In Figure 6.26, he points to the whiteboard where the key question is written. He then draws their attention to the section on the whiteboard marked “CLAIMS,” just below the key question. Here, Dave has written questions the students are to silently and individually work on answering in the circle, before the discussion begins (see Figure 6.27). These serve as scaffolds for the ensuing discussion.

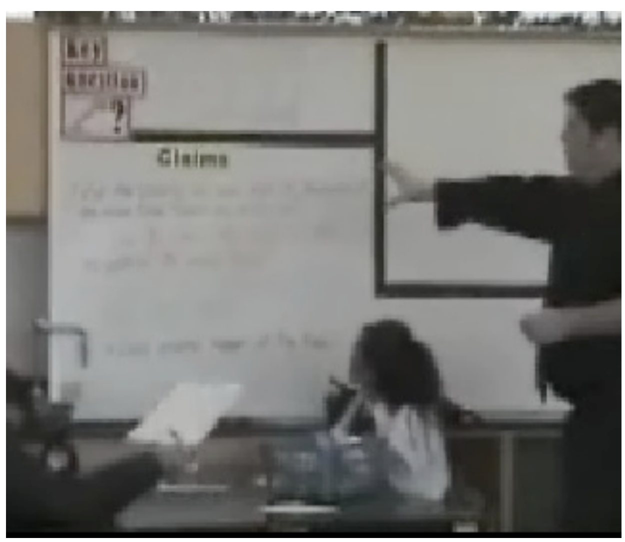



**Figure 6.27: Dave Introducing “Claims”**

For example, for this particular lesson, the scaffolded questions are:

1) Did the paperclip and wood block hit the ground at the same time+

2) How does the path of the shooter ball differ from the path of the wood block?

3) Why doesn't the parachute man fall like the wood block?

These three questions provide a sieve of sorts for students to sift through the many different types of observations they may have witnessed and recorded at their tables during the exploration phase. These questions scaffold the process by which they learn which observations will be key to answering the final key question of the day: "What type of force is gravity?" Dave consistently provides such questions for each new lesson to guide students in formulating their final claims about the key question. By so doing, he assures that they will be successful in achieving an answer. The questions provide focal points for the students' attention and observations. The first thing they do when they meet in the "post-experimental meeting area" is to individually think about, and record answers to, these questions. Then, Dave walks them through each, one by one. He guides their discussion, rather than controlling it. He listens and watches. Only when the students seem to be going off track or seem satisfied with a "wrong" finding does he put forth a new question, leading them to yet another problem, which they feel compelled to solve. While students are seated in this arrangement, Dave's job is to pose questions that will lead *through* rather than around, any puzzlement or confusion, and ultimately lead to the co-construction of consensus around a scientifically agreed upon fact or law. In my interview with Dave, he was clear that one of his main responsibilities as a teacher is to walk from table to table during the explore process and absorb as much as possible:

“Walking around the tables during the experiments is where you’re going to find out everything” (Appendix B, lines 559-560). In so doing, Dave can determine the knowledge states of each of the students and draw upon those at particularly crucial moments during the whole class discussion. The process by which Dave accomplishes this is documented in Chapter 7.

Another key component of the physical environment in Dave’s classroom are the charts hanging at the back of the classroom. In Figure 6.28, he is asking his students what type of force gravity is. They have given him answers about it speeding things up, but he is challenging them to mark this notion with a more scientific term. He points at the back of the room to remind them that in a previous lesson, they discovered and decided together that constant forces speed things up and instantaneous forces speed up and then slow down.

**Figure 6.28: Dave Pointing to Charts at Back of Room**

They recorded this definition in a chart that has since taken its place with others at the back of the classroom, along a cord reaching from one end of the classroom to the other.

This is the group of charts focus group B students attributed to their ability to recall past learning and use it in novel situations (Figure 6.29).

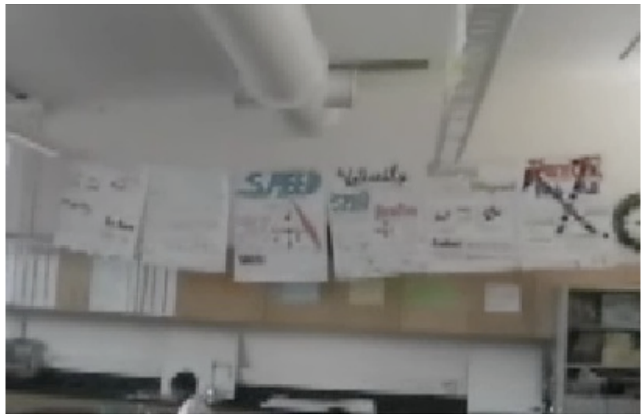


**Figure 6.29: String of Charts ("Collective Class Memory")**

Students look back at the charts to recall what they learned collectively about constant and instantaneous forces (Figures 6.30- 6.32 below). Here, they use this prior knowledge to apply these terms to gravity.

**Figure 6.30: Students Reference Charts at Back of Room**

After recalling that in past lessons they agreed that a force is a push or a pull, they are able to label gravity a "force."


**Figure 6.31: Force chart**

And, again, after their teacher reminds them of the definition of a constant force and an instantaneous force, the students are able to label gravity as a constant force.

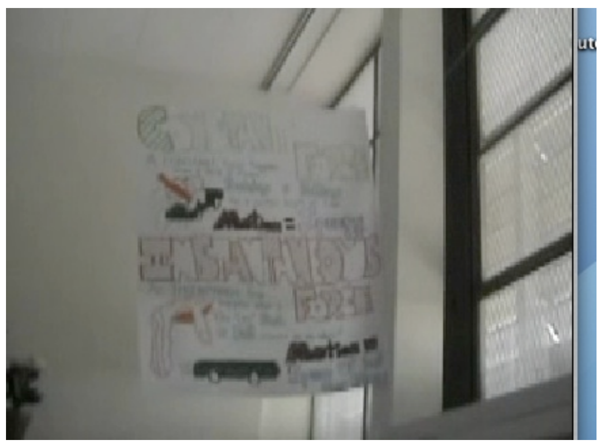


**Figure 6.32: Constant Force/Instantaneous Force Chart**

Much of their success lay in the fact that there exists a purposeful classroom arrangement where previous collective learning is sedimented into charts that students are able reference in application to new scenarios. The detailed account of how students arrive at high levels of argumentation lies specifically in instances of resemiotization, which is described in Chapter 7.

Summary and Discussion of Physical Structures in Lesson One

**Structure: Determinant of Discourse Practices**

***The "Post-experimental Meeting Area: Crucible of Discourse "Talk Moves".***

The previous section provided a rich description of Dave's physical classroom environment. The features of this environment set the stage for structure to dictate function in terms of the type of discourse expected from the students. Dave is able to engage the students in different talk formats, each of which has a particular norm for participation and turn-taking. For example, during the "lecture style meeting area," the rowed-seating formation conveys the expectation that students are either: completing a warm-up (the "prelude" of the day); receiving instruction from the teacher; or formulating a position about a demonstration, designed to reveal their prior knowledge. The rows signify that students are in preparatory mode to "receive" necessary information. Their discourse is limited to articulating what they think they know, or to answering questions revealing their understanding about instructions for the "explore" session that follows. In contrast, the "post-experimental meeting area" structure dictates the expectation that students share their emerging understandings by articulating claims backed by newly collected evidence. This structure allows for a deeper engagement with the content by creating participation frames for students that require specific reasoning between what Dave considers "equals." The post-experimental meeting area is a critical component; it is the crucible in which Dave is able to maximize his unique discourse style described earlier. Within this structure, the participation norm of equal sharing has clearly been established. As well, this circular seating arena also provides a clear visual for the reenactment of activity crucial to Dave's discourse pattern.

**Structure Provides Cognitive Web of Distributed Learning.** Throughout the data collection period, Dave's communication with his students existed in various stages of mediation across a larger cognitive web encompassing his hands, arms, body, objects, white boards, easels, and chart paper. Charts were often pre-prepared with sentences and definition prompts, and sometimes left blank purposefully, to allow for the mutually constitutive interactions of the students with one another and with their teacher.

In lesson one, we see a definitive example of how the classroom environment provides a cognitive web of distributed learning for all. As they use deictic and iconic gestures to argue in the meeting area, cognitive thinking is manifest through the physical bodies of the students and their teacher. But, it is also clear that cognitive activity takes place in the context of relevant tasks that also involve constituents from the environment itself. The amalgamation of charts, at the back of the classroom, provide an ongoing resource for the students. In this way, the environment itself is used to help do the work of cognition. Per the students' own sentiments (Appendix F, lines 261-262 and 280-281), these charts represent the collective class memory of terms and definitions learned over time. They also become anthropomorphized into actual participants, as Dave structures interactive communication fields between the artifacts and students in his classroom. The ongoing dynamics of social interaction allow for the sedimentation of learning into artifacts and other representations of the physical classroom environment. The continuous reuse and reshaping of learning from these semiotics and artifacts allows for the transfer of knowledge into new frames of application, meaning, and analysis.

We can better understand these ideas by drawing upon Wilson's (2002) view of embodied cognition. Wilson argues that the environment can be exploited to reduce cognitive workload. Human beings can make the environment manipulate and hold information until needed at a certain appropriate time in the future. As discussed earlier in Chapter 2, she identifies encyclopedias, computer files, and appointment calendars as examples of how this "cognitive off-loading" proves fruitful in the work we do in the world. Applying this to the secondary science classroom, it is clear that were this strategy not exploited by the teacher, inquiry science teaching itself would not be possible. Much of science is explored and discovered only through careful observation and trial and error. If scientists were deprived of material to record data, scientific processing would be severely impaired; it would remain at the mercy of the limitations of human attention and memory span. Much of what Dave accomplishes with his students is made possible by the strategic utilization of pre-prepared chart paper, pre-planned manipulatives, pre-planned questions, and pre-planned demonstrations designed to provoke disequilibrium in his students. This is definitive exploitation of the environment at its best.

If Dave's students did not have access to these charts, they would be running online only, to use Wilson's (2002) terms. Wilson (2002) notes that when we are forced to run online under the pressures of real-time, two strategies emerge. The first is to fall apart - not a clever option for a teacher or student. The second is to rely upon "preloaded representations acquired through prior learning" (2002, p. 628), or we make use of cognitive off-loading onto the environment. This is what is at work in Dave's classroom. He uses an easel with chart paper to record the students' emerging and final understandings of the key question of the day for each lesson. These final understandings take the form of definitions, derived formulas, and illustrations. Together, they provide a visual reference for cognitive work that has been "off-loaded" onto the environment.

**Physical Environment Provides Context for Distributed System of Cognition.** The argument for a distributed system of cognition rests on the idea that the forces driving cognitive activity do not reside solely within the individual, but instead are distributed across the individual and the situation as they interact (Wilson, 2002). The corollary, then, is that if one is to study and understand cognition, one must study the situation and the situated cognizer together as a single, unified system. For this reason, it is difficult to analyze the contributions of Dave's discourse without also looking at the contexts in which they occur- that is, without also looking at the physical structures that absorb the "off-loading" of previous learning. The charts and physical seating arrangements are important contributory factors to student argumentation; they make possible the discourse "talk moves." Ultimately, all of these factors work together to reveal a distributed view of cognition that must be studied as a unified system. This is the purpose of the pathways I uncover in Figure 6.2. By examining the system of the classroom as a whole, we can identify features that impact student learning. These ideas will be further examined in the concluding chapter of this study.

### *Classroom Systems in Lesson One*

Just as it is difficult to separate teacher practices from elements in the physical environment, it is difficult to separate the contributions and components of "physical structures" from those of "classroom systems." In practice, many of the elements from each can be said to traverse domains, and be a constituent of two, or even three domains. Additionally, some elements from one domain rely on the contribution from elements from another, to work synergistically in the classroom. In the following section, I describe how the school rules, the use of scaffolded questions, and systems used within the 5E lesson model play into the successes of lesson one. When elements appear to cut across domains, this is acknowledged and discussed.

School-wide Expectations Inform Classroom Culture

At the start of the "post-experimental meeting area" in this lesson, Dave reminds students of school rule number four (Figure 6.33 below), posted in every classroom. It is an incontrovertible call for respect. Of all the school rules, this one in particular is paramount to the success of the work that occurs during the "post-experimental meeting area." At various times during the data collection period, some students would bring objects from the "explore" portion of the lesson to the "post-experimental meeting area." In two cases they became a distraction to the discussion. There was also an instance of disrespect toward a student for a comment made that was perceived and labeled by another student as "dumb." In Dave's classroom, all student comments are critical to the learning. At the beginning of lesson one, Dave reminds all students of the importance of respect, as another student calls out "isn't that a rule?" and Dave leans forward to look at the posted rule on the side cabinets.

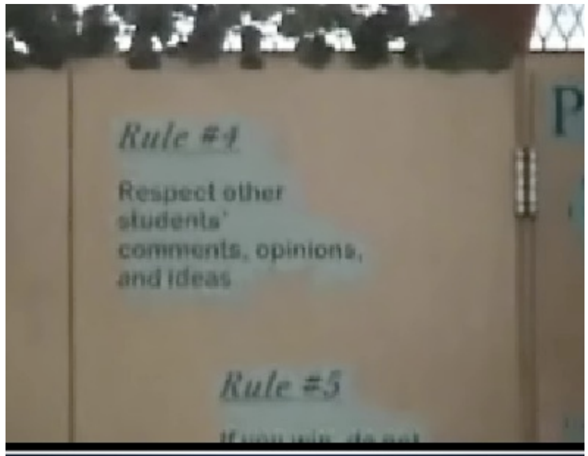



**Figure 6.33: School Rule #4**

This classroom norm enables students to feel safe to take risks, something to which Dave attributes much credence, in terms of affecting student learning in an inquiry model of instruction (Appendix B, lines 659-663).

<u>Scaffolds for Argumentation</u>

A second critical component to the formation of student argumentation is the norm of using scaffolding. In Dave's classroom, scaffolding of argumentation consists in part of designing "claims questions" that chunk the key question of the day into smaller information bites. For example, in lesson one, the "claims questions" are:

1) Did the paperclip and wood block hit the ground at the same time?

2) How does the path of the shooter ball differ from the path of the wood block?

3) Why doesn't the parachute man fall like the wood block?

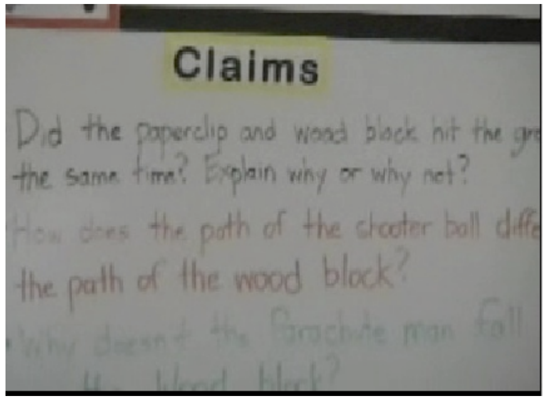



**Figure 6.34: "Claims Questions"**

Once students are seated at the post-experimental meeting area, Dave directs them to work individually on answers to these questions. They use the data recorded in their notebooks as a resource. Their answers to these questions then serve as a starting point for the intricate and deliberate process of Dave's discourse style, described earlier in this chapter under "teacher practices." This idea of using scaffolded questions to arrive at the answer to the key question of the day, falls under both a constant "teacher practice," as well as a familiar "classroom system," relied upon and understood by all students as a routine support to their learning. It is one of the examples where an element that influences argumentation does not neatly fall into one domain or another when enacted in practice.

<u>The 5E Model of Instruction</u>

A final component that falls under "classroom systems" in lesson one, is the 5E model itself. After students have gone through the "engage" and "explore" phases of the lesson, they find themselves in the "explain" portion. It is here where they attempt to collectively answer the key question of the day. In this lesson, Dave brings back the "goo" from the "engage" portion of the lesson, and revisits his original question of why the "goo" doesn't move when held in the palm of his hand, but falls as he turns his hand upside down.

**Figure 6.35: Revisiting "Goo" from "Engage"**

By choosing to bring the lesson full circle to the "engage," students are able to revisit a now "old" scenario with new knowledge.  This is the final step necessary for students to achieve their final answer: that gravity is a constant force that speeds things up.  The "engage" and "explain" sessions in this lesson, bookend the learning.

Summary and Discussion of Lesson One Across All Three Domains: Pathway One

Lesson one is illustrative of pathway one in Figure 6.2.  While it is the teacher practice of a particular discourse style that leads the way to student discourse, many other contributing factors affect the final outcome, such that the black-boxing of science occurs.  In the model, all yellow arrows represent contributions from the domain of "classroom systems;" arrows in red represent the contributions from "physical structures" in the environment; and blue arrows represent the contributions from "teacher practices."

The outcomes of lesson one are facilitated by all three domains. The main "teacher practice" influencing student argumentation is the discourse style of the teacher, located in the blue arrow on the far left of the model. This practice is embedded within a larger context of "physical structures," such as the seating arrangement, which dictates participation norms, and the use of representational media to "off load" and store collective class memory for future use. These are represented in pink and yellow, directly above the blue arrow, and are shown as tributaries to it. Additionally, classroom norms consisting of routinely used "systems" articulate with these latter domains. These include the influence of school-wide cultural norms, the use of routinely used systems for scaffolding the key question of the day, and the use of the 5E model of instruction. These "systems" are depicted in yellow arrows flush left of the model. Together, elements from these domains enable students to arrive at their own "black-boxing" of science in their final claim that "Gravity is a constant force that speeds things up." They are able to arrive at class consensus and to articulate a scientific concept in language paralleled in the discourse of the scientific community at large. This is noted in the far left bottom box, encompassing the text: "Black-boxing of Science, Authenticated by Scientific Community."

*Lesson 2 – Forces and Friction Claims, Discourse Largely Influenced by Factors in Classroom Systems Domain*

Lesson two is a 5E lesson on forces and friction. The key question of the day was: "What type of force is friction, which way does it act, and how does it affect motion?" (See Appendix G for the entire agenda of the lesson). Figure 6.36 outlines the chief activities students explored for this lesson.

DIRECTIONS

WOOD BLOCK

1) Take the wood block an give it an "instantaneous push" across the table.
2) Pay attention to how it moves (motion) across the table.
3) DRAW a picture of the wood block and LABEL the motion you see.

WOOD BLOCK with STICKY NOTES

1) Set up the sticky notes as you see in the diagram to the right
2) Push the wood block across them with the same amount of force as before
3) DRAW a picture of the wood block and the Sticky Notes and LABEL the motion you saw.

WOOD BLOCK with SAND PAPER

1) Set up the sandpaper as you see in the diagram to the right.
2) Push the wood block across the sandpaper with the same amount of force as before.
3) DRAW a picture of the wood block and the sandpaper and LABEL the motion you saw.

**Figure 6.36: "Explore" Directions for Lesson 2**

By the end of this lesson, the class achieves consensus that friction is a constant force that speeds things up. This final claim is achieved via the co-construction of input from several students who rely predominantly on watching their teacher re-enact certain portions of the explore portion of the lesson. As in lesson one, students use their words, accompanied by gesture, to articulate their emerging understandings, and build on fragments of different knowledge states of one another to achieve level four argumentation levels. In addition to the predominant leading influence of teacher practice, the physical arrangement of the classroom with the use of the "post-experimental meeting area" also plays into the students' achievement of quality argumentation. Together, these two dimensions enable the high quality of argumentation in this second example. In the sections below, I detail the contributions across each of the dimensions of "teacher practice," "physical structures," and "classroom systems."

*Teacher Practices in Lesson Two*

This second lesson is again illustrative of teacher practices emanating from Dave's belief in "cognitive derivation." It also features Dave's reenactment of "explore" activities and his use of kinesthetic modeling that enhances the discussion during the "post-experimental meeting area." Some of the practices that are also included in the findings below are difficult to separate from those that might also be considered constituents of "classroom systems," such as Dave's scaffolding of questions from a cartoon on friction. These scaffolds, then, will be detailed under "classroom systems."

<u>Reenactment of "Explore" Activities During "Explain"</u>

An additional routine found in lesson one and replicated in lesson two is the intentional repetition of the "explore" activities by the teacher in the "post-experimental meeting area." This was previously described as one of the steps in Dave's discourse style under lesson one. It is one of the elements that traverses domains, and could be considered either as a component of "teacher practices" or as an element of a normative "classroom system" that is routinely used.

Though students are not barred from bringing their objects from the "explore" with them to the meeting area, and though Dave does not collect them systematically prior to the "post-experimental meeting area," the reality is that few students bring the objects with them to the discussion format. In fact, in this lesson, only three students did so. This is interesting in light of the fact that in focus group interview data, the students in Dave's class place enormous importance on the presence of the objects during the "post-experimental meeting area" discussion. I attribute this to the routine Dave evokes nearly every lesson in which he re-enacts the activities students have just finished at their explore tables. Dave explains: "Everyone sees different things." He realizes as he walks around during the explore session that one group might perceive that their wood block moves more slowly across a set of sticky notes (see Figure 6.41) than across the table alone, while another group perceives that their wood block moves more smoothly and more quickly across the set of sticky notes. Because of this, Dave almost always re-enacts the activities in front of the whole group during the "post-experimental meeting area." By so doing, he assists the class in achieving perceptual objectification before moving on to the task of linguistic objectification. Students must first agree that they are attuning to the same perceptual phenomenon. Only then, can they think through and begin the process, through partial phrases and deictic and iconic pointing, of representing in language what they are seeing and why. The use of this practice belies Dave's belief that, while science is the pursuit of "truth," our senses don't always reveal this truth to us in the same manner. Hence, we have the need to objectify through language and semiotics what our truths are.

<u>Cognitive Derivation</u>

As in lesson one, Dave once again draws upon his notion of "cognitive derivation," where he attempts to create a situation that will initially engage his students with the science to be learned in their own worlds. In lesson one, I tied Dave's theory to his use of a very deliberate type of discourse sequence. In this lesson, I tie his theory to his choice of introduction to the concept of friction. To accomplish this, Dave presents a cartoon about friction from the popular "Magic School Bus" book and video series. The cartoon is shown on a television in front of the room while the students are seated in the "lecture style meeting area."

**Figure 6.37: "Cognitive Derivation": Friction Cartoon**

The presentation of a fictional "frictionless baseball field" engages the students in non-threatening, everyday language, and through a visual arena familiar and common to their past experiences. Again, this idea of presenting new material to his students in their own worlds, is a theory Dave has coined "cognitive derivation." Theoretically speaking, it is the presentation of concrete understandings to his students, with the intention of moving from there, to a higher level where these "spontaneous concepts" can be translated into "scientific concepts" (Vygotsky) and become "black-boxed" like much of science (Latour & Woolgar, 1979).

Dave provides questions to focus the students' attention on the salient portions of the video, which will lead to an understanding of "friction" beginning in their own personal worlds. The questions he provides are:

1) Which way do I think friction pushes or pulls?
2) What type of motion do the kids have on the frictionless baseball field?
3) Describe five actions that happen differently because there is no friction?
4) How does friction keep the bus from moving when it is in the book?

Prior to watching the cartoon, the students copy these questions into their science notebooks. Dave reminds them of the fact that they know what a "push or pull" means. A student fills in with "it's a force," directing his comment at the collective group. And again, as Dave writes question two on the board, he reminds students that they know the word motion "means it is either going to (pauses)," and a student fills in "speed up, slow down, or stay the same." Dave reminds them that they can use the charts hanging at the back of the room for reference, just as he does in nearly every lesson. By referencing these charts, the students learn to use academic, scientific terms to talk about scientific phenomena they have explored.

Kinesthetic Modeling

Another "teacher practice" we see in lesson two is one Dave used a great deal during the data collection period. I refer to this practice alternately as "kinesthetic modeling," and "embodiment." Dave often "acted out" situations in front of his students to further their thinking, and to accompany his words with a visual representation of the novel situations with which he challenged his students. For example, in lesson two, Dave modeled friction with a push of his foot back and forth across the classroom floor, as students thought through the idea of friction and grappled with its definition.

The following transcript documents the interaction between Dave and his students during a portion of lesson two. As always, the students begin in the "post experimental meeting area" by individually answering the "claims questions" Dave has prepared to answer the key question: "What type of force is friction, which way does it act, and how does it affect motion?" The claims questions for this lesson are:

1) What motion did the wood block have after you pushed it? Did it slow down with the sandpaper?

2) Did it slow down with the sticky notes?

3) Which way do you think friction pushes?

This interaction occurs after the students have agreed that friction, like gravity, is happening all the time, and thus, that it is a constant force. The conversation picks up where Dave is reiterating their claim. He then begins to work on an answer to the third question under the "claims" on the whiteboard.

| **Transcript** | **Commentary on complimentary co-occurring actions in the classroom** |
|---|---|
| T: It's a constant force, good. Friction is a constant force. Okay, so that is two of the three things we were trying to figure out today. I know it's constant. I know that it goes opposite of the way that I'm going. Now the final one – how does it affect motion? What did it do to my foot? (recalls a prior motion he has just made with slamming his foot in a backward motion across the surface of the floor) (calls on a student by name).<br><br>S: It slowed it down.<br><br>T: Yeah, it slows it down. It slows it down a lot. | Teacher writes this claim on the easel at the front of the post experimental meeting area.<br><br>(Dave scuffs foot back and forth across the classroom floor). |

**Figure 6.38: Transcript with Accompanying Movements**

In essence, the students have arrived at an answer to the last of the three things they were seeking to discover that day. Dave clearly stated that the students needed to know how friction affects motion. A student in the narrative above answers "It slowed down." But Dave is not yet sure that his students understand friction to the full extent that they are capable. Characteristic of many lessons during the data collection period, when Dave thinks his students seem too satisfied with an answer, he will pose yet another question to advance their thinking. Below, the transcript continues as Dave decides to lead his students further in their discussion of friction. He asks them what would happen it he were to put a piece of sandpaper on the floor and move his foot across it in either a front of backward motion. Students claim he would rip it. This seemingly "off track" response, has Dave pose a "hypothetical" scenario, something he often does with his students, and then attempts to enact.

| **Transcript** | **Commentary on complimentary co-occurring actions in the classroom** |
|---|---|
| T: Okay, let's go into a hypothetical. Let's say I actually made the whole ground out of sandpaper.<br><br>S: It would hurt 'cause then you might fall.<br><br>T: Why would it hurt?<br><br>[lots of chatter]<br><br>S: Sandpaper's rougher.<br><br>S: Sandpaper's rough.<br><br>S: It would scrape and it would hurt.<br><br>T: But what I'm trying to ask is what's the difference between the sandpaper and this floor right here? (calls on a student by name) | |

**Figure 6.39: Transcript with Accompanying Movements**

| Transcript | Commentary on complimentary co-occurring actions in the classroom |
|---|---|
| S: The floor has more friction than the sandpaper. | |
| T: The floor has more friction than the sandpaper? | |
| S: No, it has less friction. | |
| T: Okay, you say sandpaper has more friction than the floor? | |
| S: No, this has less friction right here [rubbing his arm] | Student rubs arm. |
| T: This has less friction? [rubbing his arm in the same place]. Okay, let's really put this in my mind. Which has more friction? Sandpaper, or like, ice? | Teacher rubs arm. |
| S [several]: Sandpaper. | |
| T: And what makes it- what do you think makes it have more friction? | |
| S: Those little bumps. | |
| T: Oh, it's got some little bumps. | |
| S: Sand. | |
| S: It's rough. | |
| T: So, let's do a test. So, Mr. ___will take his hands. I rub them like this- you've got to listen for it. No, just me. Just me. Shhhh..Okay, here's my hands. Just, hand on hand [rubs hands together]. Now I take sandpaper- do you think it's going to make more or less noise? | Teacher rubs hands together in a vigorous constant motion. |
| S: It's going to hurt you. | |
| S: More noise. | |
| T: [rubs hand against sandpaper] | Teacher rubs hands against sandpaper. |
| S: I see your skin fall down. | |
| T: Yeah [laughs]. Okay, so then we can say that it- what does it do to | |

**Figure 6.39 continued**

| Transcript | Commentary on complimentary co-occurring actions in the classroom |
|---|---|
| my hands? What does friction do?<br><br>S: It makes it bleed?<br><br>T: No….<br><br>S: It scratches them<br><br>T: It makes them….<br><br>S: Slows down.<br><br>T: Slow down. And then possibly stop (laughs). | |

**Figure 6.39 continued**

In the transcript above, we see Dave participates in a variety of enacting episodes to entertain the question: how does friction affect motion?

Summary and Discussion of Teacher Practices in Lesson Two

In lesson two, we see the prevalence of "kinesthetic modeling" together with practices emanating from Dave's practice of "cognitive derviation." The latter underscores Dave's deep-seated belief in Vygotsky's ideas of the connections between thought and language. He once again appeals to the spontaneous concepts with which his students come, and again aims to increasingly guide them to the scientific concepts that parallel those everyday conceptions. He also uses "kinesthetic modeling" to enact hypothetical situations designed to challenge and further students' thinking.

*Physical Structures/Environment in Lesson Two*

As illustrated in lesson one, lesson two on friction utilizes the same three seating arrangements. Students sit in close rows during the "lecture-style meeting area," as they complete the prelude and "engage" portion of the 5E model. In the figure below, Dave's students are seated in the lecture style meeting area and engaged in watching the cartoon video introducing them to friction.

**Figure 6.40: Students in Lecture-style Meeting Area Watching Friction Cartoon**

Next, Figure 6.41 shows students working through the "explore" portion of the 5E model at their tables.

**Figure 6.41: "Explore" Portion of 5E Model, Students Seated at Tables of Four**

And finally, Figure 6.42 shows students seated in the "post-experimental meeting area" where they write their "claims" from the scaffolded questions on the side board, and then engage in discussion with the teacher and their peers to achieve final answers to the key question of the day.

**Figure 6.42: Students in "Post-Experimental Meeting Area"**

<u>Summary and Discussion of Physical Structures in Lesson Two</u>

As previously noted in lesson one, the physical seating arrangements continue the work of dictating participation frames for students in lesson two. Through consistent practice, the students become familiar with the expectations for student discourse at each step of the lesson. Again in lesson two, the use of the "post-experimental meeting area" makes clear the expectation that students will be talking to and with one another, to achieve consensus on an answer to the key question of the day.

*Classroom Systems in Lesson Two*

<u>5E model, Key Question of Day to Frame Lesson</u>

Lesson two reveals many of the same normative classroom systems documented in lesson one. These include continued use of the 5E model of instruction, the use of scaffolded "claims questions," and a key question of the day to frame the day's lesson. Dave also continues to encourage students to reference the charts at the back of the classroom to integrate past learning into their current learning environment.

In addition to these, I next highlight two additional classroom systems that impact student discourse, though more indirectly than those previously mentioned. I describe Dave's use of "entextualization," as well as his routine use of a student to model notes on the overhead projector to free up board space and continue the process of "entextualization" throughout the lesson.

"Entextualization"

In lesson two, there is an ongoing narrative of the 5E's encoded on the front white board in a story-like format (see Figure 6.43 below).

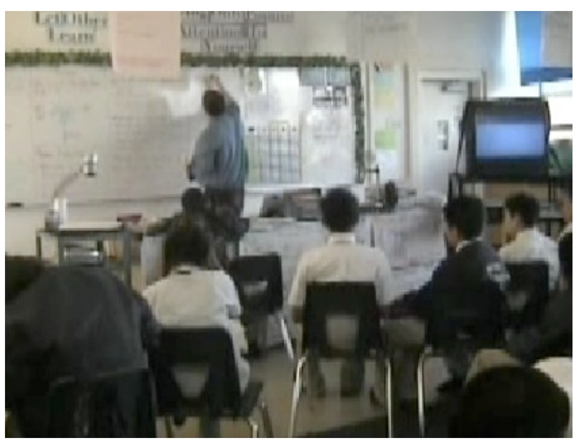


**Figure 6.43: Ongoing "Entextualization" of Lesson**

This narrative begins on the left of the whiteboard with the prelude for the day and continues in a vertical line down and then up and across to the top of the next imaginary column on the whiteboard. After the prelude, this narrative captures student ideas about the “engage” portion of the lesson, followed by directions for the “explore” portion. By the time students are seated at their tables of four to begin work on their activities, there is a logical, sequenced, “entextualized” account of the day before them, encoded in text on the front whiteboard. During certain lessons over the course of the data collection period, this narrative proved more integral to the students’ learning than during other lessons. Lesson two is one example in which the information on the whiteboard was key to the talk that developed during the “explore” session at student tables. This talk in turn affected the discourse students were able to build upon during the “explain” portion. Much of it originated from the co-constructed “entextualization” of written text on the whiteboard.

Aside from the verbal talk during the “explain” portion, the “entexualization” on the front board assisted students in other portions of the lesson as well. For example, in lesson two, as students copy the four questions they are to consider during the “engage,” as they watch the cartoon, they look back toward the charts at the back of the room. These charts serve as a type of collective class memory. In this lesson, one of those charts in particular is used for students to recall that a force is a “push or a pull,” something they have learned from a previous lesson via a similar 5E process.

In the figure below, we see the process by which students are able to use a combination of deictic pointing to and from visual media, together with text on the front whiteboard to make sense of the “engage” portion of the lesson before moving on. The notion of Dave entextualizing the class narrative provides a system upon which he can routinely rely to guarantee that he is able to capture student thinking in all modalities and convert it to written text.

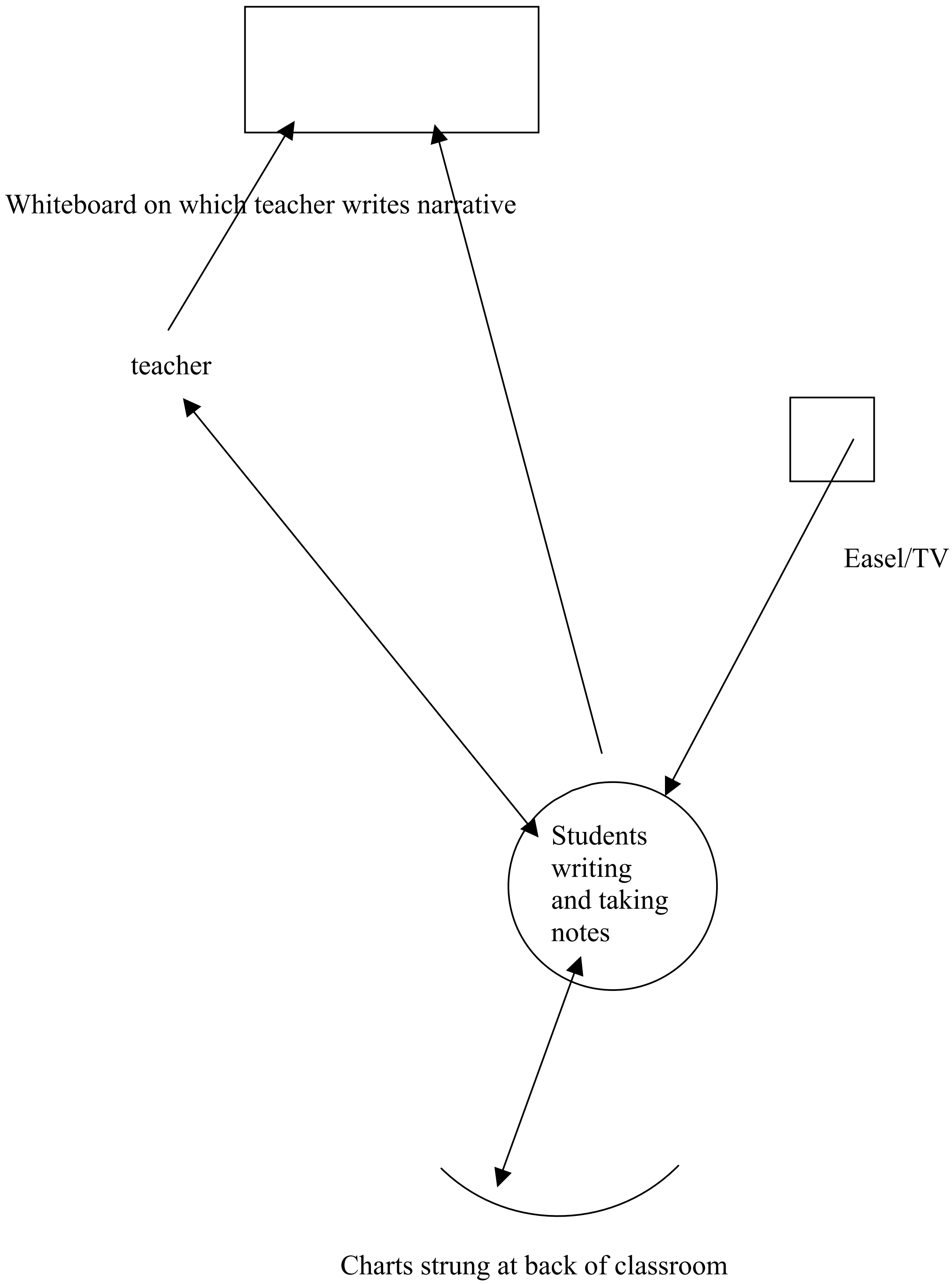



**Figure 6.44: "Entextualization" in Lesson Two**

Student Modeling of Note-taking

A document camera is used in lesson two for a student to model the process of taking proper notes during the lecture style meeting area. This is a normative classroom routine that protects board space. The use of the document camera for student modeling frees up, and essentially protects, critical front whiteboard space for the "entextualization" of the narrative of the inquiry process that takes students through the 5E stages of the lesson. The document camera enables Dave to maintain the integrity of the full text of the lesson on the front whiteboard, without sacrificing the ability to model other important skills, for example, in this case, note-taking.

Summary and Discussion of Classroom Systems in Lesson Two

The classroom norm of "entexualization" results in the presence of new written text that converges with other representational media in this lesson to provide students with rich surroundings from which to process and reprocess information. This written text adds to the cognitive web across which thinking is distributed in Dave's classroom.

Summary and Discussion of Lesson Two Across All Domains: Pathway One

Lesson two is also illustrative of pathway one in Figure 6.2. In this lesson, the normative practice of "entextualization" is highlighted as a key feature contributing to the formation of student discourse. This allows for the development of a complex web of representational media across which students process and reprocess their thinking during the "engage," the "explore," and the "explain" phases of the lesson. If we reference

Figure 6.2, we see the contribution of "entextualization" in a yellow arrow feeding into the red representation of the "post-experimental meeting area." Moving down the left side of the model, we find these contributions converge with those of the blue arrow of "teacher practices." In this lesson, teacher practices mainly include those emanating from the theory of "cognitive derivation," along with "kinesthetic modeling." All of these contributions together allow for the resemiotization of science leading to the black-boxing of the learning in unassailable terms. Both perceptual and linguistic objectification are achieved in this lesson, as required by definition of pathway one's outcome. Students in this lesson achieve a high of level four in their argumentation and are able to articulate that friction is a constant force that acts in the opposite direction of movement and slows down the movement of objects. This is the "black-boxing of science authenticated by the scientific community" depicted at the bottom of pathway one in the model.

*Lesson Three – Balanced and Unbalanced Forces Claims, Led by "Teacher Practices" and "Classroom Systems" Domains*

Lesson three is a 5E lesson on balanced and unbalanced forces. The key question of the day was: "What is the motion of balanced and unbalanced forces?" Figure 6.54 illustrates the three activities students were to complete at three stations during the "explore" session of the lesson (See Appendix G for the entire agenda of the lesson).

DIRECTIONS: Pass the ball

1. Have 2 people stand opposite one another
2. Pass the ball pushing from the chest back-and-forth
3. Draw a FORCE ARROW DIAGRAM of the ball for one pass.

Include all the forces acting on the object.

4. Copy and Answer the questions below:

Are these forces balanced or unbalanced? WHY?
What was the motion of the ball as a result of these forces?

DIRECTIONS: Parachute Man

1. Toss the parachute man in the air.
2. Notice his movement as he falls to the ground
3. Draw a FORCE ARROW DIAGRAM for the parachute man falling to the ground.

Include all the forces acting on the object.

4. If the man moved right, does that mean a force occurred?
5. Copy and answer the questions below:

Are the forces balanced or unbalanced? WHY?
What was the motion of the parachute man as a result of these forces?

DIRECTIONS: Fan Car held backwards by hand

1. Point the fan car towards your hand
2. Push back on the car so that it does not move when the fan is on
3. Draw a FORCE ARROW DIAGRAM for the fan car staying still

Include all the forces acting on the object

4. Copy and answer the questions below:

Are these forces balanced or unbalanced? WHY?
What was the motion of the fan car as a result of these forces?

**Figure 6.45: Directions for "Explore," Lesson Three**

By the end of this lesson, the class achieves consensus that balanced forces cause objects to stay the same speed, and unbalanced forces can speed up or slow down an object. This final claim is achieved via the co-construction of input from several students who rely predominantly on watching their teacher re-enact certain events from the "explore" portion of the lesson. As in lessons one and two, students use their words, accompanied by gesture to articulate their emerging understandings, and build on fragments of different knowledge states of one another to achieve level four argumentation levels during the lesson. In addition to the predominant leading influence of "teacher practice," the domain of "classroom systems" figured prominently into the opportunities for student talk in this lesson. Together, these two dimensions enabled the high quality of argumentation in this third example.

*Teacher Practices in Lesson Three*

Affective Practices: Empowering Language

Lesson three harbors many of the same "teacher practices" described in lessons one and two. Here again, we see examples of Dave engaging in his self-proclaimed practice of "cognitive derivation." We also find Dave engaging once again in "kinesthetic modeling," or "embodiment," using his body to act out hypothetical examples designed to challenge and advance his students' thinking. As well, Dave utilizes the process of re-enacting "explore" activities with the same objects used by his students. This latter practice, together with the students' use of deictic pointing at those same objects, are everyday constants in Dave's classroom.

But, lesson three introduces an element within the domain of "teacher practices" that is rooted more deeply in this lesson, than elsewhere in the previous two examples. Dave uses much more praise towards his students in this lesson than is seen in either of the earlier two lessons. I use the phrase "empowering language" to refer to this element and to describe Dave's use of praise in the affective domain of his teaching.

In many ways, lesson three is a nexus of the learning Dave's students have completed in prior lessons on forces, motion, speed, gravity, and friction. These concepts culminate in this lesson on balanced and unbalanced forces. As Dave's students embark upon lesson three, they stand poised to apply a great deal of newly acquired knowledge to novel situations. Dave goes to great lengths to empower his students through positive language. He praises his students and galvanizes them with such statements as: "We're already smart, working on brilliant," and "you are armed and dangerous with knowledge of forces… you know friction, you know gravity, you know constant force, instantaneous force, tension, compression. You know all that stuff now. So, now you're going to say, 'what is going on with parachute man, what are the force arrow diagrams?'" (Appendix J, lines 166-170)

As in lessons one and two, Dave designs an "easy review question" as the prelude, in order to begin class on a confident note. This problem allows his students to begin the class period experiencing success. It sets their confidence high, and readies them for the challenge of applying all of their recent learning to this new notion of using force arrow diagrams to understand balanced and unbalanced forces, and their affects on the motion of objects. This again, ties into Dave's philosophical belief in using a "spiraling" concept of teaching- reaching just below the zone of proximal development (ZDP) of his students, to begin with problems easily within their grasp. He then uses the successful attainment of these answers to build confidence and continue on an upward climb through the current ZPD of the collective class (see Figure 4.2 in Chapter 4). Students see the prelude on the front whiteboard each day. There, they also find the title of the agenda, the purpose for the day, and the 5E goals for the day (see Figure 6.46).

| |
|---|
| Title: Balanced and Unbalanced Forces<br>Purpose: For students to identify balanced and unbalanced forces on an object accurately, predicting the motion.<br>Prelude: A ferari goes 18 miles in 2 hours. Calculate the speed. Use G.E.S.S.<br>AGENDA<br>Engage: Multiple Forces<br>*hair dryer and ping pong ball<br>*fan car and hair dryer<br>Explore: 3 stations<br>• pass the ball<br>• parachute man<br>• fan car and hand<br>Explain: Discussion and Conclusion<br>Extend: Balanced and Unbalanced Forces Handout |

**Figure 6.46: Sample Front Whiteboard During "Lecture-style Meeting Area"**

The prelude from lesson three is clearly a problem reaching below the present state of learning for these students. It has been more than a month since they first learned to derive the formula for speed from distance and time. This is a problem they can now solve without relying on the step-by-step G.E.S.S. system. The level of this prelude allows the students to begin the day with the confidence that they can conquer what comes next. In the video data, the G.E.S.S. system is still used and encoded on the white board as illustrated in figure 6.47 below, however students have internalized the process and do not look back to reference any of the chart papers at the back of the room when completing the prelude. This was proof of the automaticity with which they could solve the problem.

| G (given) | E (equation) | S (set-up) | S (solve) |
|---|---|---|---|
| t=2h<br>d=18m<br>s=? | s=d/t | s=18m/2h | s=9m/hr |

**Figure 6.47: The G.E.S.S System Used to Solve a Prelude Problem**

Dave wrote the letters G, E, S, S, and had students tell him what to write in under each column. Dave never had to remind students where to look to find the equation for how speed, distance, and time were related, as he did in many other lessons up until this point.

Summary and Discussion of Teacher Practices from Lesson Three

Lesson three highlights the use of affective practices that empower students to approach novel concepts with confidence. Dave utilized a great deal of positive, empowering language, which he coupled with a prelude problem below students' current ZPD. These affective practices allowed students to experience success at the beginning of the lesson. It prepared them to approach a novel concept requiring them to call upon all of their previous learning regarding forces. By engaging his students in a positive manner, Dave established a climate of "relaxed alertness" (Caine & Caine, 1991) in his classroom. In this state, students experience a lowered affective filter coupled with a high degree of challenge. Brain-based learning supports the notion that social relationships, with an emphasis on belonging, being recognized, listened to, and noticed, all contribute to a sense of "relaxed alertness." In this state, a learner feels relaxed and competent. In fact, all students learn more effectively when their social nature is engaged and honored. We also know that complex learning is enhanced by challenge and inhibited by threat associated with helplessness and fatigue (Caine & Caine, 1991). Supportive, empowering environments can enhance learning. This is exactly what we find in this lesson.

*Physical Structures/Environment from Lesson Three*

As in lessons one and two, the same three seating arrangements are instrumental in creating a structure which makes possible the interactions between text and drawings encoded in multiple representations; students' use of gestures; student's and teacher's object manipulation; and verbal speech. The reprocessing of meaning through these different semiotic systems occurs at different rates, and involves different semiotics at each stage in the process of the 5E lesson. Having three different seating structures during this lesson assures that students are physically positioned with access to the artifacts germane at each step during the inquiry process. Again, these seating arrangements are: the "lecture style meeting area;" group-tables of four; and the "post-experimental meeting area."

During the "lecture style meeting area" of lesson three, students face front as in all other lessons, and complete the prelude designed to build confidence in their current level of skill with their knowledge of speed, distance, and time. They also receive instruction on the activities they will be exploring at their tables. Once at their tables of four, the students follow the directions given for each of the three activities, as Dave circulates. And, finally, as in lesson examples one and two, the students gather in the "post-experimental meeting area" where they participate with their teacher in a debriefing of the activities, and a discussion of the science behind balanced and unbalanced forces. It is this latter physical arrangement that sets the structure and context for the important work that leads to the co-construction of scientific "facts" the students are able to agree upon with their teacher. In Chapter 7, I analyze in depth how this process occurs within the physical structure made possible by the "post-experimental meeting area" design.

Summary and Discussion of Physical Structures from Lesson Three

As in both previous lessons, the post-experimental meeting is the once again the crucible in which the contributing factors from the "teacher practice" domain enhance argumentation. In this lesson, the added "teacher practice" of empowering language contributes to a state of relaxed alertness that carries through to the time students are seated in the "post-experimental meeting area," where they are empowered to use their language to articulate their ideas.

*Classroom Systems in Lesson Three*

<u>"Entextualization"</u>

Many of the same classroom systems and processes present in lessons one and two, are again used in lesson three. A student is chosen to take "model student notes" using the document camera, which projects on a side screen to the left of the front whiteboard where Dave encodes the narrative of the class period. Again, this narrative or, "entexualization" of the lesson, is encoded in words and diagrams in chronological order of the 5E sequence of the lesson. Students are seen turning their heads back to reference charts at the back of the room, specifically looking for information regarding the magnitude of force. They search the string of charts and find one that equates the magnitude of a force with the length of an illustrated arrow.

In this lesson, there is a small segment of direct instruction following the prelude and just prior to the start of the exploration activities. During this time, science phenomena are observed, drawn by Dave on the front whiteboard, then named, then explained. The visual experience is translated through gesture and oral language into a diagram that the teacher encodes on the whiteboard (see Figure 6.48). This same process is used in lesson two.

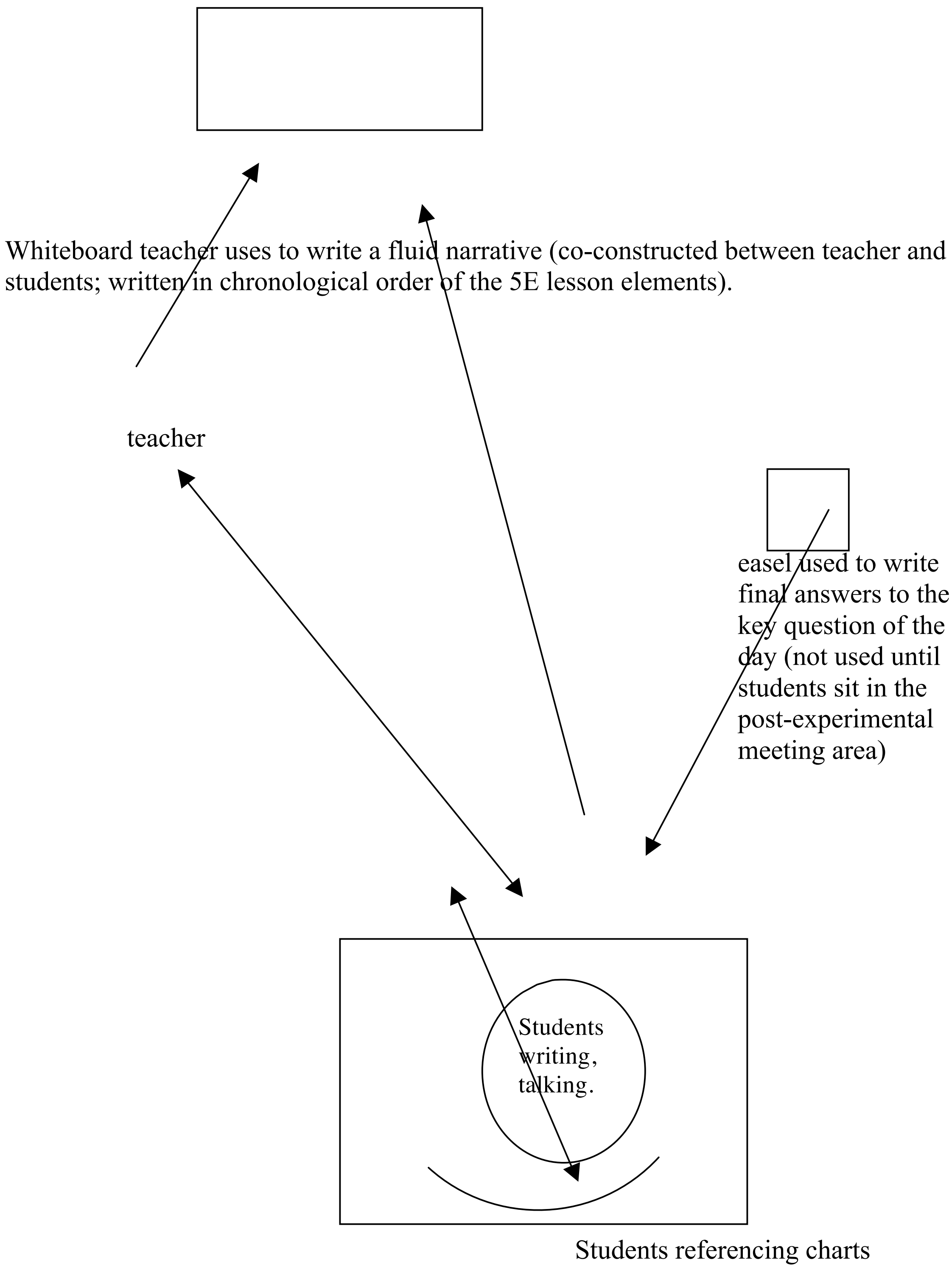



**Figure 6.48: "Entextualization" in Lesson Three**

The processes by which students and teacher arrive at meaning is analyzed in Chapter 7. There, I closely analyze the process by which students and their teacher cycle through different media and modalities to arrive at various information states, and ultimately at final answers to their key questions of the day.

Summary and Discussion of Classroom Systems in Lesson Three

"Entextualization" is again found to be a classroom norm that is paramount to classroom talk in this lesson. This process materializes text that is critical to the resemiotization of science. Students use deictic and iconic gestures to interact with the drawings and text on the front whiteboard, as well as with the text that becomes encoded on the easel during the post-experimental meeting area classroom discussion.

*Summary and Discussion of Lesson Three Across All Three Domains: Pathway One*

Notwithstanding lesson three, all of the lessons thus far are examples of pathway one in the model represented in Figure 6.2. This particular example highlights the contribution of empowering affective practices located in the blue arrow of "teacher practices." Additionally, the use of "entextualization," located in the yellow arrow of "classroom systems" once again allows for the development of a rich web of representations across which students can process and reprocess, or resemioticize meaning. Ultimately, as in the first two lessons, lesson three culminates in the black-boxing of science after perceptual and linguistic objectification congeal learning into the statement that *balanced forces cause objects to remain at the same speed, while unbalanced forces can either speed up or slow down the motion of an object.*

*Lesson Four – Representing and Articulating Forces, Discourse Enhanced by "Classroom Systems" Domain*

Lesson four is the first in a series of three lessons chosen from the data collection period in Carla's classroom. The purpose for this particular lesson is for students to be able to define a force and to understand how to represent a force in a picture. Figure 6.49 below depicts the agenda for the day, as it appeared to students on the front white board.

Agenda
Purpose: Students will be able to define a force and how a force is represented in a picture.
Prelude: see doc cam
Engage: Car Crash
Explore: Force Arrow Diagrams
Explain: Claims and Evidence
Evaluate: Conclusion
Exit Slip: ---
Extend: Bowling Ball and Pin Force

**Figure 6.49 5E Agenda as Written on Front White Board**

Figure 6.50 below alternatively depicts the agenda as it might look if all the paperwork passed out to students had been written in their chronological position within the 5E model of the lesson structure. Students did not see the lesson depicted in this way as they might have in Dave's classroom, due to the fact that Carla does not use the process earlier referred to as "entextualization."

Agenda

Purpose: Students will be able to define a force and how a force is represented in a picture.

Prelude: Two cars race towards each other. The first car traveled 457 meters in 4 seconds. The second car traveled 382 meters in 2 seconds. Calculate the velocity of the cars upon impact. Draw an energy diagram for this accident.

Engage: Car Crash

Explore: Force Arrow Diagrams

Key Question: What is the proper way to show a force visually?

Procedure:

- Use the descriptions in the data table to simulate the scenarios presented.
- Draw an energy diagram for the interactions
- Draw a force arrow diagram

Explain: Claims and Evidence

| Claims | Evidence |
|---|---|
| What object is usually drawn in a force arrow diagram? | |
| How can you tell if a force is a push or a pull in a diagram? | |
| Does it matter if the arrow is coming out or going into the diagram? | |

Evaluate: Conclusion

Write a one paragraph conclusion. Remember to include:
*Summary of what you did.
*Summary of your results.
Final claim of what occurred during this experiment.
Answer the key question.

Extend: Bowling Ball and Pin Force: Create a force arrow diagram of a bowling ball hitting a bowling pin.

**Figure 6.50: Agenda as it Might Appear with All Elements "Written-in" in Chronological Order**

The highest level of argumentation achieved during this lesson was a three, which occurred during the "explore" portion at a table of students wrestling with the "claims and evidence" questions and conclusion tasks shown above. The domain of "classroom systems" was the most influential on the level of student argumentation in this lesson. In fact, elements in the domain of "teacher practices" and "physical structures" were found to actually inhibit student discourse. I will begin with a description of how "teacher practices" constrained student talk.

*Teacher Practices that Constrained Discourse*

Two main teacher practices constrained the amount of talk that occurred in the classroom. The first was the routine use of the I-R-E discourse; the second group of practices I condense under "affective practices." Both are dominant factors contributing to a lack of student talk during lesson four.

<u>I-R-E Discourse Style</u>

For the first 26 minutes of this lesson, the teacher engages her students in a typical I-R-E discourse pattern. She repeatedly cycles through the process of asking a question, and either accepting an answer that is called out, calling on a student whose hand is raised, or calling on a student who appears to be disengaged from the lesson. Once she receives a single student answer, Carla proceeds in two different ways depending on whether the answer is correct or incorrect. If the answer is correct, Carla either repeats the answer in affirmation, or says nothing at all and writes the answer on the paper under the document camera. If it is incorrect, or if there are dissenting opinions, she simply gives the correct answer herself and moves on.

The transcript below illustrates these patterns. It begins following a silent period of time in which the students were to have tried to solve the prelude using the G.E.S.S. method by themselves. We see the I-R-E pattern occur three times in a row beginning with Carla's repetition of the prelude aloud: "Two cars race toward each other. The first car traveled 457 meters in 4 seconds. The second car traveled 382 meters in 2 seconds. Calculate the velocity of the cars upon impact. Draw an energy diagram for this accident." Carla initiates her first discourse move with the question: "So what is my distance for Car #1?" A student calls out the correct answer "457." Carla writes this answer under the "G" or "given" column of the G.E.S.S. system students used as a heuristic to solve their word problems in her classroom. This completes the first I-R-E move. Two more I-R-E sequences follow:

T: What is my time? [I]
S: 4 seconds. [R]
T; (silently writes answer) [implicit E]
T: What will I write in this next box? (Calls on a particular student). [I]
S: Velocity equals distance divided by time. [R]
T: With direction, right? [E]
S: With direction.

After this, there is a series of occurrences that force a disruption in the teacher's preferred pattern of I-R-E by a student question:

T: ___(calls a student by name), the next box.
S1: I thought speed equals d over t?
T: It's the same thing, but velocity has a direction. It's the same thing, only with direction.
S1: V equals 457 meters over 4 centimeters.
T: So, velocity is what?
S1: 114 meters per second.
S2: No!
S (Gabby): Yes!
S3: I got that.
T: (nods head affirmatively as she writes this answer on the doc cam). How about for car 2? My distance for car 2 is … (hands go up)
S (Crystal): shouts out an answer.
T: Crystal, next time you need to be in the meeting area, and you need to wait your turn.
S (Crystal): Sorry.
T: What's the time for car 2. Eduardo Nueva? What's the time for car 2?
S: (stretches, inaudible answer)
T: My velocity equals 382 divided by 2 seconds, forward.

We see here the familiar I-R-E pattern is disrupted by S1's question: "I thought speed equals d over t?" This student is confused by the teacher's use of the word "velocity" rather than "speed" – the way she remembers the formula involving distance and time. Rather than taking time to clarify this in some depth and to check for understanding among other students, Carla simply answers the question with: "It's the same thing, but velocity has a direction. It's the same thing only with direction." This terminates any chance of involving other students in the discourse process. It also enables the flow of I-R-E to continue. S1 continues answering the initial teacher prompt of asking what goes in "the next box." S1 answers: "V equals 457 meters over 4 centimeters." The teacher exercises her "E" or evaluative step by writing this "correct" answer on the board.

Carla soon encounters a second disruption in the comfortable I-R-E pattern. From the same transcript above, we see her working with the same student, S1. Carla initiates (I) below:

> T: So, velocity is what?
> S1: 114 meters per second.
> S2: No!
> S1: Yes!
> S3: I got that.
> T: (nods head affirmatively as she writes this answer on the doc cam).
> How about for car 2? My distance for car 2 is … (hands go up)

Carla receives three responses to her initiating question. S1 gives her a numerical answer; S2 disagrees, and S3 agrees with S1. Rather than using this as an opportunity to pursue student-student discourse and work towards a structure where students use evidence to back their claims, Carla simply continues with the I-R-E pattern. She follows through with her teacher E, evaluation, move. She nods her head affirmatively and writes

S1's answer on the document camera. She then continues the pattern with her next initiation (I): "How about for car 2?" This pattern repeats over and over again for the duration of the review of the prelude question.

The I-R-E pattern picks up again during the "engage" portion of the lesson. Carla has the students watch a high-speed chase of a minivan eluding Ohio State Troopers as captured on video. The minivan hits a spike strip, overcorrects, and crashes into the center median. Here is the series of I-R-E discourse moves that follows after students have seen the clip, and as the teacher attempts to lead them in an understanding of the forces, source, receiver, and energy involved:

> T: What was the energy if the minivan was the source and the center median was the receiver, what was the energy? How is energy transferred from the minivan to the center median? (I)
> S1: The wheel? (incorrect R, so teacher ignores)
> T: (ignores first student) ______, thank you for having your hand up.
> S2: The crash. (R)
> T: The crash. The energy was the crash itself. That's how the energy got transferred. (E)

Here, we see an I-R-E pattern in which the teacher chooses to ignore the first incorrect response, and offer her "E," evaluation only after receiving the correct response.

In the next portion of the transcript, Carla intersperses some direct teaching on "energy diagrams" and "force arrow diagrams," the overarching goal of today's lesson. Much of the mystery of the lesson is divulged via directly telling the students that "the force arrow diagram is only concerned with the receiver," something that was discovered through co-construction of talk in one of Dave's lessons.

> T: So, if I want to draw this. This is called an energy diagram. If I want to draw that into a force arrow diagram, there's a different type of way to put this. So, the force arrow diagram is only concerned with the receiver. It

> could care less about the source. It wants the receiver. Who gets the energy and how much energy did I get? So, the center median had a really big force hit it. Right? When something gets hit like in a car accident, is that a push or a pull?
> **S: A push.**
> T: A push. A push from the van. The center median, does it still look the same after a person has hit it going 100 miles an hour? Does it move a little bit this way (indicates a move with an arrow)?
> **S: Yes.**
> T: It moves in a little bit, right? Even if it's a full concrete wall, it moves. This shows you where the energy came from and what energy was transferred. So, it was pushed and moved. Movement from the crash. So, it moved backwards, sort of just buckled in. We can represent these with numbers. This can be like 100 Newtons, and this can be like 10 Newtons because it's not as big as the force that hits it. Force is in Newtons, but we're not concerned with the numbers yet. This is your first exposure to force arrow diagrams. By the end of the class period, you should be able to draw these.
> **S: So what do we draw in the box?**

The only student remarks are "a push," "yes," and "so what do we draw in the box?" In fact, in the entire transcript after watching the video, there are no instances of student-student talk. The I-R-E pattern prevails, alongside some direct teaching of the facts students will use, but not discover, during the "explore" section of the lesson. This reliance on the I-R-E discourse pattern is one of the factors that constrains student-student discourse, and in turn deprives the students of the chance to formulate scientific argument in the classroom beyond a simple answer that is confirmed or not confirmed by the teacher.

The prevalence of this I-R-E pattern interspersed with direct instruction allows for a very teacher-controlled environment in three ways. First, Carla does the work of the prelude on the document camera via the I-R-E method, each time the students meet. Carla does all the talking and thinking, calling for simple replies to her questions as she reviews the prelude, and many times, portions of the "engage" component of the lesson.

Two, Carla supplies much of the evidence and rationale for the science her students are supposed to be learning. For example, when she tells them in the previous example that "the force arrow diagram is concerned with the receiver only," she deprives the students of the chance to wrestle with this idea on their own. And three, because of the fact that Carla controls the pacing of the lesson with her talk and writing on the document camera, many of her students are seen in the video data as becoming disengaged. They are not important contributors to the construction of knowledge taking place at the front under the teacher's controlled manipulation of writing under the document camera. And, thus, they do not contribute much of the spoken discourse in the classroom. In fact, they can often be heard interrupting Carla on many occasions during any single lesson during the data collection period, asking: "Do we copy this part?"

Affective Practices

This leads to the second major "teacher practice" that appeared to discourage student discourse in Carla's classroom. There were many times over the course of data collection when disciplinary issues evoked a strict affect in Carla that stifled student participation. For example, at the start of this particular lesson, Carla addressed the class as such: "You come in this room, you have about two minutes to get situated. It's been about eight minutes. The tapping on the desks needs to stop. You need to silently be doing your prelude." The teacher then specifically asked me not to tape the disciplinary portion of the class that followed. Unfortunately, many times these disciplinary issues spilled over into the video data and seemed to contribute to a silencing of student talk. Carla often resorted to using a very firm, punitive tone of voice and threatened students with calling parents if they would not stop talking. Much of the time the student chatter was off-topic to the science learning of the day, yet the tactics used to address these concerns squelched student input.

When such instances occurred, the teacher would often resort to answering her own questions, as in the transcript below from lesson four. In this example, one student, perhaps having grown weary of the I-R-E pattern, has put his head down on his desk, but is still facing the teacher with his eyes open. The teacher's voice grows angry as she addresses him.

> T: So, the source is the minivan. What is the energy, ______? (student has his head down on desk, but is facing the doc cam). What is the energy in this car chase?
> **S1: I don't know.**
> T: So, let's pay attention up here instead of having your head down. What is the receiver? If the minivan was the source, what was the receiver of the minivan? (Student does not answer). The center median.
> **S: What is that?**
> S:(another student motions her hands back and forth along a long line in front of her to draw the center median for her peer).

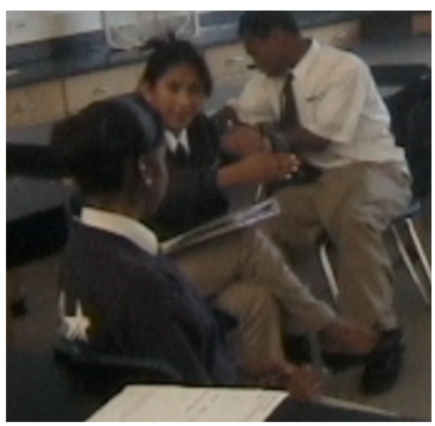


**Figure 6.51: Gesturing, Speaking Spanish**

> T: The concrete wall in the middle of the freeway. They're the ones that divide the freeway.
> **S: What does that say?**
> T: It says "the center median." So, it is cement up here and up here. And whenever one begins they have a whole bunch of cylindrical cones and big

plastic containers filled with water or sand, so that it cars crash into that, they don't die and slash their cars up like they would if they crash into concrete.
**S: Oh, I know what that is.** (Two girls gesture and speak Spanish, translating what the teacher has just said).

Here, we see that the affective filter is raised such that students are compelled to have side conversations to clarify the vocabulary being used in the example the teacher is working on the document camera. And again in the transcript example below, we see the teacher interrupt the lesson to tell the students that she will deprive them of future help if they are talking, and also that she has a list of parents to call.

T: The wood block? So, I am going to draw the push from the car. Remember your talking and goofing around whenever you have questions, because I'm going to skip you. I already have a list of parents to call next period. I am adding some names.
**S: Am I one of them?**

Immediately following this, the teacher attempts to remind students of how they should be working with each other. However, it is not clear that this is a routine the students have internalized even by three months into the school year. When asked what the room should sound like as they work with their partners, there is a blend of "whisper?" and "talk quietly?" and "silently?" – all pondered in the form of a question. Their teacher's parting words to them before they begin working is "If you get out of control, it's not going to be good."

T: What should this room sound like and look like as I hear you work?
**S: We should be absolutely silent?**
T: No, not absolutely silent.
**S: Quietly- whispering quietly?**
T: Quietly, working with your partner.
**S: Silently? Whispering?**

> T: Whisper voices working with your partner. If you get out of control, it's not going to be good.

Unlike in Dave's classroom, the idea of students talking to one another has not been reinforced in Carla's class as something integral and necessary to the learning process.

*Teacher Practices That Enabled Discourse*

<u>Opportunities for Resemiotization</u>

One main practice in particular enabled the process of student discourse in Carla's classroom. This was the opportunity she provided for resemiotization to occur in her classroom. In this lesson, resemiotization mainly took place during the "explore" portion of the lesson. This "teacher practice" reveals Carla's belief in the fact that her students need to engage with the material. She says at one point to her students, just prior to setting them loose during the "explore" portion: "There are boxes up there if you need to demonstrate and see this (points back behind her to stacked boxes with supplies, see Figure 6.52).

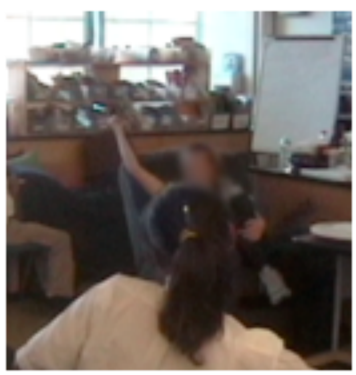


**Figure 6.52: Carla Referencing Shelves with Objects**

She acknowledges that a lot of her students "need to see it," adding, "you can't picture it in your mind. Go ahead and get a box if you want and go back to your seat. I'm passing out the lab." It this belief that is instantiated in her practice of following a 5E model, in which a crucial portion of the lesson affords students the opportunity to work with actual objects to help them picture the ideas they are learning about in science. Because this teacher practice is so intertwined within the construct of the 5E model under "classroom systems," the opportunities students are afforded from this teacher practice/belief to engage in discourse will be discussed in greater detail under "classroom systems." In Chapter 7 we will see how these opportunities for resemiotization resulted in instances in which students were able to achieve "black-boxing of science" in authentic scientific terms, as well as instances in which the "black-boxing of science" resulted in pseudo-scientific terms. This was found to depend on the articulation of students' resemiotization with the "talk moves" of a "more capable peer."

*Summary and Discussion of Teacher Practices from Lesson Four*

In summary, there were two predominant teacher practices that inhibited student discourse, and one practice that fostered it. Carla used the I-R-E talk format in her classroom almost exclusively in lesson four. In fact, whenever there was a student contribution that interrupted this sequence, it was quickly dealt with in order to revert back to the default pattern. This common discourse practice has been the most prevalent form of discourse in classrooms for many years. Findings presented here are consistent with those in the literature, which also reveal this format to be inhibiting of student discourse (Michaels, 2008). It seems the students internalized their passive roles as responders, rather than questioners, by virtue of repeated use of the I-R-E sequence.

Thought it cannot be proven, it is also likely that the stricter, more punitive tone set by the teacher confined student participation to ways not likely to foster student-student discourse.

Carla does make objects available for her students to work through scenarios during the explore session. This allows opportunities for students to use resemiotization. In Chapter 7, I show how such opportunities in this lesson lead to student-student talk that results in the outcomes delineated by pathway three in the model representation in Figure 6.2.

*Classroom Systems from Lesson Four*

<u>The 5E Model</u>

Like Dave, Carla also follows a 5E model of instruction. Unlike Dave, however, in many of her lessons, she changes the ordering of the E events. While they are traditionally found in order from “engage,” “explore,” “explain,” and “elaborate,” with “evaluation” occurring continuously, Carla often switches this order to accommodate her lesson goals. In lesson four, she maintains the traditional sequence of the events. The prelude and the “engage” consist largely of direct instruction of energy diagrams and force arrow diagrams. It is in lesson four’s “explore” portion of the lesson wherein opportunities for student discourse are notable. Students are given the choice of getting a box of materials from the shelves in the classroom. These boxes included a toy car, rubber bands, two clamps, an air pump, a balloon, and a wooden block. Students were asked to perform a series of events and to draw energy diagrams and force arrow diagrams to accompany each event, or interaction. This exploration provided students the opportunity to process through the science through a variety of modalities from written text to object manipulation, to drawings, to verbal explanations. This opportunity for students to resemiotize resulted in level three argumentation at five different times for one particular pair of students, Sandra and Alberto. This student pair worked through six different scenarios, and in all but one of these scenarios, the student pair was able to start with simple level 0 observations and work through a sophisticated blend of object manipulation, gesture, and verbal talk to construct level three argumentation that explained the scenarios for which they were responsible. "Simple thinking," or the brainstorming of possible answers that were quick to come to the tongue, didn't seem to require the use of much gesture, but often just a playing around of sorts with the objects in front of them (see Figure 6.53 below).

**Figure 6.53: "Simple Thinking" with Gesture**

More sophisticated levels of argumentation required the repeated use of gestures. These were used as placeholders for visual images in the mental frame. For example, at the end of lesson four, Sandra grapples to find a word for "size" and "distance." She works with the manipulatives and uses many gestures to arrive at a conclusion.

**Figure 6.54: Sandra Gesturing to Process Thoughts**

She ultimately settles on the idea of receivers changing their “size” or “distance” due to the energy of the source. Ultimately, she is able to articulate that receivers change their “shape” and “position” as a result of the impact from a source. She is able to articulate this as a final claim without gesture or the use of the manipulatives after articulating it a few times with the use of gesture *and* manipulatives. She finally states it confidently. Sandra and Alberto also talk about speaking Spanglish when they don’t have accurate words to express themselves solely in English. The process by which this pair utilizes resemiotization to achieve level three argumentation is analyzed thoroughly in Chapter 7. Here, I emphasize only the point that this resemiotization occurs during the “explore” session of the lesson, over the presence of material objects that can be manipulated.

The “explain” portion for lesson four is completed in partners at the students’ table desks. The class does not come together to co-construct and validate final claims and reach consensus on the key question, as in Dave’s class. In teacher interview data, it is clear that Carla sees this as an individual process and that if students don’t get the “right answer,” then she writes “what they were supposed to have learned in their notebooks." This result connects prominently with Kirschner et al.'s (2006) critique of inquiry-based approaches as likely avenues for students to uncover curricular facts.

Summary and Discussion of Classroom Systems from Lesson Four

The use of the 5E model is highlighted here as the chief "classroom system" or norm that fosters student talk. During the "explore" session, students are given opportunities to manipulate, draw, and talk about the forces at work with the interactions they are creating with their objects. All of the student-student talk documented in this lesson stemmed from the "explore" portion of the lesson, as opposed to the "explain" portion as in Dave's classroom. In fact, the "explain" portion was absent from lesson four.

*Physical Structures from Lesson Four*

There are two main seating arrangements in Carla's classroom, as explained earlier. In lesson four, it is clear that the group table formation is the physical seating arrangement that is most conducive to student discourse and allows for students' interactions and talk.

*Summary and Discussion of Lesson Four Across All Three Domains: Pathways Three and Four*

Lesson four is illustrative of pathways three and four in Figure 6.2. If we follow this path, we see that it begins in either the "explore" or "explain" portion of the 5E model, as depicted in the top large yellow arrow to the right of the model. We see that inside this large yellow arrow, the seats in red, depict the table group seating arrangement that occurs as students work in their groups. If we follow the arrow leading to "Teacher Practices that Constrain Discourse," we see that this leads to no black-boxing of the science at all. This is the outcome of pathway four. In many cases, students who worked at their tables played with the objects, but did not engage in resemiotization, nor in any meaningful discourse about the science. At other times, certain teacher practices were powerful enough to suppress student talk, also leading to pathway four. Because there was no "explain" session to promote student discussion at the end of this lesson, many students never did arrive at any meaningful science learning that I was able to observe.

However, if we follow the pathway of the broken yellow line that circumvents the blue "teacher practices" boxes to the green resemiotization box and arrow, we see that the mere presence of objects is often enough to get students talking about the science. This was the case with Sandra and Alberto. They may not have achieved perceptual objectification- that is, they may not have agreed on what they observed. They also may not have achieved linguistic objectification, or, been able to express in "scientific" language what they were thinking, but eventually, they were able to articulate their ideas in "pseudo-scientific terms."

Both of these pathways are found in the talk from lesson four, which I analyze in depth in Chapter 7. In this chapter, I use lesson four only to illustrate how the three domains either enable or constrain discourse, and how it helps to describe pathways to inquiry in the model I propose in Figure 6.2

*Lesson Five – Predicting Motion from Forces*

Example lesson number five is the second sample chosen from the data collection period in Carla's classroom. The purpose for this particular lesson is for students to be able to predict types of motion based on forces. The teacher begins the lesson with a prelude that is already solved in front of the students on piece of chart paper on an easel. The teacher reveals progressively more of the chart paper as the students copy down the answer to the prelude for the day. The teacher can be heard saying that all of this should be a review. Figure 6.55 below depicts the agenda for the day, as it appeared to students on the front white board.

Agenda

Purpose: Students will be able to predict the types of motion based on a force.
Prelude: What do I know about forces?
Engage: Thanksgiving Project
Explain: Forces
Explore: Force Posters
Evaluate: Poster Presentations
Extend: Constant vs. Instantaneous Forces

**Figure 6.55: Agenda for Lesson Five**

There was no argumentation achieved during this lesson. The "physical structures" did not seem to constrain nor enable student –student talk in this lesson; rather it was the domain of "classroom systems," and "teacher practices" that inhibited student discussion. In the sections below, I describe the "classroom systems" and "teacher practices" that constrained student discourse during this lesson.

*Physical Structures from Lesson Five*

The same two seating arrangements described in lesson four were used in lesson five. In fact, these are the only two arrangements Carla ever used throughout the data collection period. Neither seating arrangement affected the quality of student discourse. At their tables, students worked independently, and in the "elliptical meeting area," the students either listened to direct instruction from their teacher or they listened to their peers share information already presented by the teacher, only with different wording and objects. There was nothing inherent in the seating arrangement that necessarily precluded student discourse, nor anything that enhanced it, especially because students worked alone at their tables to produce their posters.

### *Classroom Systems from Lesson Five*

#### Systems that Constrain Student Talk: Altering the 5E sequence

The 5E agenda in lesson five was altered from the typical ordering of the five events. This effectively negated opportunities for students to make original claims, as I will now explain.

The agenda in Carla's classroom usually follows a predictable pattern of a prelude followed by the 5Es in order from an "engage," to an "explore," to an "explain," and then to an "extend." The "evaluate" part normally occurs when Carla checks their notebooks or gives a test. The sequence of lesson five followed a much different pattern. The "explore" and "explain" events were switched, so that students received direct instruction prior to "exploring" it; also, the "evaluate" and "extend" events were switched to reflect the fact that the students would be evaluated in class on the material they "explored," something that is not usually planned for in class. In addition, the prelude for this class is actually just review notes; there is no student thinking required. This sets the stage for a quiet period of copying notes, which continues into the "explain" portion of the lesson.

The engage stated "THANKSGIVING POSTERS" but there actually was no "engage" activity in practice. The teacher simply announced that only four of the students in the class actually turned in their packets, so they would be doing the work as part of the "explore" today. Next, followed an "explain" where the teacher gave direct instruction on forces. Normally, this "explain" should occur after an "explore" session, so that students have an opportunity to make sense of their observations and findings. However, today, the teacher gave direct instruction on how to make a force arrow diagram and an energy diagram. She told students the difference between a constant force and an instantaneous force, and then sent them to their tables to replicate exactly what they saw their teacher do in a very formulaic type manner, during the "explain" portion of the lesson. Students literally rewrote and redrew what they heard and saw their teacher do during the "explain." The poster assignment itself, by its very nature, demanded no argumentation, and in fact, very little thinking, on the part of the students. Figure 6.56 below shows the assignment as written for them by their teacher on the chart paper at the front of the room.

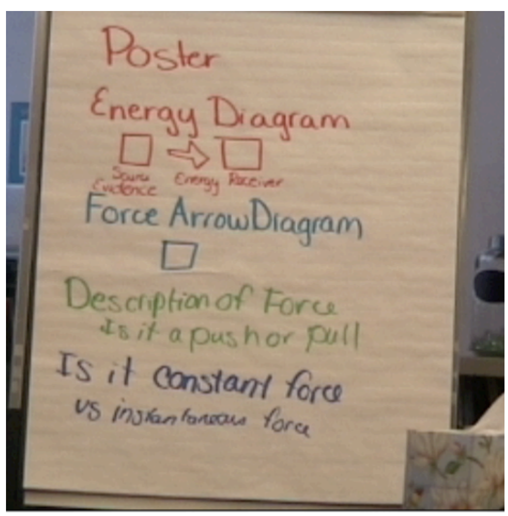



**Figure 6.56: Directions for Poster Presentations**

Students were, for the most part, reading a short situation and labeling the different parts of the situation as the "source," the "receiver," and the "energy." For this reason, there was no actual original thinking requiring claims and evidence, and hence no argumentation levels were evident in this lesson.

Summary and Discussion of Classroom Systems from Lesson Five

The altering of the normative 5E lesson sequence negated opportunities for student-student talk. Lesson Five began with an "explain," in which the teacher taught via direct instruction. Opportunities for exploration of the science were denied students. Instead, they were left to complete a poster assignment in which they essentially plugged in words from a given scenario similar to the one already presented by the teacher. Had the typical 5E sequence been intact, students might have first explored the "situations" given to them, and then come together in a discussion, during the "explain" portion to arrive at claims about the science learning. In the altering of the sequencing, the "classroom system" itself constrained student discourse, and in turn, opportunities for student argumentation.

*Teacher Practices from Lesson Five*

Practices that Constrained Discourse

In lesson five, four main teacher practices constrained the amount of student talk that occurred. As in lesson four, the first of these practices was the reliance on the I-R-E discourse pattern. The second was the use a discourse style I will refer to as P-P-P. And the third was the lack of participation frames. While Carla did make use of a number of outstanding teaching strategies, these were less effective without the implementation of participation frames and a discourse style that would allow for productive student talk that could make student thinking clearly "visible" to the teacher. This lack of participation frames I consider the third element that inhibited student talk in lesson five. In particular, the three strategies incorporated without these participation frames were the use of "kinesthetic modeling," or "embodiment," the reenactment of student activities, and the use of a strategy known as "shared reading." All of these strategies have enormous potential to elicit student talk if used in conjunction with an effective discourse format. This did not happen in lesson five, and opportunities for student participation were lost. The final teacher practice that discouraged talk in lesson five was again in the area of teacher affective practices.

**I-R-E- Discourse Pattern**

As in lesson four, the I-R-E discourse pattern was again prevalent in lesson five. In fact, lesson five opens with this pattern during the prelude:

> T: What is a force? (I)
> **S: A push. (R)**
> T: A push. Okay (E), what else? (calls on S1) (I)
> **S1: A pull. (R)**
> T: What else is a force, besides a push or a pull? (I)
> **S2: Energy. (R)**
> T: Energy. Okay, I like that. (E) A force is also, so page 88, so a push or a pull, or an interaction (teacher unfolds chart paper to reveal pre-prepared notes on forces and motion).

Here, we see the teacher initiate a question (I), receive a student response (R), and provide a type of evaluative statement (E), in this case: "Okay, I like that." The inevitable result of using this discourse style is the attainment of teacher control. By its very nature, it prevents any type of student-student discourse from occurring. It is not surprising to see Carla's heavy reliance on this style. Interview data with Carla reveal her goal to daily achieve "controlled chaos" (Appendix C, line 145). It is important to her to control the classroom. Since teacher practices are indeed teacher beliefs instantiated in practice, this makes sense. This I-R-E pattern is seen throughout the prelude in lesson five. It clearly shuts down student-student interaction and inhibits any type of discussion between the students themselves.

The next example illustrates more of the I-R-E pattern from the "explain" portion of the lesson. Carla skips over the "engage" and continues with direct instruction on forces. While the very word "explain" might seem to suggest a teacher-controlled "lecture" of sorts, the 5E model of "explain" is actually the time when students are supposed to "explain" and "make sense" of the activities they have been exposed to during the "explore" portion of the lesson. In the example below, we again see Carla in control of the classroom talk. We hear students ask three times in a very short amount of time, whether or not they should copy something down. They seem to be more concerned with what to copy than with what to think.

T: Motion- is push related to forces?
**S: Do we copy that down?**
T: Is motion related to forces? Tell me. Yes. How is motion related to forces? (a student raises his hand).
T: (Calls on S1)
S1: Like energy.
T: Energy. It moves. Motion is a push or a pull. (Teacher points to corresponding notes on the chart paper she stands next to). So motion is a movement in a direction. This should be review to you guys. This should be easy.

**S: Do we need to copy this?**
T: Yes (stands with hands on chart paper). Energy diagrams (unfolds more of the notes). Energy diagrams. You have the source, the energy and the receiver (teacher points at diagram with source and receiver). Beneath it you have your evidence. A lot of you are giving me evidence that is only one word. Your evidence needs to be at least two sentences. When you give me supporting evidence for a claim it should be two sentences. At least! Force arrow diagrams (points to chart paper). You have your cube, your block. You have arrows either coming into it or going out of it (gestures arrow towards her body and away from her body).
**S: Do we copy the evidence too?**

**P-P-P Discourse Pattern**

A second discourse style in use during lesson five I refer to as P-P-P, or "prompt-present-praise." It also inhibits student talk. This discourse style is a variation of I-R-E and occurs throughout the poster presentations listed under the "evaluate" portion of the 5E model. The teacher first prompts (P) a student to "Go!" and begin presenting. The student then presents (P), and the teacher then praises (P) the student. The example below illustrates the P-P-P discourse move where a typical student presentation receives one teacher comment before the class moves on to the next presenter.

T: Go!
S: (looking at poster) The energy diagram, the source is the slingshot, the loss is the energy, the target is the receiver. The evidence of this is the slingshot gives evidence to the motion to the target. And, the force arrow diagram, the arrows go here (points). It is instantaneous because is not holding it there all the way.
T: Yeh, it just hits it for a split second. Thank you, _____.

Here is another example, accompanied by Figure 6.57 of the P-P-P discourse turn at work:

T: Go!
S: My thing is water in the river is pushing against a rock in a river. My source is the water. The energy is the waves (makes a metaphorical gesture with hands). The receiver is the rocks. My evidence is the source, or the water, is moving the rock in the center of the river. It's a push

because the water pushed the rock into the middle. It's a constant force because it keeps on going on, so.
T: Good job.

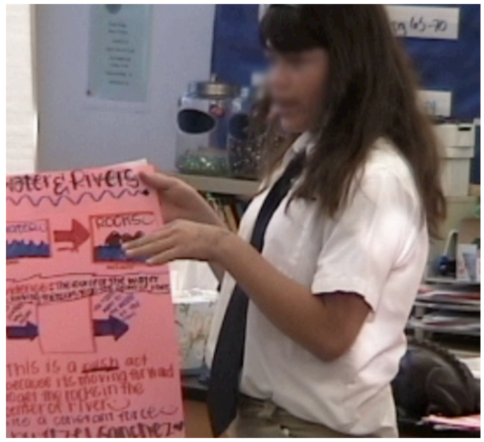


**Figure 6.57: Student Presentation During Use of P-P-P Discourse Pattern**

These examples show how the use of the P-P-P style is not likely to foster student-student talk, as the teacher closes each presentation with either her own concluding comment or a simple, "good job."

The next example provides evidence that the use of the P-P-P discourse style actually discourages student-student talk. A student presents his situation of a construction worker, who slides a piece of construction paper across a piece of wood. He lists off the required elements, looking back at the teacher's charting to be sure he has included all the requirements (see Figure 6.58 below).

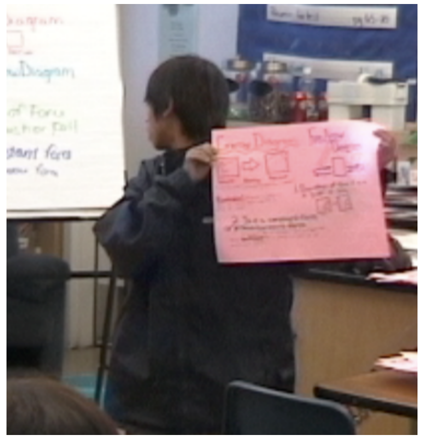


**Figure 6.58: Student References Teacher Chart During Presentation**

He then continues:

> S: ...my energy diagram is that the source is a construction worker, and the energy is muscular strength and the receiver is a piece of sandpaper. The evidence is that the construction worker pushes the sandpaper across the piece of wood.

As he goes on to explain why he thinks this represents a constant force, he “acts” out both what a constant force and what an instantaneous force would look like. He uses papers on a nearby table to act out the two forces (see Figure 6.59 below).

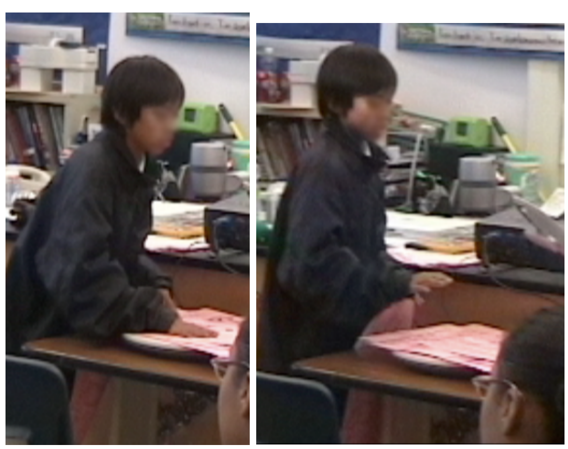


**Figure 6.59: Student Acting Out “Constant” and “Instantaneous” Forces**

The rest of the P-P-P discourse proceeds as follows. The teacher inserts a clarification question in between his final remarks and her final "yep," cementing the learning segment.

> S: For my force arrow diagram, I drew it like this because the construction worker pushes the sandpaper, and yeh, I believe it looks like that because it goes back and forth **(moves his paper back and forth)**, and so for the first question you wrote up there, description of force if it is a push or pull, I put both because he has to go back and forth to make the wood move. I think it's a constant force because, well, a constant force has a pull and has a push, because it switches off, and they go back and forth, so -
> T: So they're going constantly back and forth and back and forth?
> S: Yeh, you can't do it instant, like **(motions with a push of a paper on a flat surface).** You have to go, **(moves paper back and forth with his hands).**
> T: Yep.
> **S2: (whispers). That's not a constant force.**

It is the final student whisper, from a boy listening to the presentation, that illustrates the poignant, striking loss of opportunity here. In this example, we have another typical beginning- a student stands to present and narrates his given situation. The student offers gesture to accompany his claims, and provides examples of what a constant and an instantaneous force would look like. The teacher confirms that he is correct, but the small whisper of a student is heard on the tape in disagreement: "That's not a constant force." It is significant that the student whispers, as it has been made clear by the P-P-P format that there is no place here for additional student input. The structure of this activity clearly does not allow for any disagreement from anyone other than the teacher, so the student gives up, does not pursue his alternative view, and an opportunity to engage students in a discussion of constant and instantaneous forces is altogether missed.

In this next example, the P-P-P is again interrupted by a student question. In the former example, the teacher asked a clarifying question which resulted in the student presenter providing additional gestural evidence to support his claim. In this next example, the teacher asks a question because something is wrong with the information on the presenter's poster:

> S: My situation is, Eddie Guerrero lived… I don't know how this is called (points to force arrow).
> T: Force arrow.
> S: My force is the arrow going this way.
> T: Why is it going that way? Am I pushing this way or am I pushing this way? (Teacher motions with hands and arms in air).
> S: Up.
> T: So why are your arrows that way?
> **S: I don't know. I am going to change them.**
> T: Well, see, that's an important thing. Your arrows go in the direction of the force. Up (motions up with pen in her hand). This is a learning process here my friends.

Rather than working through the misconception the student holds, the teacher accepts the student's response of "I don't know," rather than trying to ask him what it is he *does* know and build from there. Another discourse move would be to open it up to the other students and hear from them, but that would significantly alter the predictable P-P-P pattern. No students challenge any of the presenters and no students ask any questions. All remain silently seated along the periphery of the "elliptical meeting area" as the teacher prompts, praises, and occasionally probes to yield the corollary, or what might be referred to as the "prompt, present, probe, and praise," or P-P-P-P move.

**Lack of Participation Frames to Realize Effective Discourse**

In the next example of discourse in lesson five, we see that Carla uses some outstanding teaching strategies to convey content. In the excerpt below, Carla illustrates the notion of "constant force" by pushing one of her students around the meeting area carpet (see Figure 6.60).

**Figure 6.60: "Constant Force"**

She then gives the same student one gentle push in his back to illustrate an "instantaneous force."

T: So, ______, come here.
(Student comes to the front of the room). A constant force is this…(pushes student around the periphery of the room, see Figure 6.60). Constant force. Instantaneous force (pushes student once).
**S: Oh, constant force is like…**
T: Always happening. Instantaneous is one instant. Instantaneous is for a split second (snaps fingers). Just for that moment (snaps fingers). Constant force occurs for a distance or for a period of time. Me nagging you about your notebooks being awful is a constant force. Instantaneous force is when your parents see your progress report and go, 'oh, you're failing. Why? You're failing, you're grounded – that's an instantaneous force.
**S: It's like often?**
T: Constant is all the time. Instantaneous is just for a moment. It's just for that moment.
**S: You could start with like** (gestures with her finger around the periphery of the room.
T: So, constant force is me pushing Eduardo around the room, and instantaneous is me shoving ______ (uses a gesture to show shoving).
**S1: What? Say it again?**
**S2: Constant is like when she pushed _______ a lot, asi-** (gestures around the room)

T: keeps on going. Gravity is a constant force. It happens all the time.
**S1: Gravity?** (student writing quickly)
T: Gravity. We can't get away from it unless we go out into outer space.
**S2: and instantaneous is like fast, like that moment** (pushes hand out quickly in front of her).
**S1: Do we copy that in page 11?**

Carla here uses a very effective teaching strategy to illustrate the differences between constant and instantaneous forces- visualization through enaction. However, she is clearly missing opportunities to engage in dialogue with her students, and opportunities to allow students to engage in full classroom discourse with one another. Her teaching practice lacks the existence of participation frames whereby her students would be able to take control of their own learning and engage in dialogue with one another. We see instances where a few students initiate statements as in "Oh, constant force is like…" and "you could start with like…" but they are interrupted by the teacher, who reinstates control over the discourse and continues with her explanations of the science. There are also a couple of students who ask clarification questions such as: "It's like often?" and "Gravity?" Rather than asking more questions to empower students to seek solutions to these questions on their own, or rather than redirecting the question to the class as a whole, the teacher reverts to answering all of the questions herself. This, then, leaves the students in a passive role, left to ask questions such as "What? Say it again?" and "Do we copy that in page 11?" One student does take it upon herself to answer her classmate who has just asked "What? Say it again?" She answers, "Constant is like when she pushed _______ a lot, asi- (gestures around the room)… and instantaneous is like fast, like that moment" (pushes hand out quickly in front of her). However, these are side conversations that benefit one student only. If Carla were able to utilize students' emerging understandings, not only would student-student talk become ignited, but these emerging understandings would come delivered via a blend of word and gesture-something from which many of the other students could also potentially benefit.

**Affective Teacher Practices**

As in lesson four, there were a number of instances of strict disciplinary measures taken during lesson five. Early in the lesson, the teacher approached a sleeping student and slammed a book very loudly on the table in front of him, shouting: “You! Don’t fall asleep in my classroom again! Put your head up!” Though discipline is a necessary component to instruction, some of the disciplinary actions lead to a disinclination to speak during class time. There appeared to be a high affective filter present in the classroom when the teacher said things such as: “So, if you pay attention in class today, you will have no problem on this quiz. You don’t pay attention, you’re going to have a problem.” This seems to imply that if you listen, you learn; if not, you don’t. There is no emphasis on engaging with the material in a meaningful and thought-provoking manner. Rather, the emphasis lies on “paying attention” as if things would be explained and the student is merely to “take it all in.” This implies any lack of understanding is directly due to a lack of attention alone.

In another example, the teacher can be heard saying: “We’re going to get these done in the next five minutes, so…” Students then echo: “Hurry up!” followed by the teacher again: “Go! C’mon ________. Read it out loud!” Time is clearly of the essence here and takes precedence over student talk. It is clear from the way the poster activity was structured in this lesson that each individual student is presenting individual work, but only the teacher is commenting on it. There is quite literally no "time" for other input.

Summary and Discussion of Teacher Practices from Lesson Five

Many of the "teacher practices" prevalent in lesson five, discouraged student-student talk. Punitive disciplinary tactics seemed to create an environment that shut down student talk. The use of a P-P-P discourse format also did not allow for student contributions to classroom talk, but rather positioned the teacher at the helm of the oral presentations across from a single student presenter. And finally, an overall lack of participation frames for student talk prevented otherwise effective teaching practices from achieving full potential in terms of student contributions.

*Summary and Discussion of Lesson Five Across All Three Domains: Pathway Four*

The "physical structures" domain was the only one that remained neutral in its effect on student talk in this lesson. The other two domains were found to constrain student discourse. This lesson is an example of pathway four in the model presented in Figure 6.2. If we follow the large yellow "explore" and "explain" arrow on the far right of the model, down to "teacher practices that constrain discourse" in blue, we can locate the "lack of participant frames" seen in lesson five. Together, the many teacher practices that constrained student talk in this lesson, contributed to a lack of student ownership over the learning in any meaningful way. Though the students are able to create posters, these posters merely represented a "plug in and substitute" type of assignment that did not demonstrate authentic learning on the part of the students. It is difficult to ascertain what they do and do not understand of the science. They have clearly not unpacked the learning and made it their own, before repackaging it back into the black-boxed version first presented to them by their teacher. In fact, their versions appear alarmingly identical to the one presented to them through direct instruction by their teacher.

*Lesson Six – Identification and Definition of Frictional Forces, Discourse Led by "Teacher Practices" Domain*

Lesson six is the final sample chosen from the data collection period in Carla's classroom. The purpose for this particular lesson was for students to be able to identify and define frictional forces. Figure 6.61 below depicts the agenda for the day, as it appeared to students on the front white board.

| |
|---|
| Agenda |
| Purpose: Students will be able to identify and define frictional forces. |
| Prelude: What is friction? What causes it to occur? |
| Engage: Car |
| Explore: Friction in sports |
| Evaluate: |
| Extend: Putting It All Together |

**Figure 6.61: Agenda for Lesson Six**

The highest level of argumentation achieved during this lesson was a two, which occurred during what the teacher identified as the "explore" portion of the lesson. Students were participating in a "shared reading" about the sport of curling. This is an activity that would typically be more conducive to the "engage" phase of the lesson, as it is designed to peak the interest of the students and to evoke whatever prior knowledge they possess on the topic of friction. Therefore, it is out of place in the "explore" section of the 5E model. The three highest instances of argumentation were achieved by two different students. In each case, the claim and evidence were co-constructed via words and gestures, and the teacher's prompting. Aside from these, the predominant level of argumentation from lesson six hovered at a level one. There were seven level "1,"s, two level "0"s, and three level "2s" during this lesson.

Overall, the domain of "teacher practices" had the most influence on the student discourse in this lesson. Below I describe which teacher practices constrained student talk and which fostered it.

*Teacher Practices Constraining Student Discourse*

As in lessons four and five, there is a predominant use of the I-R-E discourse style in lesson six. There are also similar affective practices to those seen in lessons four and five; all of these practices constrained student talk in lesson six.

<u>I-R-E Discourse Style</u>

In the example below, we see the teacher begin the lesson by asking students what they think friction is. This is not a topic that the class has studied before this lesson, so in essence, this is the teacher's first attempt at eliciting prior knowledge.

> T: ____, what's friction? You had your hand up first. (I)
> S1: A source of energy? (R)
> T: A source of energy. Okay. (E)
> S2: Oh, it is?
> T: No, you say what you think it is because he might not be right. What do you think it is? (I)
> S2: (Consults two papers in front of him). It's a force that pushes me in an opposite way? (R)
> T: Ooh! A force that pushes in the opposite way. Wow! You're smart and you're right. (E) So today's activity involves all sorts of balls…

Here, we see two turns in the I-R-E sequence, the first with S1's uncertain answer of "a source of energy?" and the second with S2's response of "a force that pushes me in an opposite way." If Carla had indeed intended to follow the 5E model as it was originally intended, this would be a time for her to elicit as much information as she possibly could before moving on to the "explore" session. The collective student remarks would then be revisited at the end of the lesson during the "explain" portion. However, we do not see that here. Rather, we see Carla cycle through until she gets the "correct answer," which consists of the input from only two students. Carla then deems the second response from the second student as both "smart" and "right" respectively. This effectively shuts down any further student contributions. Carla's next statement, "so today's activity involves all sorts of balls," makes it clear that the "correct answer" has been achieved, and they are ready to move into the activity for the day.

I-R and I-A Discourse Patterns

We see even shorter discourse patterns occur immediately after the above example. Rather than the previously documented I-R-E sequence, we see even shorter I-R and I-A sequences during this lesson. Both discourage student talk. In the I-R sequence, we see Carla initiate a question (I) and receive a single student response (R), but with no (E,) or evaluation afterward. This is immediately followed by an I-A pattern, where Carla initiates a question (I), but then answers (A) her own question, and moves on. These patterns are described in the context in which they occurred below.

After the prelude, Carla takes out the objects the students will be working with in the lab. All the objects are balls used in sporting events: tennis balls, racquetballs, baseballs, basketballs, soccer balls, whiffle balls, bocce balls, etc… This activity comes from SPAWAR's Materials World Module (MWM) Kits – modules given to local teachers who agreed to become trained at SPAWAR on how to teach science and engineering through an inquiry approach. In the training module, teachers are directed to to allow students to spend time observing and handling the balls, which are cut in half to reveal their inner materials. Specifically, the manual instructions ask students to: ***"Make observations of the ball you are using. Measure its mass. Describe its surface texture. Include a description or sketch of any surface irregularities. Record any other observations you have about the ball that you think might relate to the way the ball will roll on different surfaces."*** Instead of following this part of the lab, Carla performs all the object manipulation, observation, and talking herself, as seen in the example below. As she does so, she utilizes a brief I-R followed by an I-A and an I-R-E sequence of discourse.

> T: So, if we take a ball, like this tennis ball, and we cut it in half, the inside of this tennis ball is hollow. Everybody see that? (holds tennis ball up and then sets it on the document camera).

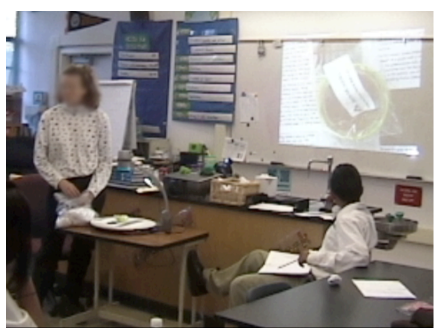


**Figure 6.62: Tennis Ball on Document Camera**

> T: The inside of the tennis ball is hollow. Here, I have a softball and a baseball (shows them, also cut in half, walks around the inside of the elliptical meeting area). So, are these two made of the same material? (I)

**Figure 6.63: Teacher Shows Softball and Baseball**

Ss: Yeh! (R)
T: Well, what about this one? (I) Is that the same as this (holds up two more kinds of balls cut in half)? This is a little league ball. It's got like a wooden core, with a bouncy ball around it. So, little league balls are different from major league baseballs. It's got more bounce to it, so you can hit them out. (A) (Sorts through plastic bag of materials and pulls out another ball part, holds it up). What is that? (I)
Ss: A basketball. (R)
T: A basketball. (E – affirmation of student's response)
S: Oh, that's sick right there (teacher ignores comment).
T: Soccer ball (holds up another one). Inside (holds up both) the basketballs and the soccerballs are the same.
S: Air is the reason they bounce. LEVEL 1 (ignored by teacher)

In this example, we see the teacher complete one I-R, followed by an I-A and then the common I-R-E pattern again. She understandably ignores one comment by a student who calls out "that's sick right there," but then misses the opportunity to expand on another student's comment that "air is the reason they bounce." This statement is actually an important claim that might have initiated a poignant discussion on what factors can and do influence the "bounce" of a ball. Unfortunately, the level one claim is never built upon. Rather than drawing students into a conversation about what they observed, by allowing them to hold the balls and make their own observations and hypotheses, Carla holds and controls all the materials in her own hands. She even tells the students outrightly what they should be discovering on their own. She tells them that the insides of basketballs and soccerballs are "the same," and that the difference between little league balls and major league baseballs is that the former has a spongy area surrounding the pithy core that both balls otherwise share in common. Carla uses the document camera to showcase some of the balls from afar (see Figure 6.62) and at other times, circulates about the elliptical meeting area to show the balls to the students (see Figure 6.63). In all cases, she tells the students how the balls differ, and does not give them a chance to hold the materials at this point at all. Because of this tight control over the objects, as well as the tight control over the turn-taking in talk, students do not have the chance to engage in any hypothesis generation or argumentation.

Affective Practices that Constrain Student Talk

Lesson six is tainted by an overall affective teacher practice that discourages student talk. At several points in the lesson, the teacher reminds the students they are not to talk. One of these instances occurs at a point in the lesson that should be done as a discovery portion, as described above. Students should be holding and exploring the insides of the severed sports balls themselves. Instead, as Carla controls and talks about each ball, we hear a student excitedly claim: "That looks like a croquet ball!" Rather than capitalizing on this remark, the student is shut down. Carla says: "I'm sorry. I'm teaching. You're not talking." As mentioned previously, Caine and Caine (1991) identify "relaxed alertness" as a necessary component in brain-based research. This entails low threat combined with high challenge. We see, in this example, high threat, (conveyed in teacher tone), and low challenge, (low level questions). This combination is not conducive to learning, nor to the generation of student talk in the classroom.

Lack of Participation Frames During Excellent Instruction

As in lesson five, we see that Carla uses some outstanding teaching strategies to convey content, but most of the time lacks participation structures that could frame and enable students' engagement in argumentation. In lesson six, Carla again makes use of "kinesthetic modeling" when she moves her chair across the carpet to illustrate the combative force of friction (Figure 6.64).

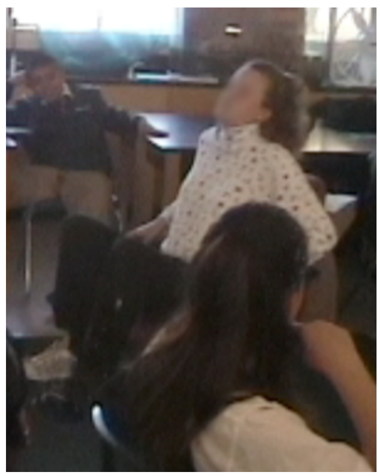


**Figure 6.64: Teacher Demonstrates "Sliding Friction"**

She also utilizes the process of re-enactment that we saw in Dave's classroom, whereby she performs again the same activities the students completed in their exploration in order to achieve perceptual objectification (Figure 6.65)

**Figure 6.65: Re-enactment of Dropping Bocce Ball on Foam**

However, both of these notable teacher practices are used without participation frames that provide students' access to conversation and discussion around the science they are learning. During both examples, the talk is teacher-centered. Accompanying the "kinesthetic modeling" of sliding friction, we hear Carla's commentary after she reads portions of the article on the sport of curling out loud:

> T: The amount of friction between two objects depends upon the surface of each object" (reads from article on document camera). So, the amount of friction between two objects depends upon that surface. So, I don't have very much friction up here. I can go like wheee! (slides her own chair towards another student's chair). I can go on carpet (has to work harder to slide her chair). I can't go very far. There's no whee factor.

She then continues reading from the article about the sport of curling. There is no point of access for students to question or comment. Carla reads, illustrates and explains all.

The context surrounding Figure 6.65 is that the teacher has just asked which surface has the least amount of friction. One student claims that it is the pink styrofoam. The regular foam is deemed the next surface possessing the least amount of friction. Rather than polling the students and creating a discussion of this possibility, Carla chooses to reenact the dropping of the bocce ball onto the foam surface (Figure 6.65). She says:

> T: Because notice what happens (takes the foam back out and lays it out in front of the group). Here's my foam. (Takes out bocce ball). Here's _____'s ball (drops it on the foam surface).

This would be the ideal time to access a participation frame that would maximize student discussion, as seen in Dave's discourse pattern of polling the class and taking alternative responses. And, in fact, one student in Carla's class does initiate, by stating "ooh, that thing went straight through," acknowledging the heavy weight of the ball bearing down and smashing the foam into a thin packet on impact. But, rather than utilizing this as an opportunity to enter into class discussion with the students, Carla again reclaims control, essentially *telling* the students the relationship between foam, heavy items, and friction:

> S: Ooh, that thing went straight through. LEVEL 0 – observation.
> T: Yeh, it's heavy. So, is foam- if the object is heavy, is foam good for friction? Does it provide a lot of friction? Is this why we wrap up all our collectibles in foam? (rhetorical questions)
> S: Roll it! I want to see it!
> T: I'll roll it. It doesn't go very far. (Tells students the answer without allowing them first to observe the re-enactment themselves)
> S: It doesn't go! LEVEL 0- observation.
> T: (rolls yellow bocce ball across the foam surface for the class to see). See, it stops. Now, the lightest ball (takes out the wiffle ball, and rolls it across the foam). There. The wiffle ball keeps going. You can use this data. Excuse me- you're going to use this data to answer the questions on the last page of the lab. I'm going to give you a copy. You may read the last page and start copying them.

Here we see Carla continues to control the talk through her re-enactment practices with the lightest ball, the wiffle ball. Again, rather than using this re-enactment as an opportunity to poll the class and test out students' hypotheses, Carla chooses to control the action. She rolls the wiffle ball and states what she, not the students, sees: "The wiffle ball keeps going." She continues controlling the classroom talk by next shifting gears from the observation and analysis of the balls' movements across surfaces, to giving directions about students' next steps, telling them they will now use this data to answer questions on the last page of the lab. The teacher has presented herself as the "source of all knowledge" so to speak. She even leads the class by asking questions, but then answers those questions herself. Her final about-face to "you will now use this data to answer the questions on the last page" effectively ends all discussion.

Both the practice of using re-enactment and the practice of using "kinesthetic modeling" to illustrate science, are effective practices for student visualization; Carla is to be commended for using such practices. However, the verbal talk that preceded and followed these practices did not allow for "checking in" with the students. While they are effective visualization practices, they need to be combined with a discourse style and participation frames that would allow for student talk to make student thinking "visible" to the teacher. In the next example, I describe teacher practices that Carla *did* use with participation frames; these enabled, rather than constrained, student argumentation in the same lesson.

*Teacher Practices Enabling Student Talk*

<u>I-R Discourse Style within Context of A "Shared Reading Activity"</u>

As mentioned earlier, Carla made use of a strategy called a "shared reading" before allowing students to explore the rolling of different sports balls across four different surfaces: styrofoam, foam, astroturf, and indoor-outdoor carpeting. A "shared reading" is a strategy in which a teacher visually shares a text with students to explicate her thinking. The goal of the entire lesson was to observe and uncover the effects of friction. Figure 6.66 below shows Carla seated at the document camera, projecting the text of an article that her students also had in front of them. The article is about the Olympic sport of curling. In this sport, athletes sweep ice in front of, and in back of, a rolling ball, with the ultimate purpose of directing the ball into the opponent's goal.

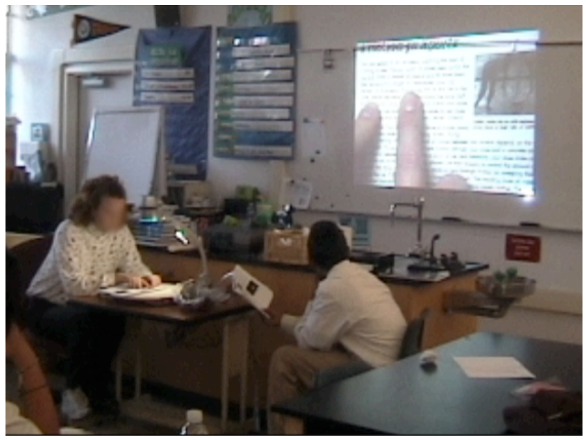


**Figure 6.66: "Shared Reading" on Sport of Curling**

During the "shared reading," Carla reads portions of the text, following along with her index finger trailing the words as she speaks them aloud. She pauses occasionally to either clarify a word, elaborate on a point made, or to illustrate a point that may be unclear to the students. During the "shared reading," there were two instances of a level two argumentation that were made, the highest achieved during the entirety of lesson six. These two instances are described below.

In the first example, we see that Carla has desisted from her default discourse pattern of I-R-E. Rather, she uses a more probative style with her students.

> T: Why are they sweeping the ice back and forth? (I)
> S: So, it will keep on going faster? (R) LEVEL 1 – Claim= the team is sweeping the ice back and forth so the stone will keep on going faster.
> T: So, the stone will go faster. Why? (I)

S1: (hand is up).
T: (calls on student with hand up).
S1: So the ice is smoother (gestures a flat surface with her hands). (R) LEVEL 2 Claim= the team is sweeping the ice back and forth so that the stone will go faster because the ice is being made smoother by their actions (co-constructed with use of student gesture and teacher prompting).
T: So the ice is smoother? Is the ice sort of melted or is it just, or are they brushing off the dust? (I)
S1: They're brushing off the dust because when they skate, there's like bumps and stuff. (R) LEVEL 0
T: Are they brushing out all the bumps? (I)
S: Yeh. (R)
T: Are they melting some? (I)
S1: (shrugs)
T: You don't know?
S2: Yeh. (R)
T: Yeh, you think so? (I)
S2: Yeh, because the water like makes it slide (gestures a flat surface and sweeps his arm across in front of him). (R) LEVEL 2- The water makes the ball slide, so therefore the ice must be melting (co-constructed with gesture).
T: Okay, let's keep reading and find out.

Six turns of the I-R move, yields two instances of level two argumentation. In the transcript above, we see Carla initiate a question, and then receive a student response. Rather than defaulting to a typical pattern of then assessing that student response, Carla does something I seldom saw her do doing the data collection period. She continued to initiate questions and probe her students' thinking by not commenting on their initial responses, and waiting to see where her further probing might take them in their thinking.

In the section earlier, we saw this I-R pattern described as one that contributed to the inhibition of student talk, whereas here it fosters and encourages student talk. The difference is that here we see the pattern is immediately repeated over and over again, six times, achieving a momentum that facilitates student participation. I refer to this as I-R "chaining." In fact, we see the student in this first example in the midst of what Crowder and Newman (1993) call the "sense-making" stages of her thinking. As Carla probes her to think about why the curlers are sweeping the ice back and forth in front and in back of the ball, we see the student articulate partly in words and partly in gesture her level two argumentation, a claim with evidence.

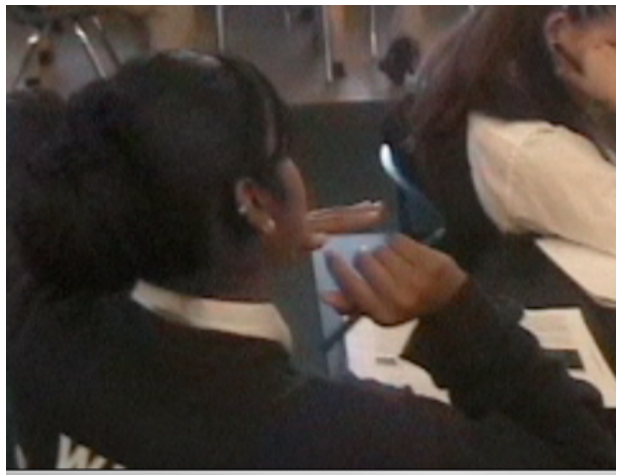


**Figure 6.67: Student (S1) Articulates Argument with Gesture**

S1 states: "So the ice is smoother," and as she says this she gestures a flat surface with her left hand, while continuing to gesture with her right hand, in well-timed rhythm with her speech. By virtue of the repetitive I-R pattern of Carla's discourse style, a claim is co-constructed between the teacher's probative questions and S1's staccato speech and gesture. The level two argumentation can be strung together to make the following sentence: the team is sweeping the ice back and forth across the surface so that the stone will go faster because ice is being made smoother by their actions.

The I-R pattern continues still after this first level two is claim is made. Carla probes S1 further, but ultimately receives a shrug from S1, and the discussion thread shifts to S2:

T: So the ice is smoother? Is the ice sort of melted or is it just, or are they brushing off the dust? (I)
S1: They're brushing off the dust because when they skate, there's like bumps and stuff. (R) LEVEL 0 - observation
T: Are they brushing out all the bumps? (I)
S1: Yeh. (R)
T: Are they melting some? (I)
S1: (shrugs).
T: You don't know.
S2: Yeh.
T: Yeh, you think so? (I)
S2: Yeh, because the water like makes it slide (gestures a flat surface and sweeps his arm across in front of him) (R) LEVEL 2- The water makes the ball slide, so therefore the ice must be melting (co-constructed with gesture).
T: Okay, let's keep reading and find out.

As with S1, the second student is also able to achieve level two argumentation through a co-construction of partial words, his own gesture, and the teacher's gentle probing.

**Figure 6.68: Student (S2) Communicates Argument with Gesture**

Following the established sequence of thought to this point, S1 has said that the team is sweeping in order to make the ice smooth. Here, S2 adds that the ice is actually melting, as evidenced in "the water like makes it slide." His contribution to the conversation then, is that the team is sweeping the ice to melt it so that the ball will slide faster. By the use of this repetitive I-R pattern involving two students, Carla successfully paves the way for an understanding of friction. She then says: "Okay, let's keep reading and find out."

Unfortunately, for the rest of the "shared reading," only level one argumentation levels are attained. The I-R "chaining," or repetitive pattern as used in the two examples above, ceases after S2 makes his point. Following this, though Carla does continue to use the I-R model, she opts to do "direct teaching" and "tells" students what they could be discovering through student-student-teacher discourse and argumentation. The next transcript example shows where Carla leaves the I-R turn for a segment of "direct teaching." This essentially stops further student contribution, until the next "I" is tossed to the group.

> T: So, if I try to play golf in really long grass, is my ball going very far? (I)
> Ss: No. (R) LEVEL 1 Claim- ball will not go far in long grass.
> T: What if I have really, really short grass, like my carpet (points to meeting area carpet). Is my ball going to go very far? (I)
> Ss: Yes. (R) LEVEL 1 Implicit Claim= The ball will go far on short grass, but then the teacher supplies all the rationale in her explanation below.
> T: Yeh, it's going to keep going. (Begins direct teaching) "On a golf green, on a golf green, the condition of the grass can have a major effect on how well the golfer plays because the type of grass, how densely it is packed, and how short it is, determine the amount of friction between the ball and the green. The golf course at Torrey Pines? Their grass is like this (gestures a width with thumb and forefinger). This short, and dense. Really, really short grass, because normal grass is like that wide (gestures again, see Figure 6.69 below).

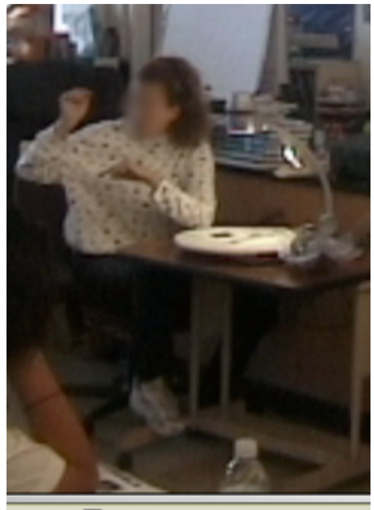


**Figure 6.69: Teacher Gestures During Direct Instruction**

T: Their grass is like this long (gestures, see Figure 6.70 below), and really, really densely packed.

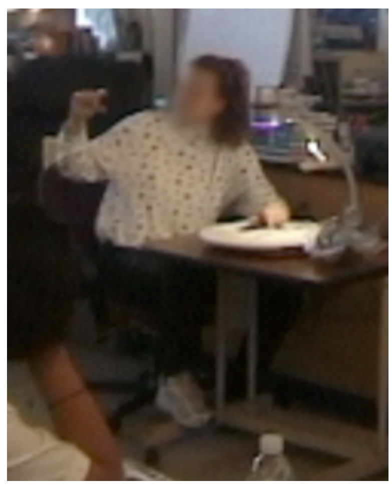


**Figure 6.70: Teacher Gestures Grass During Direct Instruction**

T: You cannot count how many pieces of grass there are if you pull it out. Whereas, at my house, my grass is really long, especially now because of the rain. At my house, you could count how many pieces of grass there are if you pulled it out from the ground. My grass is really long, especially since it rained, my grass is super long. "How densely it is packed together and how short it is cut determine the amount of friction between the ball and the green. This in turn affects how fall the ball can roll. On a firm green, a softly putted ball can roll a long way. The same ball put on a softer green might stop several feet short of the hole. For this reason, green's keepers help golfers by measuring the speed of the green with a

> device called the stepmeter." Did you know there is actually someone who gets paid to see how fast the green is?

The loss to the momentum of the I-R pattern, where the teacher tosses out probing questions in quick succession, causes a halt to the attainment of higher levels of argumentation. In fact, for the rest of the period of the "shared reading," once each I-R turn is followed by direct instruction, the only other student comments that are made consist of short utterances, and one curiosity question, tangential to the science:

- "Uh-huh" (in response to teacher's "It's slippery, right?")
- "No" (in response to teacher's "Do we have ice [in San Diego]?")
- "No," and then, "yes" (in response to teacher's questions about whether a ball will roll far in long grass and short grass respectively) – Level 1 argumentation (an "implicit claim" with no evidence).
- "How much they get paid? A million?" (in response to the workers at Torrey Pines green)
- Where'd you get that? (in response to the astroturf used for the lab)

There is very little student talk, with only two instances of level one argumentation. Teacher talk dominates most of the time that remains during the "shared reading" once the I-R discourse move is followed by periods of direct instruction only.

*Summary and Discussion of Teacher Practices in Lesson Six*

There are numerous teacher practices that constrain student talk in lesson six. We see the continued use of the I-R-E discourse format in this lesson, punctuated by its shorter versions of I-R and I-A; there is a lack of participation frames during much of the lesson that inhibits students' access to the discussion during periods of teaching that actually include excellent instructional strategies such as "kinesthetic modeling;" and, we once again see certain disempowering affective practices that seem to shut down student talk.

However, we also see the presence of a new discourse format in this lesson that carries the promise of student access to classroom discourse. This is the I-R chaining discourse format, wherein a momentum of turn-taking is achieved between students and teacher that facilitates student participation and includes their voices in the formation of arguments about the science of friction. It is this teacher practice that enables the instances of level two argumentation in this lesson.

*Classroom Systems/Processes*

In this lesson, the 5E lesson model system appeared to have a neutral effect on student discourse. Rather, the achievement of argumentation, or lack thereof, was mainly influenced by the discourse style the teacher chose to use at different stages of the 5E model. Nothing inherent in the 5E structure itself affected student discourse. However, the "explain" portion of the lesson was never completed due to disciplinary issues. The lack of having this discussion occur could have contributed to the overall learning or lack of learning. I did not have access to the students' notebooks to see their achievement in writing. But, not having the opportunity to fully participate in the "explain" portion of the lesson certainly inhibited student argumentation opportunities in lesson six.

*Physical Structures*

As in all of Carla's lessons, the two main seating arrangements that were used were the students seated at groups of two or four at tables, and the "elliptical meeting area" formation (see Figure 6.71 below).

**Figure 6.71: "Elliptical Meeting Area"**

To achieve this formation, students simply rotate to the inside part of the desks closest to the meeting area carpet as seen in Figure 6.71. There does not appear to be any strict rule about when the students are asked to gather in the "elliptical meeting area." Therefore, there does not seem to be any correlation between student argumentation and seating arrangement for this lesson. In fact, in lesson six, the "elliptical meeting area" is actually used a "punishment" to the students when they cannot get quiet for the teacher. This is illustrated in the following transcript:

> T: Which surface slowed it down? Stop boys! I'm sorry. Come up to the meeting area.
> S: Oh my G-d!
> T: Meeting area, c'mon. Boys, stop (students begin to form the "elliptical meeting area"). 19, 18- (teacher begins counting down).
> S: Hey, you're not in the meeting area!
> T: Which surface slowed your balls? (Points to question on the doc cam. Students now seated in the meeting area). Number two, "How do your data compare with those of your classmates?" So, that's where you're

> going to use that class data table. "For all the different kinds of balls, was there one surface that allowed the ball to roll the farthest? Was there one that impeded the ball's motion? Number three, did some balls roll farther across all surfaces than other balls did?" Did some balls roll farther regardless of the surface? You have to look back at that class data. Which ones? "Which types of balls stopped rolling soonest?"
> S1: The big ones. LEVEL1 Claim- the big balls stopped rolling the soonest.
> T: So, "the big ones" won't be a complete enough answer.
> S1: The heavy ones! LEVEL 1 Claim- the heavy balls stopped rolling the soonest.
> S2: The bocce!
> T: Guys- the heavier, larger, more dense balls. (Teacher tells them the answer).
> S1: Where do we write this?
> (Students chattering)
> T: Wait just one second! This is ridiculous!

The fact that students come to the meeting area does not seem to change the discourse in any way. In the above interaction, we see that two level one arguments are made after coming to the meeting area. Before coming to the meeting area, the teacher used the same discourse style and there were also only two level one claims made, following the class data collection. After the final frustrated remark by the teacher with which the above transcript ends, the students are required to work alone on answering the rest of the questions and to take their work home for homework if they do not finish in class. This effectively ends any opportunities for students to engage in interactive discourse or argumentation formats. Although this occurs while students are seated in the "elliptical meeting area," it is seen as an effect of a "teacher practice."

*Summary and Discussion of Lesson Six Across All Domains- Pathway Two*

Lesson six is illustrative of pathway two in the model represented in Figure 6.2. We begin with the large yellow arrow at the far right which houses the red representations of tables. In this lesson, the seating arrangements did not appear to influence opportunities for talk. Following the arrow down to the middle blue "teacher practices" box, we see that the I-R chaining talk format was conducive to generating student ideas. This, in turn, allowed for the process of resemiotization to take place, which in turn led to the black-boxing of ideas about friction. Although there were not consistent opportunities for perceptual objectification, there were instances of "pseudo-scientific language" emerging that represented the students' best attempts to express the science they were learning. Without the opportunity to discuss the activities in a group, students used whatever language they could to repackage their learning into whatever linguistic forms they could. I represent this learning in the final box under pathway two as the "Black-boxing of Science in Pseudo-Scientific Terms."

## *Summary and Discussion of the Chapter*

From the six sample lessons we can see that factors from the domains of "teacher practices," "classroom systems," and "physical structures/environment," do not always fall within only one domain. For example, it was sometimes difficult to claim that a particular factor was a component of "teacher practices," rather than an element of "classroom systems." In Dave's classroom, the practice of using questions to scaffold the process of making claims can be both a "system" that the students have routinized, or a "teacher practice" that points to a particular belief instantiated in Dave's practice. These domains were useful constructs in studying the factors that constrained and enabled student talk. However, they are fluid constructs, and ultimately, it was not important to the outcome of this study to permanently commit factors into one specific domain versus another.

Irrespective of those elements that might be said to traverse domains, I have identified four main pathways that lead to varying degrees of student articulations of their understandings of science. Figure 6.72 below depicts these four pathways once again.

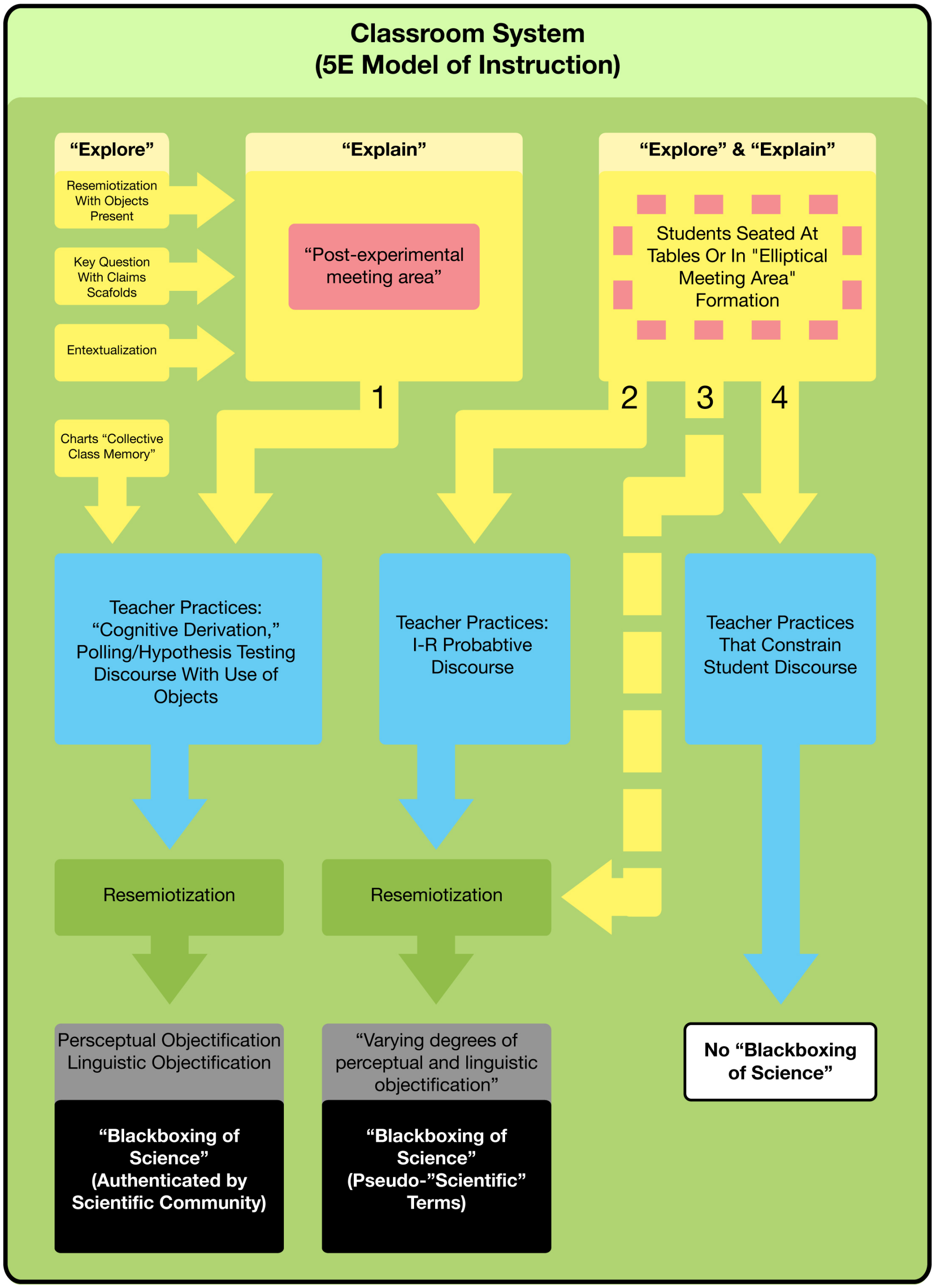



**Figure 6.72: Four Pathways Leading to the Black-boxing of Science in Inquiry-Based Settings**

"Classroom systems" are coded in yellow, "teacher practices" in blue, "physical structures" in red, and opportunities for resemiotization in green.

One of the main goals of this study is to expose the processes inherent in Latour's notion of the black-boxing of science. How is it that science becomes encoded into neat little "black boxes"- charts, tables, graphs, words? Such neat packages hide the processes by which the work is accomplished. In pathway one of the model, we see that the students, like scientists, are able to "black-box" their understanding of science into facts that are linguistically objectified in a way that is authenticated, recognizable, and unassailable to the scientific community at large. This does not mean it is necessarily as sophisticated in its sentence structure, etc… For example, the simple claim that friction is a constant force that acts in the opposite direction of movement, and slows objects down, is one that has consensus in the larger scientific community. It is a widely accepted claim by the scientific community. On the other hand, a statement such as "Your fingers pull the rubber band and give it the elasticity to hit the air," is not a claim that can be coded via scientific talk in a manner that can be authenticated by the larger scientific community. Such a statement has not yet moved beyond the situated activity in which it first took root, and therefore does not contribute knowledge in any meaningful way to the body of science. This would be an example of the results of both pathways two and three, where student understanding is expressed in a black-boxing of science that may or may not be "correct" and that is the result of varying degrees of both perceptual objectification and linguistic objectification. Student learning is expressed in variations of "pseudo-scientific terms."

Pathway four leads to no black-boxing of the science at all. Students are left in a state of possibly or possibly not understanding the science behind the exploratory work they have accomplished. There is little or no articulation of the science to determine the state of student knowledge. Below, I describe the confluence of the three dimensions and describe their contributions in each of the pathways identified.

*Pathway One*

In the first pathway, we see there is a confluence of red, yellow, and blue. As described previously, the red represents the physical structures of the classroom; the yellow represents the classroom systems at work; and the blue represents the teacher practices utilized during the data collection period. The classroom systems of "key questions with claims scaffolds" together with the work of resemiotization during the "explore," with "entextualization," and the system of using charts from the collective class memory, all filter into the large yellow "explain" arrow at the top of pathway one. It is here, within the "explain" portion of the 5E model of instruction where most of the work of black-boxing begins. Within the larger framework of the "explain" arrow, we see the red "post-experimental meeting" area which makes possible the structure for students' participation frames. In this structure, students are able to interact with each other and with their teacher. Following pathway one vertically down, we see that the "teacher practices" in blue then add to the model. These practices provide the necessary "more capable peer" who uses "empowering language," "cognitive derivation," and a discourse style that makes use of a polling and hypothesis-testing model over the use of objects. The multiplicative power of these colorful arrows converge to a green arrow representing “resemiotization.” The students are able to achieve perceptual objectification in the “post-experimental meeting area” through their teacher’s reenactment of activities; but they are also able to achieve linguistic objectification through successive iterations of resemiotization and the careful, purposeful guidance of their more capable peer, the teacher. By orchestrating discourse that operates at a level four, the teacher is able to guide the class to a black-boxing of the science in language that closely approximates scientific authenticity.

Data from lessons one, two, and three contributed to the model of pathway one. It is the identified pathway that leads to the highest levels of argumentation documented in this study. In this pathway, the “post-experimental meeting area” was consistently found to be the crucible of student talk. Its structure enabled effective classroom normatives to operate, such as the distribution of learning across multiple representational media and the reference to entextualization on the white boards. Embedded in this structure, were the different types of teacher practices described above. Of all the components, it seems the teacher practices that enable discourse are most crucial to cementing pathway one.

*Pathway Two*

Pathway two results in students’ black-boxing of science into “pseudo-scientific” language. In these cases, the words used to describe and explain the science are not words universally accepted by the larger scientific community. In this model, we see that the crucible beginning this journey is identified in the large yellow arrow labeled “explore and explain” at the upper right of the model. Pathway two represents instances where results are achieved either as students sat in their group tables (Carla’s class) or as they were seated at the "elliptical meeting area" (Carla's class). Both of these seating arrangements are depicted in red within the larger framework of the yellow "explore and explain" arrow at the upper right of the model. From here, pathway two includes teacher practices (middle blue box) that enabled student discourse. Such practices include the use of the I-R "chaining" discourse style requiring the intervention of a more capable peer (teacher, or researcher as we will see in Chapter 7), and the reenactment of student activities with objects, leading to perceptual objectification. When these factors were present together, opportunities for resemiotization were made possible, in turn enabling a black-boxing of the science. However, in pathway two, linguistic objectification was not always achieved. Rather, the science was left conveyed in "pseudo-scientific" language not paralleled in the scientific community at large. Data from lesson six was the main impetus for the creation of this pathway within the model.

*Pathway Three*

Like pathway two, pathway three also begins in the crucible of the yellow "explore and explain" arrow at the upper right of the model. The main difference is that pathway three represents instances where the students are left on their own. There are not a lot of mediating teacher practices present at all. Students are working at their tables with a partner and work on resemiotizing the science through language, object manipulation, drawing, and writing. The problem is that there is no "more capable peer" present to assure that perceptual objectification is established. Even when this does not appear to impede ongoing progress with the resemiotization, students do not produce linguistic objectification that could be authenticated in the scientific community. The language they use does indeed achieve some type of "black-boxing" of the science, but the terms are only "pseudo-scientific," just as they are in pathway two. Data taken from lesson four was instrumental in designing this third pathway.

*Pathway Four*

And finally, pathway four illustrates the route to a non-successful black-boxing of science. It begins within the same crucible as pathway two: in the large yellow arrow of the "explore and explain" at the upper right of the model. However, in lessons taking this path, there appear to be the additional presence of teacher practices (in blue) that constrain student discourse. These include practices that do not create what Caine and Caine (1991) call "relaxed alertness," or a state where there is a climate of high challenge and low threat. These also include discourse practices that inhibit student-student interaction such as those previously identified as I-R-E, P-P-P, I-R, and I-A. As well, these include some outstanding teacher strategies such as "kinesthetic modeling" and the use of "shared readings" that are not also accompanied by participation frames for students to make visible their own thinking through talk. When such constraining teacher practices are present, there is no black-boxing of the science at all, and students are often left in a passive state of listening to the teacher and asking what to copy until time runs out and the conclusion is left for the students to complete alone at home. Data from lessons four and five were the contributing sources for this pathway in the model.

*Conclusion*

Of the four pathways, pathway one is the paradigm for the use of inquiry-based instruction that leads to authentic black-boxing of science. It involves an intentional blend of effective “classroom systems,” “physical structures” that clearly provide for student participation frames, and “teacher practices” that promote student discourse. All three of these domains (yellow, red, and blue) converge to provide opportunities for students to resemiotize their learning through multiple modalities via multiple iterations. This, in turn, allows for both the perceptual and linguistic objectification that leads to the black-boxing of “correct” science into authentic scientific language agreed upon by the class as a whole, and validated by the larger scientific community. Pathway one is an exemplar of guided-inquiry-based instruction.

# Chapter 7- Orchestrating Resemiotization in Guided-Inquiry to Actualize Scientific Argumentation

*Overview of Chapter*

In the last chapter, I investigated the factors affecting students' opportunities to engage in classroom talk, by analyzing the two classroom contexts along the three dimensions of "teacher practices," "physical structures," and "classroom systems." I also proposed a model that illustrates how these dimensions work with and against each other, resulting in four pathways for guided-inquiry instruction. Of the four, pathway one is regarded as a paragon of guided-inquiry instruction. In this chapter, I continue to explore the over-arching research question of this study, seeking to provide further insight into the factors that promote inquiry-based instruction in middle school science classrooms. I specifically look at the levels of argumentation students are able to achieve, and then deconstruct their talk into the contributing modalities that inform their final ideas. I do so in order to understand what factors promote high levels of argumentation in inquiry settings.

This chapter analyzes discourse from thirteen selected clips in four of the six lessons described in Chapter 6. These four lessons were chosen because they include the highest argumentation levels achieved during the data collection period: threes, fours, and fives. In addition, these clips were also chosen from the final lessons of the data collection period, in order to maximize the time classroom communities had to practice shared norms.

Analysis of the thirteen clips suggest the following findings:

- Hybridized words and gestures often accompany students' "first-draft thinking."
- "First-draft thinking" is often a prerequisite to more sophisticated argumentation levels.
- The teacher is the leading participant in orchestrating student gestures and verbal phrases into collective final claims.
- The process of resemiotization facilitates the realization of both perceptual and linguistic objectification.
- The process of resemiotization facilitates the genesis of student claims and the construction of final claims.
- Text encoded in artifacts around the physical classroom can be important contributions to the construction of argumentation (on charts, whiteboards, etc…)
- The lack of transparency of certain modalities can create the need to construct higher levels of argumentation.
- Resemiotization often occurs in a patterned formation with initial ideas processed first through object manipulation, then replaced by gesture over objects, then in gesture with words, and finally in words alone.
- During "sense-making" stages of thinking, speech and gesture are asynchronous; however, in articulated thought that has been rehearsed and of which a student is confident, speech and gestures are well-coordinated and often exist simultaneously.

- Resemiotization mediated through "talk moves" of a "more capable peer" can advance student thinking, while resemiotization without sufficient background in the science, and without a "more capable peer" can potentially lead to non-scientific conclusions.

In the sections that follow, the thirteen clips are grouped thematically, by these findings; together, they illustrate the complex interrelationships between modalities, "talk moves," and argumentation levels. Each is followed by a summary and discussion of how the findings tie in with, or add to current research in the field of science learning.

The chapter concludes by revisiting the model proposed in Chapter 6, illuminating the contributions of resemiotization from the data presented in this chapter.

### *Using Gesture and Words to Formulate Claims (Clips One and Two)*

#### *Clip One, Lesson One*

The first clip illustrates students' reliance on a blend of gesture and words to articulate scientific understandings. It originates from lesson one described previously in Chapter 6. Students are studying gravity and its effects on motion. Looking again at the same transcript analyzed in Chapter 6, we see that there are a variety of modalities students draw upon during the co-construction of a level four argumentation. At the start of the discussion, we see little evidence of argument. Students give yes or no answers as to whether objects drop at the same time, and there are only two claims made: one, that the wood block is heavier than the paper clip; and two, that the objects fall at the same rate. These observations and simple implicit claims stem from students visually watching their teacher reenact the same events they performed at their tables.

However, from lines 391-442 (Appendix H) a level four argument is achieved within the short timeframe of only 1.27 minutes. On line 391 (Appendix H), a student, makes the claim: “They’re falling at the same rate.” And on line 442 (Appendix H), another student, we will call Gus, punctuates this section with the identical claim: “”They’ll both fall at the same rate.” In between these identical claims is a plethora of activity represented in many different modalities. Students receive visual input from their teacher’s manipulation of objects and re-enaction of events; they make deictic, iconic, and metaphorical gestures in relation to the objects their teacher holds in the center of the meeting area; and they build on the verbal input of others. The result is a level four argument.

Many students make partial contributions to this argument through talk and gesture. These are punctuated by the teacher’s purposeful “talk moves” until Gus is able to articulate without gesture the final claim that: “So that one’s big and the air is holding it back and that one’s small and the air isn’t holding it back so they level up and they fall at the same time.” In the narrative below I describe the intricate process by which this final claim is constructed. As a reminder, I have arrived at these levels of argumentation from the definitions I adapted from Toulmin (1958) as depicted in Table 3.8 in Chapter 3. I reproduce this table again below for reference concerning the analysis in this chapter.

**Table 3.8: Revised Rubric: Instrument for Analysis of Argumentation**

| | |
|---|---|
| Level 0 | Evidence only; observations only; or warrant only. **No claim is made**. |
| Level 1 | Level 1 argumentation consists of arguments comprised of **a claim**, a series of claims, or a claim vs. a counterclaim, **but no evidence or very weak evidence, or evidence that may be unclear.** These **may be "implicit claims"** (a yes or no answer to a teacher's question, or a hand raise to a teacher question such as "How many of you think two objects always fall at the same time?" An implicit claim does not include clarification questions regarding observations of what students "see." |
| Level 2 | Level 2 argumentation has arguments consisting of **claims with data, or a claim with warrants, or a claim with data and warrants.** |
| Level 3 | Level 3 argumentation has arguments with a series of **claims with either data and/or warrants as well as counterclaims with data and/or warrants,** but no rebuttals. |
| Level 4 | Level 4 argumentation shows arguments with a **claim backed by evidence and a warrant and/or a counterclaim with or without evidence.** No rebuttals. Such an argument may have several claims and counterclaims, but it is not necessary. |
| Level 5 | Level 5 argumentation displays **an extended argument with claims and counterclaims both backed by evidence and/or warrants, and with one or more rebuttal.** |

Notably for this section, to reach level 4 argumentation, an argument must either be comprised of a claim backed by evidence as well as a warrant, or it may or may not also include a counterclaim with or without evidence. A level four is distinguished from a level three primarily by claims backed by both evidence as well as warrants.

Process of Construction of Level Four Argument, Clip One

**Students Use a Blend of Words and Gestures to Form Claims**

In Figure 7.1 below, we see the genesis of the argument. The teacher has just re-enacted the first task students were asked to complete in groups at their tables and has asked the class why the wood block doesn't fall faster than the paperclip. Gus is pointing to the wood block and paper clip his teacher is holding as he states: "That one has a surface, makes it when it's going down, it's like holding it a little and the paperclip, since it's like…"

**Figure 7.1: Gus, Deictic Gesture (Pointing)**

These words alone do not convey a complete idea; in fact, from his words alone, it is not at all clear what Gus is attempting to communicate. However, his deictic gesture at the objects Dave holds appear to stand in for the lack of words Gus is able to verbalize. Taken together, Gus's words and gestures fully articulate his thinking. As seen below, he is able to describe the motion of the objects using both words and gestures.

**Figure 7.2: Gus Gestures Flat Surface of Wood Block**

After his deictic gesture at the wood block, he gestures the flat surface of the wood block and also accompanies this with the words: “that one has a surface.” Clearly, both the paperclip and the wood block have some sort of surface, but what Gus is attempting to state is that the wood block’s surface is flat, something he can only do at this point through a hybrid of gesture and speech. He is then interrupted by another student voice that adds in: “has holes,” and gives a property to the paperclip that Gus cannot seem to verbalize. These words “has holes” provide a rationale for *why* the paperclip is different from the wood block, and seem to assist Gus in continuing his own talk. Gus continues with “Yeah, yeah, it goes right down.” This latter statement is accompanied by a dramatic gesture of a flattened hand streamlining towards the ground, as seen in Figure 7.3 below.

**Figure 7.3: Gus, Metaphorical Gesture**

Just after this, the student sitting to the left of Gus makes a gesture with her hands as seen in the far right of Figure 7.4 below. As she gestures, she adds: “like the little things,” making the elongated shape of the edges of a paper clip.

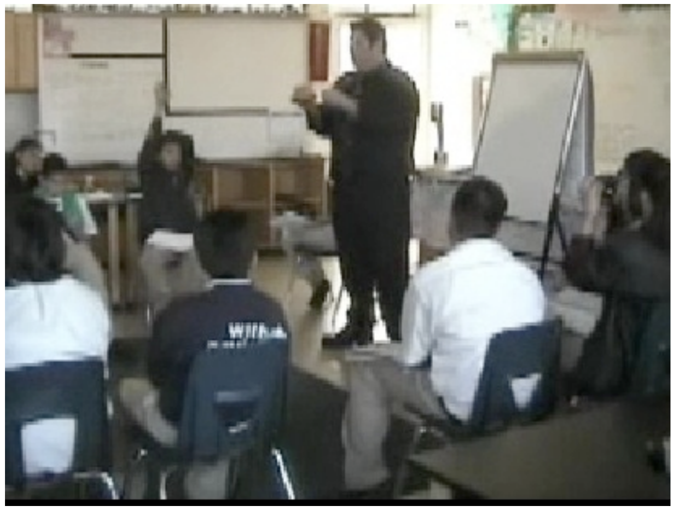


**Figure 7.4: Girl Gesturing Shape of Paper Clip**

Here, the partial articulation of one child, Gus, coupled with his own deictic and metaphoric gestures over and towards the objects the teacher is holding, merge with the partial articulation of a second student and the gestures of a third, to provide evidence for the claim that the objects should fall at the same time, no matter their size.

**Adding Teacher "Talk Moves" to Students' Words and Gestures**

Up until this point in the transcript, the evidence students collectively provide exists in a blend of gesture and words. In order for the students to be able to fully own their claim, the teacher must necessarily work in guiding them to achieve a more linguistically stable form of their ideas. He does so by posing a challenge to the students; he argues the opposite of what he knows they are striving to articulate. Dave asks: "But you didn't say this one went faster. You said they hit at the same time." As we look further down the transcript, additional partial student statements such as "like the little things" and "because one's got wind and one's not" conflate with the gestures of others who are making the elongated edges of an imaginary paper clip and stating "so, if it was open," and "because of the air." Gus is able to again combine partial words and gestures amidst this input of his classmates to make the claim that objects fall at the same time. "That's why," he states, "So the bigger one maybe goes fast, but since that one's smaller, it's going at the same time." Figure 7.5 below illustrates Gus's tapering hand gesture downward to depict what seems to be the effect of "wind" that Gus has not yet been able to express in words.

**Figure 7.5: Gus Gestures Streamlined Movement of Paper Clip**

Through the combination of his words and gestures, Gus makes his point clear to the teacher who then solidifies Gus's and the other students' words and gestures into the following statement: "So, you're saying that this one's got a big surface, so the wind's pushing against it, but it overcomes that because it's heavy? And this one doesn't have much surface, but it's light, so they travel at the same speed?" As the teacher objectifies the students' collective words and gestures into verbal language, two other students talk over him punctuating his remarks with caveats of "So, if it was open…" indicating a possible understanding of the way wind might affect solids versus "open" objects, and "because of the air," indicating an emerging understanding of the way air slows object movement.

Once the teacher has clarified and objectified the students' words and gestures into a succinct statement of verbal language, Gus is able to fully articulate an argument without resorting to gestures as placeholders for his words. He states: "So that one's big and the air is holding it back and that one's small and the air isn't holding it back so they level up and they fall at the same time." Gus's articulated statement this time consists of a claim with evidence and an implicit warrant, that air slows things down. His ideas previously consisted only of a claim with evidence that was not coherent, but existed in a hybridized state of gesturalized language and speech together.

In clip one, we see that multiple students' input through words and gestures plays against the purposeful "talk moves" of the teacher to culminate in a level four argument.

*Clip Two, Lesson One*

Clip two also reveals students' dependence on both words and gesture to articulate their understandings. Another instance of the achievement of a level four argumentation in clip two occurs shortly after Dave re-enacts the third task students completed at their tables in groups. Dave asks the students why the parachute man and the wood block don't fall at the same time, when everything else they dropped did fall at the same time. The students are here confronted by the teacher with a discrepant event that contradicts their earlier agreed upon claim that all objects will fall at the same time when dropped from the same height.

Again, on lines 625-667 (Appendix H), students co-construct with their teacher the claim that the parachute man falls more slowly because gravity and air resistance work against one another affecting the speed of an object. This time it is not Gus who is fore-grounded, but a student named Daniel. Daniel is the final voice to integrate all previous fragments of evidence existing in the partial phrases and gestures of his classmates into a final, stable verbal claim. Below, I describe how this level four argument is achieved.

<u>Construction of Level Four Argument, Clip Two</u>

Figure 7.6 presents a chronological list of the partial statements and gestures that lead to Daniel's final claim. The teacher asks why the parachute man falls more slowly, and these are the resulting statements and gestures of relevance:

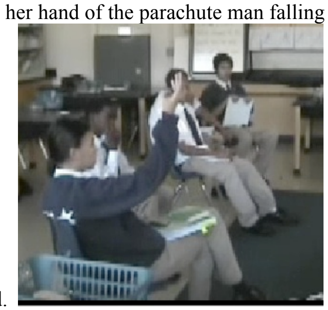
| Statements | Accompanying Student Gestures |
|---|---|
| "Because the air hits the parachute." S1 | none |
| "You breathe it [air]." S2 | none |
| "Particles." S3 | |
| "Because, um, the parachute helps to keep that kind of stuff from going down so fast." (Thelma) | Thelma raises her arm and makes a slow metaphorical gesture with her hand of the parachute man falling from above her  head. |
| "No, um, when the guy is falling down, he doesn't go, like all the way down, he just, he has the parachute to keep him from falling to the ground fast." (Thelma) | Uses her hand to quickly move from above her head straight down (gesturing the path of the wood block) and then again uses her hand to gesture the slower motion of the parachute man falling from above her head to her chair.  |
| "It slows him from falling." (Thelma) | none |
| "When he's falling, the air's going up into the parachute, pushing it up so that he falls slower. And gravity's pulling him down too so he's going more slowly." (Daniel) | |

**Figure 7.6: Transcript with Thelma's Accompanying Gestures**

The above shows the combination of partial verbalized thought coupled with gesture that are ultimately combined, built upon, and sedimented into Daniel's final claim that both gravity and air [resistance] work opposite one another to affect the speed of an object.

Many students contribute to this final claim. One student begins the series with the statement that "the air hits the parachute." While Thelma states in language that the parachute man "doesn't go, like all the way down," she never attributes this movement to the air. Independently, other students state phrases like "you breathe it" and someone says "particles" in answer to the teacher's question regarding the identity of "those things" in the air. But it is through a mixture of gesture, partial phrases, and single words, that language and thought become intertwined and an argument ultimately emerges from the seemingly chaotic blend and expression of different modalities. Daniel brings together the slow gesture of Thelma's hands, the word "air" from a classmate and the concept of gravity from the previous series of argumentation to put the following statement in order: "When he's falling [parachute man], the air's going up into the parachute, pushing it up so that he falls slower, and gravity's pulling him down too so he's going down slowly." This is a claim with evidence and a warrant, created from a series of input from his classmates, just as was seen in the previous example of Gus and his classmates.

*Summary and Discussion of Clips One and Two*

Clips one and two from lesson one illustrate the important notion that students use a blend of both words and gestures in formulating their scientific ideas. This would suggest that it is important to provide spaces for students to use these modalities to process their thinking. The presence of objects seems to be one factor that enables the use of gesture to occur in these settings. This might have implications for teachers of inquiry who currently use objects for exploration only, and not during class discussions of the science under study.

Clips one and two have robust connections to current themes in the literature on science discourse and the role of gesture in science learning. These connections are illuminated in the following sections.

Hybridized Words and Gestures in “First-draft thinking”

Despite the recent emphasis on the importance of talk and argumentation in science and in the learning process in general, most middle school classrooms are not typically rich with opportunities for students to engage in productive communications (Michaels, et al., 2008). In fact, the National Research Council (2008) has posed the question: “How does a teacher create the conditions that allow all children- despite their cultural, linguistic, or experiential differences- the same access to classroom conversations and to be held accountable to the same high levels of academic rigor in their talk, reasoning, and representations?” (Michaels, et al, 2008). Research suggests that the science classroom is a good environment in which to teach diverse language populations (Michaels et al, 2008). Talk is often about materials and events that all students see and experience together. However, most research on talk and argument in science focuses on oral and written language as the primary tools for communication. Oral and written language are considered to be the primary mechanisms for making thinking public. But what about for children of diverse linguistic backgrounds, such as those in clips one and two? Clearly, in oral and written language are not the sole vehicles by which learning advances. Rather, much of their thinking is expressed in gesture.

These first two clips belie the importance of providing time for students to enter into scientific practice through what Michaels et al. (2008) refer to as "first-draft" thinking. As Gus and his peers (clip one), and Daniel and his peers (clip two) engage in scientific practice, they utilize the powerful resource of gesture to further their thinking. Through deictic pointing, they harness their gestures to objects their teacher holds in the center of the meeting area. After many partial verbal articulations, repetitions, hesitations, and false starts, their initial exploratory talk finally congeals through an increasing progressive translation of words and gestures into a final verbal argument. This process of using gesture and words is what Michaels, et al. (2008) mean by "first draft thinking." Missing from their model however, is the critical feature of gesture. I add this modality to the model I propose for scientific communication depicted in Figure 7.7 below.

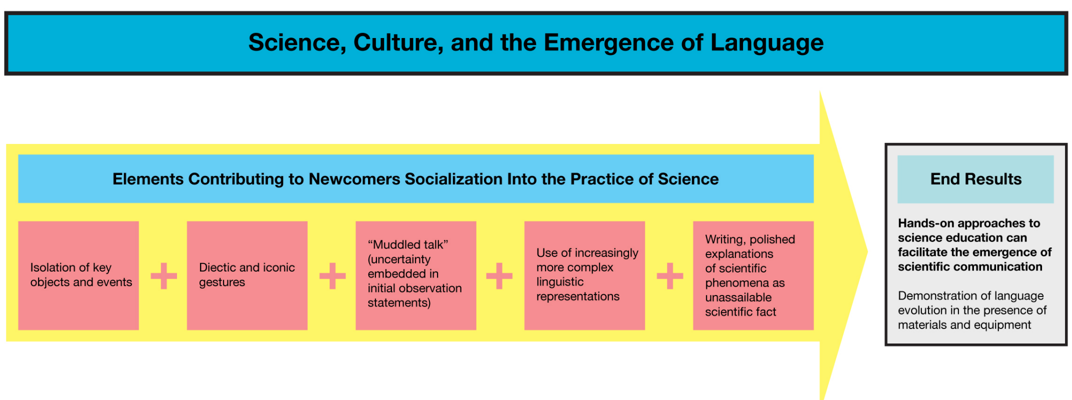



**Figure 7.7: Science, Culture, and the Emergence of Language**

In my proposed model, we see the process of argumentation as a type of pipeline in which deictic, iconic, and metaphorical gestures are crucial components. Over time, they combine with partial phrases and "muddled talk," to form more stable, linguistic representations recognized and used by scientists themselves. In both of these clips, Gus and Daniel, respectively articulate their final claims without gestures. Their final verbal language replaces the necessarily earlier functions of gestures, partial phrases, and incomplete, and/or incoherent statements. In the scientific community, communication is largely accomplished through written documents. As such, the model ends with this as the ultimate step.

## The Role of Gestures in Science Learning

The findings from clips one and two corroborate Roth and Welzel's (2001) study in which high school students used gesture to construct complex explanations of physics. These students were invited to plan and execute investigations of their own interest. Roth and Welzel's (2001) findings revealed that students initially used gesture to construct their explanations in the absence of scientific language to address observed phenomena. They found that over time, speech increasingly took over and there were either decreases in the delay between gesture and verbal speech, or long pauses before gestures and utterances overlapped. This suggests a promising link between hands-on activities, the gestures students develop, and the onset and emergence of science-related discourse. Gestures seem to provide a medium for constructing complex explanations by lowering the cognitive load and allowing for a slower emergence of the scientific discourse. Gestures also seem to provide what Roth and Welzel term "the material that 'glues' layers of perceptually accessible entities and abstract concepts" (p. 103). Clearly, these ideas are at work in Dave's classroom.

<u>The Teacher as Conductor of Semiotics and Modalities</u>

What is not included in Figure 7.7 are the teacher's comments and prompts in between student utterances, which account for much of the outcome of what students consider through their words and gestures. The discourse moves of the teacher are what foster the assembly and integration of all student contributions. The teacher's work is invisibly present in the multiplication symbols in the model (Figure 7.7).

For example, after Thelma gestures and explains that the parachute man "doesn't go, like all the way down," and that the parachute keeps him from falling "fast," Dave asks simply "How?" but this is enough to engage a mechanical shift in the student's focus from the parachute speed to what is causing the parachute's motion and enable them to then put parachute slow speed + air together at once in their thinking. The discourse style, or series of "talk moves" Dave uses are discussed thoroughly in the previous chapter. In many ways, Dave serves as a conductor, of sorts, of a musical score. Having circulated about the group tables during the "explore" portion of the lesson, he is well aware of which students understand the concepts, which still hold misconceptions, and which are off-track. He acknowledges this important role in his interview with me (Appendix B, lines 575-577). This knowledge serves him well, as he makes split decisions during the "explain" portion of the "post-experimental meeting area." All students are free to contribute their growing knowledge during this time. However, Dave's role as conductor is to know just when to bring in certain voices and thoughts so that a cacophony of discordant claims is not the result. In this way, through his purposeful discourse moves, Dave orchestrates his own prompts with specific students' input via talk and deictic, iconic, and metaphorical gesture, such that a musical symphony results. This idea of teacher as conductor, knowing when to draw different student voices into the score, ties back to the theoretical framework of distributed cognition.

*Using Resemiotization to Facilitate Perceptual and Linguistic Objectification*

*Clip Three, Lesson Two*

Clip three illustrates the use of multiple modalities to process and re-process information to attain both perceptual and linguistic objectification. This use of resemiotization facilitates the realization of perceptual and linguistic objectification. Although only verbal and visual modalities were necessary to achieve perceptual objectification, the addition of "kinesthetic modeling" is necessary to secure linguistic objectification. Additional verbal, visual (drawings), kinesthetic, and gestural modalities were also necessary to achieve the final work of answering the key question of the day through argumentation structures. There was not a correlation between the level of argumentation and the different modalities used; however, it was found that resemiotization facilitated the procurement of the final claims in general.

In this clip, the highest level of argumentation achieved is a level three. However, it is not my intention in this example to focus on the numerical level, as it will be in other clips. Rather, in this example, I seek to unfold how the process of resemiotization facilitates perceptual and linguistic objectification, and the final claims students articulate about friction. In the sections that follow, I first provide a context for understanding the videoclip, followed by an analysis of the transcript highlighting the contributions of resemiotization.

Context of Clip Three

Clip three was taken during the "post-experimental meeting area" in Dave's classroom at the end of a 5E lesson on forces and friction. Students had just completed a series of three activities during the "explore" session of the lesson as shown in Figure 7.8 below, and are ready to begin the class discussion of their observations.

DIRECTIONS

WOOD BLOCK

4) Take the wood block an give it an "instantaneous push" across the table.
5) Pay attention to how it moves (motion) across the table.
6) DRAW a picture of the wood block and LABEL the motion you see.

WOOD BLOCK with STICKY NOTES

4) Set up the sticky notes as you see in the diagram to the right
5) Push the wood block across them with the same amount of force as before
6) DRAW a picture of the wood block and the Sticky Notes and LABEL the motion you saw.

WOOD BLOCK with SAND PAPER

4) Set up the sandpaper as you see in the diagram to the right.
5) Push the wood block across the sandpaper with the same amount of force as before.

DRAW a picture of the wood block and the sandpaper and LABEL the motion you saw.

**Figure 7.8: Directions for "Explore," Lesson Two**

**The goal of the lesson is to answer the key question of the day: What type of force is friction, which way does it act, and how does it affect motion? Students are given the following "claims questions" to scaffold their thinking:**

Claims Questions:

1) What motion did the wood block have after you pushed it?
2) Did it slow down more with the stickies?
3) Did it slow down more with the sandpaper?

Analysis of Transcript

The transcript I examine next commences just after the teacher and students have achieved perceptual objectification. Dave tells his students, "Everyone sees different things," and, as in the clip from lesson one, he establishes a class consensus of the perceptual reality for each of the three activities before moving on to the task of linguistic objectification. This is crucial since science has been set forth to these students as the pursuit of "truth." In the world of scientists it is understood that there is no "true reality," but only approximations of it. But, in the science classroom, students and teacher must do their best to arrive at some shared understanding of "reality." Because our senses don't always reveal the same "truth" to each of us, we must necessarily objectify our individual observations through language and semiotics to further the work of science.

Dave attempts to establish this type of shared reality via perceptual objectification with the class. He uses an easel poised at the front of the meeting area to draw the three scenarios of the wood blocks across the table, across sticky notes ("post-it notes"), and across sandpaper. Thus far, the students are attempting to collectively transfer their object manipulation from the "explore" session into drawings with written text explanations. Students provide input about the three claims questions above. In Figure 7.9 below, we see a student raise his hand to disagree with the claim of his classmate, positing the first level two argument in the lesson.

**Figure 7.9: Establishing Perceptual Objectification**

The short exchange appears below:

> T: Speed up then slow down? Okay, speed up and then slow down. Anybody else disagree with that? Okay. Uh, next one. When I push the wood block over the sticky notes, did it slow down more or did it slow down less?
> S1: What?
> T: When I push it over the-
> S2: Slowed down more. [jumping in]
> T: Slowed down more? Does anybody agree with that? Or disagree with that I should say?
> S3: I would like to disagree. 'Cause ours speeded up.
> T: Okay, so, yours slowed down less then? 'Cause it still slowed down, but it just didn't slow down as fast. Okay, so it slowed down less. Okay. Put "or" right there. Slowed down more or it slowed down less. Anything else? Anybody see anything else?

Here we see Dave carefully negotiating the perceptual realities of two students, S2 and S3. S2 claims the sticky notes slowed the wooden block down even more than the bare surface of the table. S3 contests this, claiming that the sticky notes slowed the wooden block down more. The larger "musical score," or goal, for this lesson is really about friction. Ultimately, the students need to decide what type of force friction is, how it acts, and how it affects motion. One of the remarkable aspects of this particular segment is that Dave honors all perceptions of the events explored at their tables. Here we see him underscore the fact that it is okay if one group seemed to think the sticky notes slowed the wooden block down more than the surface of the table did. The important idea is that both surfaces actually did slow the wood block. As they share these claims, Dave, the careful conductor of the larger musical score, articulates the "bottom line" for the students:

> D: Okay, so, yours slowed down less then? 'Cause it still slowed down, but it just didn't slow down as fast. Okay, so it slowed down less. Okay. Put "or" right there. Slowed down more *or* it slowed down less.

Dave then completes taking inventory of the way the block moved on the sandpaper surface and redirects the entire class back to the overall "musical score," saying:

> D: Okay. So going back to our key question today - there's three things we're trying to figure out. We know that this thing called friction is happening. But I'm trying to figure out what type of force it is, which way does it act, and what type of motion does it have, or what kind of motion does it cause? Alright, so right now I need everybody to stop what they're doing and put your hands together like this [puts his hands together palms in]. Alright, now, when I'm cold in the morning and I'm standing out on supervision duty, you can see my sometimes doing like this [rubs hands together].

Up until this point, the students have worked in only two modalities at the meeting area: the verbal modality and a visual (drawing modality). This was sufficient to answer the simple perceptual "claims questions." Thus far, Dave has used verbal and drawing modalities to transfer the work of object manipulation to perceptual objectification, and a level three argumentation level was attained. This work accomplished, the modalities used, and the argumentation levels achieved are summarized in Table 7.1 below.

**Table 7.1: Modalities Used to Accomplish Specific "Work" Goals in Lesson (I)**

| *Work Accomplished* | **Modalities Used** | **Highest Level of Argumentation Attained** |
|---|---|---|
| Perceptual objectification | Verbal and drawing transferred from object manipulation in "explore." | 3 |

To get the students to jump to the overarching key question of the day, however, Dave moves into the kinesthetic modalities. He begins to invite his students to use their bodies and gestures to shape an answer to the questions regarding the nature of friction.

Interestingly, most of the "post-experimental meeting area" discussion consists of a long series of either level zero (observations) or level one (simple claims) argumentation. There is one segment of the discussion involving a series of claims and counterclaims that take the level of discourse to a three. However, most of the discussion that leads to important linguistic objectification occurs at a level one, with the students ultimately able to generate the well-established scientific notions that friction is a constant force that acts in the opposite direction of movement, and that slows objects down. I will next examine the contributing modalities to the sequence of student-student and student-teacher interactions involved in arriving at these conclusions.

Contributing Modalities to Level Three Argument

There are essentially three answers Dave needs the students to arrive at in order to "play" the musical score, or to achieve the goals of the lesson. The first is that the students need to arrive at the understanding that friction is a constant force; the second is that friction moves in the opposite direction of movement; and the third is that friction is a force that slows objects down. To get the students to "play" these notes, Dave begins the process of combining his verbal discourse moves with "kinesthetic modeling." In the figure below we see him begin to rub his hands together; he asks the students to rub their hands together as well.

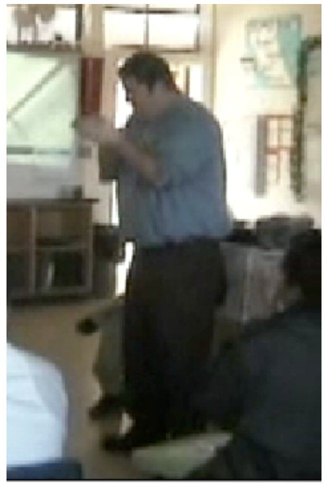


**Figure 7.10: Dave Rubs Hands**

**Figure 7.11: Dave's Students Rub Hands**

Dave begins his "kinesthetic modeling," with the verbal instructions:

> D: Alright, so right now I need everybody to stop what they're doing and put your hands together like this [puts his hands together palms in]. Alright, now, when I'm cold in the morning and I'm standing out on supervision duty, you can see my sometimes doing like this [rubs hands together].

Dave asks what two things the students notice when they rub their own hands together. The students provide a string of level zero argumentation consisting of observations such as "It gets hot," "your hands get warm," "you get tired," and "you hear a sound." Dave builds on this latter remark, labeling this sound as "friction." Having established linguistic objectification with the students, Dave admits that knowing that this sound is friction still doesn’t help them answer any of the three questions, or notes, they set out to “play” in the musical score.   He says: “I hear a sound. Okay. So that sound and that heat are because there's this thing called friction going on. Okay. But, my question is, ‘what type of force is friction?’ That still doesn't help me.”  Dave has now added a modality to the discussion to achieve linguistic objectification.  But he will need to do something more to continue in his efforts to have the students “play” the notes he desires.  The work accomplished, modalities used, and levels of argumentation thus far are again summarized in Table 7.2.

**Table 7.2: Modalities Used to Accomplish Specific “Work” Goals in Lesson (II)**

| *Work Accomplished* | **Modalities Used** | **Highest Level of Argumentation Attained** |
|---|---|---|
| Perceptual objectification | Verbal and drawing transferred from object manipulation experiences during “explore” | 3 |
| Linguistic objectification | Kinesthetic modeling | 1 |

From here, Dave decides to remind his students of the cartoon, “The Magic School Bus.” They watched this cartoon at the beginning of this lesson during the “engage.”  As the students conjure up the visual imagery of the cartoon, Dave asks them what happened on the frictionless baseball field, and what happened if the characters tried to stand up or walk?

With the addition of this visual prompt, the students are able to achieve a level two argumentation with the claim that the kids in the cartoon could not stand up or walk because it was slippery and there was no friction.  Dave elaborates on and reinforces this claim by scuffing his foot several times loudly across the concrete floor in the meeting area (see Figure 7.12).

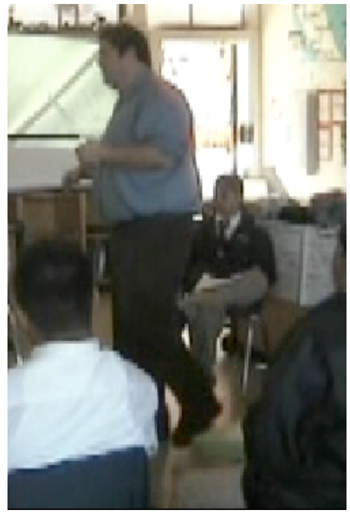


**Figure 7.12: Teacher Scuffs Foot to Model Friction**

He further cements the students' ideas with his language and kinesthetic movement:

> D: Okay, so, in the movie, when they tried to put their foot down like this, it would just slip and they would be like [he makes a slipping sound effect]. Okay, but in real life, when you put your foot like that, you hear, it makes that sound, right? [scuffs foot on floor to make scuff sound]. Okay, my shoes do it really well. Okay, so that is friction going on right there.

Dave continues with his modeling of friction by scuffing his foot repeatedly across the concrete floor. He finally asks the students which way friction is acting, and the students are able to arrive at the answer to the first part of their key question of the day with their answer: "It goes opposite to how you move."

In the table below, we see the use of additional modalities helps to spawn another level two argument. The addition of visual prompting of the cartoon together with further "kinesthetic modeling" helps arrive at one-third of the answer to the key question of the day.

**Table 7.3: Modalities Used to Accomplish Specific "Work" Goals in Lesson (III)**

| *Work Accomplished* | **Modalities Used** | **Highest Level of Argumentation Attained** |
|---|---|---|
| Perceptual objectification | Verbal and drawing transferred from object manipulation experiences during "explore" | 3 |
| Linguistic objectification | Kinesthetic modeling | 1 |
| Answer to first part of key question: friction moves opposite to movement | Visual memory of cartoon and kinesthetic modeling | 2 |

What follows is another instance of linguistic objectification as students co-construct, with their teacher, the idea that, like gravity, friction is a constant force. This is accomplished as three students share their ideas about friction. The first student says that friction assists a walker in not falling; the second student adds: "Um, yeah, like, friction, when you run, like, you have, when you're running up a hill, you slowing down, with friction." The teacher provokes a succinct statement about friction, by posing the following question: "So, do you say that friction's always happening?" A few students simultaneously answer yes, and another student, Carlos, follows with a hybridization of gesture and words (see Figure 7.13) to state: "I agree with them because you're always on something, like, you're never, like, flying, because you're always sitting on something or laying on something or standing on something (uses gesture to convey positions as he says them)."

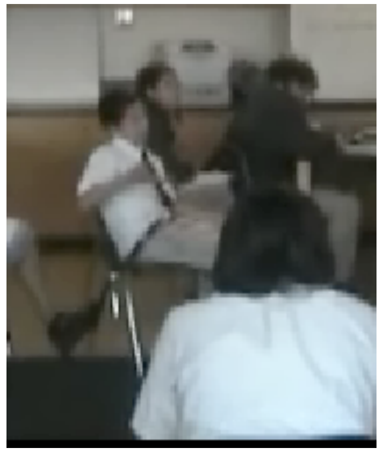


**Figure 7.13 Gesture Accompanying "Always on Something…"**

This discourse sequence segues into a second linguistic objectification that is co-constructed by Carlos and the teacher. Dave follows up Carlos's claims with the question: "Oh, what is that thing that's always having you on something?" and Carlos answers: "Gravity." Dave then interjects: "Interesting. Alright, so if we're saying that gravity's always happening, what kind of force is friction then? It's always happening?" The students have previously learned that constant forces are "always happening," whereas instantaneous forces are only "for a moment" and happen just once. In fact, these are definitions encoded on charts at the back of the classroom. Carlos is then able to answer that indeed friction is a "constant force," and this level one claim successfully provides the information for the second part of the key question. Dave replies:

> D: It's a constant force, good. Friction is a constant force [writes this on easel]. Okay, so that is two of the three things that we were trying to figure out today. I know it's constant. I know that it goes opposite of the way that I'm going. Now the final one - how does it affect motion? What did it do to the wood block? What did it do to my hand? What did it do to my foot?

Table 7.4 summarizes the contributing modalities up to the point where the students have achieved two of the three answers to the key question of the day:

**Table 7.4: Modalities Used to Accomplish Specific "Work" Goals in Lesson (IV)**

| *Work Accomplished* | **Modalities Used** | **Highest Level of Argumentation Attained** |
|---|---|---|
| Perceptual objectification | Verbal and drawing transferred from object manipulation experiences during "explore" | 3 |
| Linguistic objectification | Kinesthetic modeling | 1 |
| Answer to first part of key question: friction moves opposite to movement | Visual memory of cartoon and kinesthetic modeling | 2 |
| Answer to second part of key question: friction is a constant force | Co-construction or student-teacher words and student gesture | 3 |

The answer to the third part of the key question of the day is supplied by the contributions of a student, Milton. This occurs immediately after Dave's restatement of the first two aspects of friction. Dave restates that friction is constant and goes "opposite of the way I'm going." He then asks: "Now the final one - how does it affect motion? What did it do to the wood block? What did it do to my hand? What did it do to my foot?" The first immediate response is Milton's: "It slowed it down." Even though this is the correct response, Dave continues with the discussion. He maximizes student participation by proposing a medley of hypothetical situations to work through possible discordant information, and arrive back at the last melodious note of "friction slows objects down." To do so, he engages the students in questions about which surfaces have more friction than others: the floor, ice, sandpaper. Students argue and point to different surfaces (deictic gestures) to make their claims. He continues to engage the students in more "kinesthetic modeling," rubbing his hands against sandpaper, and asking them how the addition of the sandpaper surface will affect motion.

**Figure 7.14: Teacher Rubs Sandpaper**

This series of kinesthetic modeling is coupled with teacher and student gestures, and words, to produce level three argumentation. Through these modalities, Dave and his students jointly contemplate which surfaces will produce more friction and which surfaces will produce less friction. Ultimately, in terms of the original question, the answer remains the same: Friction slows objects down.

**Table 7.5: Modalities Used to Accomplish Specific "Work" Goals in Lesson (V)**

| *Work Accomplished* | **Modalities Used** | **Highest Level of Argumentation Attained** |
|---|---|---|
| Perceptual objectification | Verbal and drawing transferred from object manipulation experiences during "explore" | 3 |
| Linguistic objectification | Kinesthetic modeling | 1 |
| Answer to first part of key question: friction moves opposite to movement | Visual memory of cartoon and kinesthetic modeling | 2 |
| Answer to second part of key question: friction is a constant force | Co-construction of student-teacher words and student gesture | 3 |
| Answer to third part of key question: friction slows objects down | Recollection of object manipulation, kinesthetic modeling through teacher prompting: "What did it do to the wood block? What did it do to my hand? What did it do to my foot?" | 1 |
| Reinforcement of answer to third part of key question: friction slows objects down | Object manipulation by teacher, deictic pointing by students, kinesthetic modeling by teacher. | Fast paced level 3 |

This final process is added to the table above (Table 7.5).

*Summary and Discussion*

Table 7.5 summarizes the events of clip three. It provides a clear look into the nuanced effects of resemiotization on learning. Looking down and across the table we see the correlation of the presence of varying degrees of resemiotization with the realization of both perceptual and linguistic objectification. We also see that varying degrees of resemiotization exist as students construct answers to the three parts to the key question of the day. Though no conclusions may be drawn concerning the levels of argumentation and the types of modalities used, it is clear that resemiotization does facilitate perceptual and linguistic objectification as well as opportunities for students to generate scientific claims leading to substantive scientific argumentation.

Clip three has important connections to the literature on embodied cognition, perceptual and linguistic objectification, and resemiotization. These connections are discussed in the following sections.

Embodied Cognition

Clip three harbors clear examples of embodied cognition. In the many instances where Dave "models" aspects of friction with his body, he demonstrates how off-line cognition can be body based, such that mental imagery and working memory can both be said to off-load information onto perceptual and motor control systems in the brain, without off-loading all the way out into the environment. The mental representations he hopes students generate from his physical modeling are grounded in the notion that our bodies and minds are interconnected. Dave also relies on students' abilities to recall exploratory activities (the movement of objects) and visual media (the Magic School Bus cartoon) to "relive" and "automatize what was formerly effortful" (Wilson, 2002, p. 633). In reminding the students of these past experiences, he relies on students' ability to transfer mental memories of embodied experiences (with objects) and of visual representations (video) to mental models that can be transposed into even more modalities in an ongoing process of resemiotization. For example, in this lesson, Dave brings the ideas first presented in the cartoon back to life again with the actual objects in the meeting area. He is then able to reprocess the ideas embedded in the visual cartoon into object manipulation with the wood block, and finally to kinesthetic modeling. Ultimately, a fading of the scaffolds used to arrive at final claims will result in setting to memory past events as scientific understandings.

## Perceptual Objectification

As discussed in Chapter 2, perceptual objectification refers to the act of representing actions and events as if they were actually objects (Halliday, 1993). This is a necessary process in everyday life, and especially in the discipline of science. If we are able to "capture" the action or event into an objective reality, we can hold it "still" and "label" that reality with a word used to provide collective access to the event or action, even if members of a given collective were not initially present to witness it. This "labeling," or, linguistic objectification, relies on and presupposes the former process of perceptual objectification.

In clip three, Dave leads the students in attaining perceptual objectification. By first accepting all answers to what they observed, he is honoring the norms of participation he has worked to construct in the months leading up to this lesson. There is no room for "right and "wrong" at first. He responds to critical opposition by stating "everyone sees things differently." But ultimately, he needs to ensure that the students know that science is not based simply on opinion. Rather, we do need to use our senses sharply to observe the closest approximations to "reality" in nature as possible. Dave assures the group that both the stickies and the sandpaper both slowed the objects down. He is able to reach this class consensus, perceptual objectification, through the use of only two modalities: visual and verbal. The students and Dave have now successfully oriented themselves to the activity and materials in such a way that they are able to carve out, or identify a "thing" to talk about. They have achieved this by transferring their observations during object manipulation to drawings that they then talk about in the group formation. In this lesson, perceptual objectification is achieved in only two modalities- the two routinely discussed in the research literature: verbal and visual (drawings).

Linguistic Objectification

Once students orient themselves to the materials, perceptual objectification is transformed into more stable linguistic representations through linguistic objectification. In clip three, we see that this requires additional modalities beyond just verbal and visual (drawings). It requires the addition of kinesthetic modeling and the use of deictic, iconic, and metaphorical gesture. This process, formerly described as resemiotization (Iedema, 2001, 2003), is a necessary step to the attainment of linguistic objectification. We see the students begin to emulate their teacher's kinesthetic modeling, and to use gesture to transform visual, tactile, and actional knowledge into linguistic representations that can then be built upon in future settings. As has been documented in the research literature, a great deal of interactional work is done on the part of the teacher, Dave, to create associations between the visual phenomenon he is acting out and its linguistic representation (Massoud & Kuipers, 2009). The use of certain pedagogical approaches, which involve question and answer sequences and discourse markers, are important interactional tools for building coherence and consensus. These were described previously in Chapter 4.

Objectification and Resemiotization- Putting it all Together

The notions of perceptual and linguistic objectification and resemiotization are useful in analyzing how students' talk in situated interaction is negotiated and built upon. With the assistance of more knowledgeable others (Vygotksy, 1978), students incrementally build on small details and pieces of evidence, working step by step to move from observation to interpretation, and build consensus along the way. By applying linguistic terminology to their actions and observations, students further objectify their lab experiences and resemiotize their interaction with materials. These linguistic representations, in turn, serve as mediational tools (Wertsch, 1991) in future learning situations and allow for a move from peripheral to a more central participation (Lave & Wenger, 1991). These new linguistic representations become scientific terms that are infused with robust meanings built over time through first-hand experience and class discussions, rather than terms that are merely memorized from a lecture or textbook. In Dave's classroom, these linguistic representations serve as the collective class memory when they are encoded in a series of charts hung from the ceiling in chronological order of their making (see Chapter 6, Figure 6.29).

*"Getting to Fours and Fives" – Contributing Factors to Highest Levels of Argumentation*

The video data in this section is drawn from four clips taken from lesson three in Chapter 6. Together, these clips illustrate that along with words and gestures, the text encoded in artifacts around the physical classroom can be important contributions to the construction of argumentation (on charts, whiteboards, etc…) The data also reveal that a failure of one modality to express meaning can create the need to construct higher levels of argumentation, drawing upon additional modalities in the process.

In the following sections, I analyze two clips from the "explore" session, and two from the "explain" session from lesson three from Chapter 6.

*Context of the Clips*

During the "explore" portion, students are tasked with completing a series of three activities depicted in Figures 7.15-7.17 below, in order to investigate balanced and unbalanced forces.

DIRECTIONS: Pass the ball

1. Have 2 people stand opposite one another
2. Pass the ball pushing from the chest back-and-forth
3. Draw a FORCE ARROW DIAGRAM of the ball for one pass.
Include all the forces acting on the object.
4. Copy and Answer the questions below:
Are these forces balanced or unbalanced? WHY?
What was the motion of the ball as a result of these forces?

**Figure 7.15: Directions for Station: "Pass the Ball"**

DIRECTIONS: Parachute Man

1. Toss the parachute man in the air.
2. Notice his movement as he falls to the ground
3. Draw a FORCE ARROW DIAGRAM for the parachute man falling to the ground.

Include all the forces acting on the object.

4. If the man moved right, does that mean a force occurred?
5. Copy and answer the questions below:

Are the forces balanced or unbalanced? WHY?

What was the motion of the parachute man as a result of these forces?

**Figure 7.16 Directions for Station: "Parachute Man"**

DIRECTIONS: Fan Car held backwards by hand

5. Point the fan car towards your hand
6. Push back on the car so that it does not move when the fan is on
7. Draw a FORCE ARROW DIAGRAM for the fan car staying still

Include all the forces acting on the object

8. Copy and answer the questions below:

Are these forces balanced or unbalanced? WHY?

What was the motion of the fan car as a result of these forces?

**Figure 7.17: Directions for Station: "Fan Car and Hand"**

By the end of this lesson, the class achieves consensus that balanced forces cause objects to stay at the same speed, and unbalanced forces can speed up or slow objects down. This final claim is achieved via the co-construction of input from several students who are facilitated in discussion through purposeful questioning by their teacher. As seen in previous clips, students use their words, accompanied by gesture to articulate their emerging understandings, and to build on fragments of different knowledge states of one another. In lesson three, students are able to achieve multiple instances of level four argumentation and even one level five. As I present each of the four clips, I analyze the contributing modalities to the discourse in each and comment on the salient features of the discourse.

*Combining Words, Gestures, and Text from "Entextualization"*

Level Four Argumentation – "Explore"- Alan, Ian, Daniel, Mark: Clip Four, Lesson Three

Clip four is illustrative of the interplay of words, gesture, and text encoded in artifacts in the surrounding physical environment. As described earlier in Chapter 2, "entextualization" (Massoud et al., 2009) is the process by which knowledge encoded in one objectified form (e.g. verbal discussion to written text) can be lifted out of its setting and applied to another context. For example, entexualization occurs when information from verbal interactions become encoded in written text, which can then be decontextualized and applied to new circumstances, and recontextualized as a result of its text-like objectified form. In the chosen segment, entexualization figures prominently in the attainment of a level four argument, as four students negotiate meaning surrounding the given scenario in Figure 7.17. Just prior to this discourse sequence, Ian holds down a motorized car with his finger, while Alan moves around the table adjacent to Ian and asks if there is any way to turn up the fan on the car. Alan claims: "Look at the wheels! Look at the wheels!" while Ian continues to hold the car down. Finally, Ian turns the car off, all four boys write in silence, and the following dialogue ensues.

> Alan: Okay, this is a constant force because it keeps on happening.
> LEVEL 2
> Mark: (looks back to reference entextualized information on front white board, see Figure 7.18)

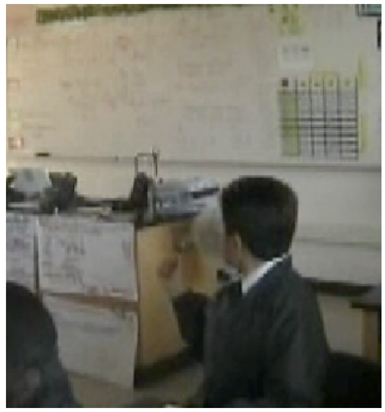


**Figure 7.18: Mark References "Entextualization"**

It's balanced force because the- LEVEL 1
Alan: (goes over to Mark's paper and students look over the drawings Mark has in his notebook, see Figure 7.19).

**Figure 7.19: Alan and Mark Jointly Attend to Drawings**

It's constant cuz it keeps on happening. LEVEL 2
Daniel: We have to answer if it's balanced or unbalanced. So, what's the first one?
(Marcos again turns around to look at Dave's entextualization on front white board).
Alan: Oh. It's balanced and it's- LEVEL 1
Mark: They are the same. Balanced. The friction (gestures right hand in toward center of body)

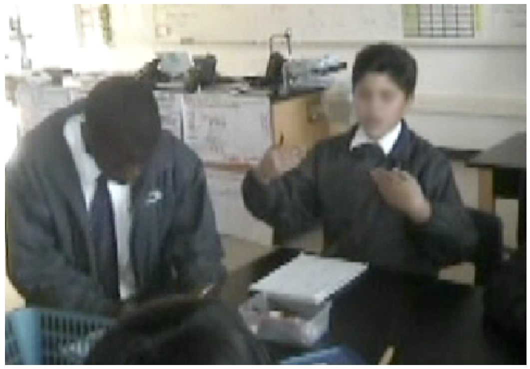


**Figure 7.20: Mark Gestures: "They are the Same."**

and the force (gestures left hand in toward center of body, see Figure 7.20, then re-checks front whiteboard) balance it. (All four students write again). LEVEL 2.
(series of claims in a row with evidence make this a level 4)

*Summary and Discussion*

Words, Gesture, and Embodied Cognition

Here we see three students co-construct a level four argument wherein a series of claims with evidence are articulated. This is accomplished through partial verbal phrases and gestures, as seen in previous examples. However, in this clip, we see that Mark and Alan make very deliberate references to the "entextualization" of words and drawings in their notebooks and at the front whiteboard. What is different about this clip is that we clearly see the important contribution of the information entextualized, or off-loaded onto the environment. Mark relies on previous learning co-constructed by his peers and the teacher to recall all the many forces that act on an object. This information has been off-loaded onto the whiteboard, much like a storage unit to contain necessary information that will reliably remain until needed for retrieval and integration into a novel scenario. Alan also refers to these whiteboard drawings that he has copied into his notebook.

In her article, "Six views of embodied cognition," Margaret Wilson (2002) argues an emerging viewpoint of embodied cognition that harbors six distinct claims, discussed previously in Chapter 2. Clip four clearly embodies one particular component of Wilson's model- that is, that there are limits to human attention and to what our working memories can do. To this end, Wilson (2002) argues: "we exploit the environment to reduce the cognitive workload" (p. 626). Wilson contends that human beings can make the environment manipulate and hold information for us, until needed at a certain appropriate time in the future.

In clip four, we see Mark twice turn to representations on the front white board, where "Dave" has created a concrete visual of the abstract forces on different objects. This previous learning has been off-loaded from the working memory of Mark and his peers, so they are free to engage in the work of forming relationships between different scientific phenomena, and of creating a series of claims backed with evidence. The "off-loaded" diagram is critical in making the abstract entity of "force" a concrete one for the students to "see" and use in their arguments. Mark does just this as he glances back at the white board, and then continues with his gestures regarding the forces of gravity and friction.

*"Getting to Five by Ourselves"- Alan, Ian, Daniel, Mark: Clip Five, Lesson Three: Lack of Transparency of Certain Modalities Leads to Higher Argumentation Levels*

In the discourse segment below, we see the same four boys working on the scenario of the parachute man described in Figure 7.16. The students have spent the previous "explore" session tossing the parachute man up into the air, and are supposed to now draw and explain all the forces acting upon him throughout his gradual fall. They then need to decide if these forces are balanced or unbalanced. At the start of the conversation, Daniel is perplexed. Alan suggests that it all has something to do with "weight," or "gravity," and then a sequence of gestures, object manipulation, and partial verbal articulation begin:

> David: I don't know.
> (silence for several seconds, boys draw in their notebooks, then set the parachute man in the center of their table)
> Alan: Hey, I think weight has to do with - I think gravity's pulling down on it. LEVEL 1
> Mark: Yeh.
> Alan: No, I mean it's pulling down on it stronger than other forces. LEVEL 1
> Ian: I think this one's balanced because-LEVEL 1 (LEVEL 3- series of claims without evidence)
> David: It's going up (gestures up with pencil, see Figure 7.22), and the air resistance is going down (gestures down with pencil). Provides evidence for previous level 1 claim to bring this to a LEVEL 3.

**Figure 7.21 Daniel Gestures Up with Pencil: "It's Going Up"**

> Ian: The air is going through the parachute (gestures parachute with fingers and hands, see Figure 7.22),

**Figure 7.22: Ian Gestures Parachute**

making it slow down,

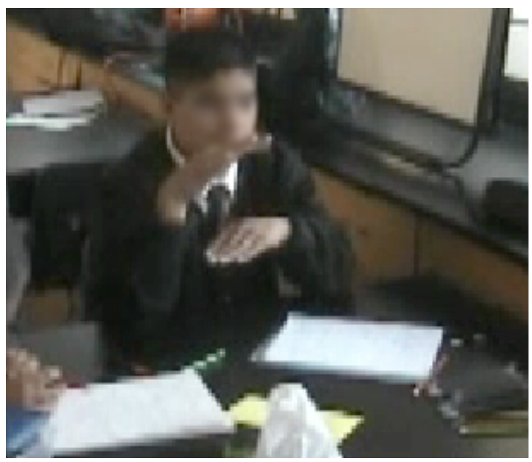


**Figure 7.23: Ian: "Making it Slow Down"**

which makes gravity and the- LEVEL 3 –series of claims without evidence.
Mark: Friction goes up (gestures up with hand) and gravity goes down (gestures hand down). LEVEL 1

Figure 7.24: Mark Gestures: "Friction Goes Up and Gravity Goes Down"

Ian: Yeh, but they're both the same. LEVEL 3- series of claims/countercaims See, the parachute- (cups hand to represent parachute)
Mark: (Shakes head no) Yeh, but friction is stronger.
Alan: Hey, it's like this right here- (lifts up notebook to show his drawing, while Mark begins to lift the parachute up and down in front of the group. All talking at once.)
Ian: Gravity's pulling on it at the same time. Hey, it's not- That's what I'm saying. Look. It's just that this (grabs parachute) is slowing it down.

**Figure 7.25: Ian Grabs Parachute to Make His Point to Mark: "This is Slowing it Down."**

So, it's unbalanced. LEVEL 3 –series of claims with evidence recalled through recall of motion of the parachute man.
Mark: So, yeh (nods head in agreement).
Ian: It's unbalanced. It's unbalanced.

Ian concluded for the group that the forces on parachute man are unbalanced forces. In this segment of talk, we see that the students draw upon multiple modalities in making their claims. Much of the discourse consists of choppy phrases punctuated by gestural thinking. The students literally use their hands to reenact the movement of parachute man. They also use their hands to track the direction of the forces they perceive as affecting the movement and speed of the parachute man. Ian's final claim: "It's unbalanced" represents the solidification of handwork, object manipulation and phrases synthesized into verbal language, as he repeats twice: "So, it's unbalanced. It's unbalanced."

*When Modalities are Insufficient*

In small group work, there were instances when words and gesture proved insufficient to convey meaning from one peer to another. During these times, the students who understood the content but who were experiencing difficulty conveying their understandings to other students, often redoubled their efforts to communicate their claims by drawing upon additional modes of communication to express themselves. They sometimes used object manipulation to construct counterclaims and rebuttals in their renewed efforts at communication. This bolstered the ultimate argumentation levels achieved by the students in these small group settings.

What happens immediately following Ian's claim in the previous example is important to achieve a more complete understanding of how children think and learn. Alan admits that he does not understand Ian's claim, though Mark and Daniel seem convinced and appear to be in agreement with Ian. Unlike them, Alan has not thus far been able to construct meaning from the hybridized verbal talk and gesture his peers have performed.

Alan is not able to follow the argument without additional explanation from his peers. The only instance of object manipulation used in the above discourse was at the very end when Ian grabs the parachute man and says: "Look. It's just that *this* is slowing him down," referring to *the parachute* itself. This reference to the parachute is enough for the other three boys to follow the argument, but it takes more reenactment for Alan to finally agree. Since gesture alone did not suffice, Ian switches from gesture to more substantiated object manipulation to convey his thinking to Alan. The following discourse ensues:

> Alan: Wait, why's it unbalanced?
> Ian: Alright (grabs parachute). If he didn't have the parachute, he would just- (throws parachute man straight down on table) fall.

**Figure 7.26: Ian Throws Parachute Man Down on Table**

> But since he has the parachute, (lifts parachute in hand and up at face height), making him go slower-

**Figure 7.27 Ian: "…But Since He Has The Parachute…"**

Mark: (adds a slow gesture with his hand moving down, and looks at Alan)

**Figure 7.28: Mark Gestures Slow Movement of Parachute Man Downward, as Ian Holds the Actual Object, Parachute Man, in Hand**

Alan: air resistance-
Ian: yeh (points at Alan in affirmation),
Daniel: which makes him fall slower.
Ian: yeh, the air resistance slows him and gravity, gravity always stays the same, but in this case, it's going like (moves the parachute man slowly side to side and down)
Alan: Okay, so the air resistance is up, and the gravity's kind of down.
David: When it's going down, the air is going up (gestures an upward movement with his hand).

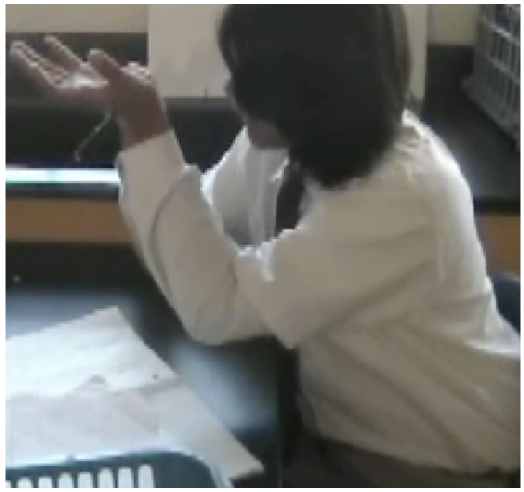


**Figure 7.29: Daniel Gestures "…The Air is Going Up"**

> Air resistance is going up, making it fall slower.
> (all four students write).

Here we see a level five argumentation is achieved, as all four students co-construct argumentation via gestural input and verbal talk. Ian adds the "exception" to the stated claim, by saying that if there were no air resistance, the parachute man would just fall. We see him re-enact this for Alan before showing what really happens to parachute man with the presence of air resistance. This discourse segment illustrates that when words and gesture are not sufficient for understanding, a more robust demonstration with the actual objects is in order, leading to higher argumentation levels. And, at least in this case, the lack of transparency of the words and gestures, leads to a higher level of argumentation. The boys have to work harder to convince their peer, Alan, of their claims, and so go the extra step of adding "exceptions" to their argumentations, bringing them to level fives.

*Summary and Discussion*

Arguing Well: A Distributed View of Cognition

Clip five provides evidence for claim four in Wilson's "Six views of embodied cognition" (2002), which states that the environment is part of the cognitive system. Though Wilson rejects this claim, in this example, we see the students working within a distributed system that clearly illustrates that the forces driving cognitive activity "do not reside solely within the head of the individual, but instead are distributed across the individual and the situation as they interact" (p. 630). Indeed, this clip is largely representative of what I observed throughout the data collection period during the "explore" portion of Dave's classroom. These portions of the lesson consistently revealed a distributed view of cognition. Students repeatedly used body movements together with gestures and verbal language which enabled them to reach points I do not believe would be possible were these facultative systems not studied holistically. If we were only to look at students' words without gestures, or only see demonstrations without the charting of definitions, much about what we know about how students learn would be missed. As Alac & Hutchins (2004, p. 638) assert:

> the correct unit of analysis is not one semiotic modality, such as speech or gesture taken in isolation, but the entire complex. The meaning of a complex emerges from the interactions among the modalities that include the body, as well as material objects present in the environment.

Gestures as Integral to the Emergence of Scientific Language

Clip five underscores the findings of Roth (1996a, 1996b) in middle and high school classrooms which suggest that gestures such as the ones "Dave" and his students use are not only an integral part in students' proto- scientific language, but that these gestures actually facilitate the emergence of scientific language and communication. This clip, we see the first instance of students using object manipulation to further the understanding of another student. In previous clips, we witnessed the power of students gesturing at the objects while their teacher's held them; here, we see the students themselves manipulating the objects to construct arguments. By examining both student gestures over manipulatives in their environment, as well as their words, a much richer understanding of what they do and do not understand emerges.

*Using Gesture for Personal "Sense-making" and Public Argument- Clips Six and Seven, Lesson Three*

Clips six and seven highlight students' use of gesture for three different purposes: one, for their own private sense-making; two, to add to their words and make a claim during a class discussion; and three, to construct a counterclaim to oppose another's ideas. These private versus public uses of gesture are explored in the analysis of clip six. Clip seven provides evidence for the finding that "first draft thinking" is necessary before "final draft" ideas are formulated as final verbal claims. This "first draft thinking" may consist of words and gestures, as well as reference to written text and drawings.

Both examples come from the "post-experimental meeting area" during the "explain" portion of lesson three. Even though all the groups have already been discussing the three scenarios during the "explore" session, this is the time they all come together to reach consensus on their findings. Students achieve level four and five argumentation levels, again through a hybridization of words, gesture, and drawings.

This is orchestrated via the teacher's facilitation of student input, which is highlighted in the analyses below.

*Clip Six, Lesson Three*

In the first transcript segment below, Dave is interacting with his students over the parachute man scenario (Figure 7.16). He is attempting to achieve consensus on how to draw the forces involved, what those forces are from, and how long the arrows indicating those forces should be in relationship to one another. As the conversation begins, level one argumentation is immediately and easily achieved. Alan and Daniel claim that the forces involved are air resistance and gravity. As they verbalize their answers, Dave draws corresponding visuals and words on his easel. Alan and David use deictic gesture, pointing to the easel, as well, when they indicate how to draw the force they have each articulated. This is seen in the section of transcript below.

T: Okay. Parachute man. What forces were acting on parachute man? Alan?
Alan: Resistance. LEVEL 1
T: Which one?
Alan: Resistance.
T: Oh, wind resistance. How do I draw that?
Alan. Uh, you draw.
S: Oh. [interrupting]
T: Okay. Hold on a second. Alright, Alan, what was it? Wind resistance? Which direction?
Alan: Huh?
T: Which direction?
Alan: Up (deictic pointing at easel).
T: Up. Okay. So I draw it like this? [drawing arrow up on easel] Wind resistance [writing at the same time]. Okay, what was another force acting on parachute man? Daniel?
Daniel: Gravity. LEVEL 1
T: Okay, gravity. Which way should gravity go?
Daniel: Down (gestures hand down). LEVEL 1

This type of factual knowledge does not require much argumentation. The students have seen parachute man before while working through other scenarios on previous days, so there is little thinking required. They simply point and say a word. The discussion continues as Dave asks about the length of the arrows representing the forces for gravity and air resistance. This question is answered with dissenting ideas by several students. Both Gibbs and Gus rely on their own gestures to fully articulate their ideas, as seen below.

T: Would that be longer or shorter or the same as wind resistance?
Daniel: Shorter? Because it's making it fall?
T: So you think it would be shorter like that?
Daniel It's making it fall slower. LEVEL 1
T: Gibbs, do you agree with this picture?
Gibbs: [nods]
T: Everybody agrees with this picture?
Gus:I think there's only two! (claps hand together). That's all there is. LEVEL 1
T: You guys agree with the length of the arrows - this being bigger than the gravity?
Ss: Yes.
T: So, so...
Gibbs: No, I think they'd be the same 'cause if, then it would be like that (moves hand slowly down), slow (moves hand very slowly down). LEVEL 3- Counterclaim within a series of other student claims, without evidence

**Figure 7.30: Gibbs Gestures: "…then it would be like that…"**

T: Okay, Gibbs thinks they should be the same. Gus?

Before adding Gus's viewpoint, it is important to note that Gibbs has not actually articulated his evidence for his claim in words. His actual claim is that "they'd be the same," referring to the arrows for gravity and air resistance. However, the evidence for his argument is not presented in words, but rather in gesture. He states: "'cause if-, then it would be like that, slow." His gestures add a very slow movement in a downward movement, adding to his verbal statement. With this additional gesture, it seems clear to him that he has provided evidence for his position; however, it is not clear what exactly the "cause if" is referring to. Therefore, in this case, the addition of the gesture to his words is successful for his own *internal* understanding, but it has not successfully made his point clear to others. Rather than calling attention to this, Dave decides to continue taking student input, and moves on to Gus, who also has raised his hand to comment.

As the discussion continues, Gus adds his own ideas, saying that he actually drew three arrows. He goes on to say that one was to illustrate the parachute man being thrown up into the air; the second one was to show gravity pulling down; and the third was to depict the wind. In describing the movements, Gus relies on a blend of words and gesture to convey his thoughts. His description of the wind moving the parachute man sideways is, in words: "…and the wind pulling kind of to the side 'cause when you throw it up it didn't, like, go straight down, it went like-." In words alone, his thought is incomplete, but as he adds the gesture and sound to it, a complete argument emerges. Unlike with Gibbs, then, Gus's use of gesture improves his verbal claim and the group can clearly grasp what he is attempting to communicate. This is captured in the transcript below:

Gus: On that one, I didn't put two arrows. I put three. One was the one because you threw it up, (gestures a hand thrown up in the air), the hand, which is up, gravity pulling down,

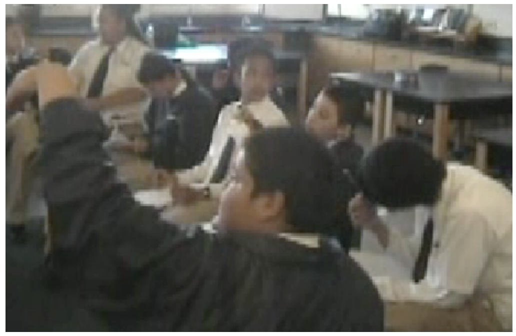


**Figure 7.31: Gus: "…Gravity Pulling it Down"**

and the wind pulling kind of to the side 'cause when you throw it up it didn't, like, go straight down, it went like [makes wind noise and makes gesture with his hand showing wind down and to the side]. LEVEL 3 – series of claims

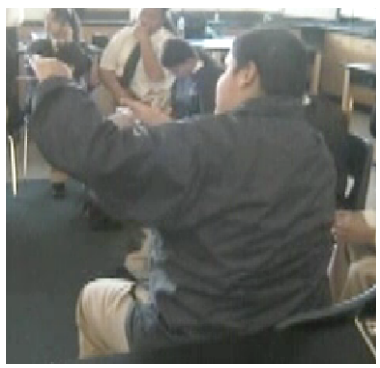


**Figure 7.32: Gus Making Gesture to Show Parachute Moving Sideways**

Gibbs and Gus are not actually arguing opposite viewpoints as it first seems. Gibbs has, incorrectly, decided that the arrows for gravity and air resistance should be the same; and Gus does not answer this question at all. Gus is still at the beginning stages of articulating his thoughts about *the drawings* he made and trying to convince himself and others of the reality of the parachute man's movement. Gus is stuck one step behind the teacher's question of "are the arrows okay?" He has not yet addressed the length of the arrows in his thought process, but is still negotiating which arrows he drew, why he drew them, and what they represented. Gibbs has used words and gestures to arrive at the faulty conclusion that the air resistance and gravity arrows should be drawn “the same.” Dave is now faced with the task of guiding the students in the direction of a “correct” answer that the gravity arrow should be longer. Currently, the students have asked Dave to draw the gravity arrow a bit shorter than the one representing air resistance. So, one representational state exists in written text on the front easel. Gibbs has just stated that the arrows should be the same. And, as the discussion picks up below, yet another student claims that the gravity arrow should be “bigger.” Three different possibilities are all expressed and on the table for discussion. The dialogue picks up with these three possibilities below:

> T: My question, though, is, are the arrows okay?
> S1: Yes.
> S2: I think that gravity should be a little bit bigger. LEVEL 3
> T: She thinks that gravity should be bigger. Right now we have it shorter. Gentlemen [to chatty students]. Gibbs - you said that they should be the same size. So we need to figure this out. We need to all agree on this. Gus - your attention needs to be up here please. Okay, Daniel and then Ian.

Dave clearly articulates the current state of the problem: three different viewpoints are being expressed and “we need to figure this out.” He then calls on three more students to provide input, and it is here where we see the argumentation level increase to four and five.

> Daniel: I disagree with Gibbs because (points at arrows on the easel) if we put them as the same length,

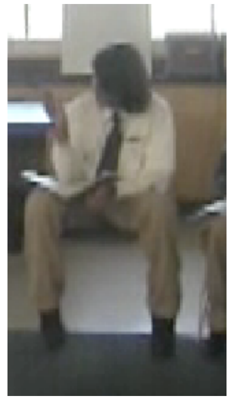


**Figure 7.33: Daniel: Deictic Pointing at Arrows on Easel, "I Disagree with Gibbs because…"**

it would be balanced, (holds right hand with pencil out flat to represent parachute man idling in mid-air)

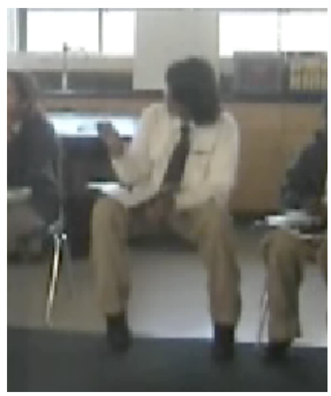


**Figure 7.34 Daniel Holds Pen Flat to Represent Parachute Man "Balanced" in Mid-air**

it would just- LEVEL 5- a series of claims/counterclaims is developing with accompanying evidence, and an "exception" to the previous claim
T: It would just stay right there, right?
Daniel: It would just keep standing still. (still part of the argument documented above)
T: Okay. So anybody want to come back against that. Gus?
Gus: I agree with whoever said that the gravity thing should be bigger because it went down, (gestures hand going down), chewww… LEVEL 4 continued
T: Okay. Ian?
Ian: I was going to agree with Gus. If the wind resistance were heavier it would be going up (gestures right hand rising up into the air, Figure 7.35),

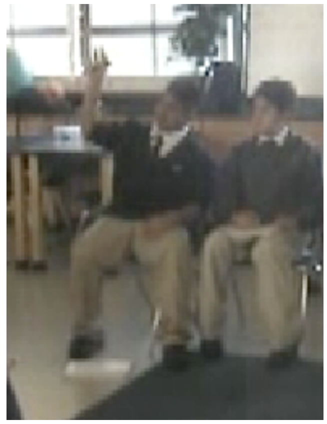


**Figure 7.35: Ian Gestures Hypothetical Parachute Man Rising Up**

instead of coming down. LEVEL 5- series of claims is maintained, now with the addition of at least one articulated "exception" to another student's claim.
T: Yeah, if the wind resistance were heavier, wouldn't it be pushing it actually going up? (teacher mirrors Ian's gesture up).

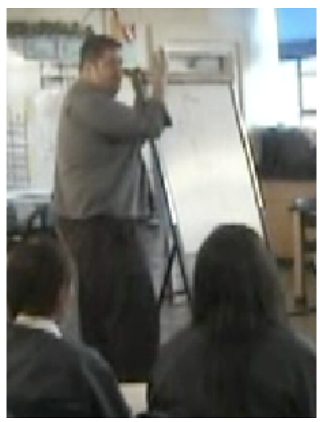


**Figure 7.36: Teacher Mirrors Ian's Gesture "Up"**

Here we see Daniel answer the question right on the mark. He says he disagrees with Gibbs. Even though it was not clear from Gibbs' gestures what his evidence was, it was clear what his claim was: that the two arrows of gravity and air resistance should be "the same." Daniel states that he disagrees with this, implicitly claiming then, that he believes the arrows should be of different sizes. Because there has not been a series of claims made, this raises the level of argumentation to a level 3. As he continues talking, however, Daniel provides an exception to Gibbs' claim, when he states verbally in conjunction with gesture, that “if we put them at the same length, it would be balanced, …it would just stay right there,” raising the discourse to a level five with the inclusion of this clause of exception. Since everyone has clearly seen that parachute man does not “just stay right there” suspended in air, Daniel’s evidence resting on a point of exception to Gibbs’ counterclaim is infallible. Even so, Dave asks if anyone would like to come back against this claim to make a different argument. Gus, who previously was still working through his force arrows and what they stood for, now falls in line in agreement with Daniel, stating: “I agree with whoever said that the gravity thing should be bigger because it went down.” Interestingly, he states this claim without the use of gesture, but then follows his words with a “chewwww” sound and a quick gesture of his hand sailing down. It seems that Gus needed first to establish his own developmental sequence of thought, providing rationale for the three arrows he drew, and then concentrate on the two arrows pertinent to the parachute man’s movement. Only after he had worked through his own thought process through gesture, could he move into the realm of argumentation about the length of the arrows using his words alone. He needed to “work through” information states in the form of hybridized talk and gesture, before feeling more certain of his thinking and entering into the discussion.

Ian also joins in the argument by adding that he too, agrees now, with Gus. Ian adds an exception to the opposite claim, raising the discourse to a level five. He states: “I was going to agree with Gus. If the wind resistance were heavier it would be going up instead of coming down.” He uses his right hand to gesture an upward moving, representing parachute man’s hypothetical rising in the absence of more gravity. Here the implicit evidence is that the man is coming down, and the exception is that if the air resistance were “heavier,” or greater than the force of gravity, the man would actually be rising up. The perceptual reality agreed upon by the class was that parachute man did indeed go down, therefore, the gravity arrow must be longer.

Both Ian and Daniel raise the discourse to a level five argument by providing different examples of exceptions to the opposing claims. For his part, Daniel examined the notion of the parachute man remaining idle in mid-air; Ian examined the notion of parachute man continuing to rise in the air. Both of these students provide exceptions to the opposing argument that render the claim incorrect. What is interesting is that part of the argumentation chain involves Gibbs, who early on, gives an incorrect answer to the question, and Gus, who initially articulates information tangential to the actual question. However, collectively all of the individual information states of these students contribute to the highest level of argumentation documented during the data collection period. All the contributions of Gibbs, Gus, Ian, Daniel, and others who chime in with one-liners or partial statements, are considered and built upon to achieve the final “correct” notion that the gravity arrow should be longer than the air resistance arrow in this scenario. The teacher solidifies this idea, sedimenting all student input into a clear, coherent, verbal statement: “So then we can agree that gravity should be a longer arrow like this (draws on easel). Gravity should be stronger than wind resistance because he is falling down to the ground. Alright, so, you guys are saying that gravity's longer so he's going down.” This linguistic objectification is then transferred into the “black-boxing” of arrows on the easel in front of the students for their final visual output of learning.

*Summary and Discussion*

Gesture for Proof, Gesture for Sense-making

In clip six, we see students use gesture for three different purposes. First, Gus and Gibbs both use gesture for their own personal sense-making. Second, Gus and many others use deictic gesture to refer to Dave's easel drawing and make claims with evidence; and third, students use both deictic and iconic gestures to make counterclaims to oppose one another's ideas in meaningful argumentation structures.

*"First Draft Thinking" Paves the Way for Higher Levels of Argumentation*

*Clip Seven, Lesson Three*

Clip seven provides evidence for the finding that "first draft thinking" is necessary before "final draft" ideas are formulated as final verbal claims. In clip seven, "first draft thinking" is inclusive of words, gestures, movement, and references to written text and drawings. It seems a prerequisite to more sophisticated levels of argumentation.

Context of Clip Seven

Once students have established the length of the force arrows operating on parachute man, they attempt to describe the motion of the parachute man. As in example one, we see the students begin the conversation with simple claims accompanied most often by gestures. And, again, as in the previous example, we see that Dave allows the students to "work through" their first understandings via gesture and words before the argument really gets under way. This is the same type of "first draft thinking" referred to previously in the analysis of clips one and two.

Constructing "First Drafts" of Thinking

Raquel and Ian both gesture their differing perceptions of the movement of parachute man. Raquel gestures a flat movement from left to right in front of her, whereas Ian gestures a spiral motion gradually descending downward.

> T: And then, describe the motion of the parachute man.
> What about this sideways? What does that make him do? Does he go like [draws a line straight down on the picture]? What does he do?
> Raquel: It makes him travel like in a [makes a gesture to the side with her hand].

**Figure 7.37: Raquel Pushes from Left to Right**

T: Okay, so he kind of goes like [draws another line on the picture]. Is that right?
Ian: No, it kind of [makes a spiral motion with his right hand]. LEVEL 0 – observation.

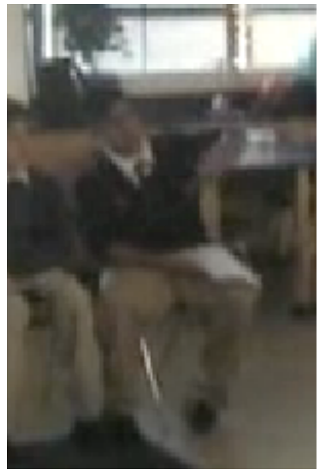


**Figure 7.38: Ian Gestures Spiral Motion with Right Hand**

Here again, we see the students' need to first articulate their ideas through a hybridization of gesture and words in their unique versions of "first-draft" or "exploratory thinking" (Michaels et. al, 2008). Alone, the words do not suffice to express what they are thinking. Raquel's only words are: "It makes him travel in like a," and Ian says only: "No, it kind of." Alone, neither student's words convey the movement each is attempting to express. Yet, this seems an important and consistent phase the students need to work through before moving on to more sophisticated argumentation structures in their discourse.

Moving Towards "Final Drafts" of Thinking

Once the students have had the opportunities to create their "first-draft thinking," Dave reminds them that they have learned some fixed definitions in relation to motion. Two students have clearly given different indications of what they saw the parachute man doing in terms of his movement pattern (sideways or spiraling down), and Dave reminds them that when he says the word "motion," they should think of? This revisitation of learning that has already been neatly black-boxed through past learning, is now the catalyst to move the discussion forward:

> T: Remember what were the three things when I say the word motion you think of...
> S: Speeds up, slows down, or stays the same.
> T: Okay, so what was the parachute man doing? (points to drawing he has made so far on the easel).
> Ian: He was slowing down (makes spiral motion with hand). LEVEL 1
> T: Slowing down?
> Gus: Speeding up! LEVEL 1- counterclaim
> T: Parachute man is falling. What do you think?
> S: I think it stays the same and then stops. LEVEL 3- series of claims/counterclaims with no evidence
> T: Okay.
> Gibbs: No, 'cause he goes like this, he goes [takes a piece of crumbled paper, opens it like a parachute and makes it begin to descend slowly]. Begins to provide evidence to bring to a level 4
> Gus: (simultaneously talking while Gibbs is) I think he's speed up (gestures)

**Figure 7.39: Gibbs Reenacts Parachute Man as Gus Gestures "Speed Up"**

> because gravity's a constant force so gravity's pulling him down (gestures down)

**Figure 7.40: Gus: "Gravity's Pulling Him Down"**

so that means he's speeding up. LEVEL 4
Gibbs: Hey, no, Mr….

We see the exact same pattern above as in clip six. Dave receives three different answers to his query about the motion of the parachute man: one student says he is speeding up, another says he is slowing down, and a third that he is saying the same speed. This series of claims is accompanied by varying evidence to raise it to a level four argument. As before, Dave takes charge and articulates the obvious: that they now have a lot of different ideas and they need to work through this. Interestingly, Gibbs relies heavily on object manipulation to provide his claim. He creates a makeshift parachute man out of a piece of crumpled paper, and then opens it and slows it's path as he brings it in a downward descent. His claim, that the man slows down, is demonstrated through the act of manipulating the object. Gus primarily uses a hybridization of verbal words and gesture, and the student who thought that he stayed the same speed uses her words alone.

T: Okay, so we've got a bunch of different ideas. Okay, so we've got one person saying he's slowing down, one person says he stays the same speed and then he stops because he hits the ground, and another person says because of a constant force he's speeding up. What do you guys think?
Ian: Speeds up.
Daniel: Speeds up because gravity's a constant force. LEVEL 4
T: Is it a constant force that causes things to speed up?
Ss: Yes.
Ian: But the parachute slows him down. LEVEL 4
T: We know he's definitely not staying the same speed.
Ian: It's slowing down because-
Maria: (a student who had previously claimed it stayed the same speed, giggles and covers her face with her hands momentarily)
Ian: Slowing down. It's slowing down because of the parachute. That's what makes it slower as it goes down. LEVEL 4

Here we seem to have a standstill between those who agree with Ian that the man slows down, Maria who thinks the speed stays the same, and Gus, who thinks the man speeds up. Since they are not being successful in convincing each other of their viewpoints, Dave decides to remind them of the consensus they just finished reaching with one another. He reminds them that they just finished telling him to draw the gravity arrow longer than the air resistance arrow. And, if that is the case, then the larger arrow will "conquer" every time, and therefore speed up the motion.

> T: Okay, but you guys drew this arrow much longer than this arrow. So this one's going to conquer every time right?
> S: Yes.
> T: So even though this one's pushing against it, it's still going to be speeding up, just not as much.
> Gus: Yes! So I'm right, right?
> T: Alright, so if you didn't get those answers, there we go. Alright, moving on to our next picture.

Unfortunately, there still appears to be confusion even though Dave articulates the final statement that the parachute man speeds up. It seems the students are confusing the net movement downward with the notion of speed. Ian seems to think that the speed is slowing, even though the net movement is downward. Gus seems to circumvent these related issues by simply evoking the definition of constant force as speeding things up, and identifying the force of gravity acting on parachute man, as a constant force. There is a halt to the opportunity for resemiotization to continue taking place, as Dave sediments the student input into a final answer and claims that parachute man "speeds up." We then hear Gus triumph, "Yes! So I'm right, right?" Without the continuing orchestration of student input via gesture, verbal talk, and object manipulation, there does not appear to be a consensus reached within the group. They reach a high point in the discourse where they are disagreeing, and then the teacher simply provides the answer by referencing an earlier point the class did agree upon. It is not clear many of the students were content with the leap from this earlier agreed upon claim to the new one. In fact, after the teacher states the final claim, we can see Ian turn to Mark and continue to whisper something to him. His body language appears to convey that he remains unconvinced of the final claim, though he reaches for an eraser to make revisions to his notebook. What is clear is that once resemiotization ceases, so does the ability to reach consensus.

*Summary and Discussion*

Orchestrating "First Drafts" into "Final Drafts"

In the final moments of this lesson, students are able to co-construct a final claim. They contend that unbalanced forces can speed up or slow down the object, and balanced forces cause objects to stay the same speed. This consensus is achieved by the discussion of each of the three scenarios from the "explore." Students are afforded opportunities to resemiotize their learning of the science during the discussion, drawing upon gesture, verbal talk, object manipulation, and written text and drawings to achieve their final claims for each scenario. Key to this process seems to be the initial opportunities Dave affords the students to create "first-draft thinking" via their own unique constructions of pieces of words, gestures, and movement. Dave scaffolds the process by first asking students to arrive at a consensus of the length of the arrows in each diagram for each event, and then to think about the motion of the objects in each scenario- whether they speed up, slow down, or stay the same. In the process, they draw upon different modalities and engage in argumentation to make their points. Finally, they are able to synthesize the findings from all three scenarios into one final claim about balanced and unbalanced forces. In this particular clip, Dave's orchestration, or careful selection of different voices to contribute to the learning, plays a key role in the final claims the students are able to make.

*Patterned Resemiotization: Lesson Four – Clips Eight, Nine, Ten, Eleven, and Twelve*

The data from lesson four suggest that when students work in partners, resemiotization often occurs in a patterned formation with initial ideas processed through object manipulation first, then transferred into gesture over those objects, then to gesture alone, then into words with gesture, and finally into words alone. Data also suggest that during sense-making stages of thinking, speech and gesture are asynchronous; however, in thought that has been rehearsed and of which students are confident, speech and gesture are well-timed and often exist simultaneously.

*Context for Lesson Four*

In lesson four, students in Carla's class are learning to define and represent forces in pictures. They have just watched a video clip of a high-speed car chase involving a mini van and an Ohio state trooper. The minivan crashes into the center median, and the teacher uses this information to teach students about sources, receivers, energy, forces, energy diagrams and force arrow diagrams. Students have been given scenarios to work through with objects, along with the directions depicted in Figure 7.41 below:

FORCE EVENTS

Key Question: How does energy transfer during a force event?

Supplies: Balloon, air puck, wood block, sand paper, 2 clamps, rubber band, balloon air pump, car

Activity:

1. Read each scenario and identify the source, the receiver, the energy. Draw the force arrow diagram.

| Claim | Evidence |
|---|---|
| What do all of the sources in your events have in common? | |
| What do all of the receivers have in common? | |
| How does the energy transfer during these force events? | |

Conclusion:

Summary of what you did.

Summary of your results.

Final Claim of what occurred in this experiment.

Answer the key question.

**Figure 7.41: "Explore" Scenarios, Lesson Four**

In the entirety of lesson four, the highest level of argumentation attained is a level three. This occurs five times among a duo I call Sandra and Alberto during the "explore" portion of the lesson. Because of the way Carla structures the 5E lesson this day, students are not afforded the opportunity to participate in the "explain" portion of the 5E model in whole class formation, as in Dave's class. In essence, the "explore" and "explain" are one continuous portion of lesson four that blur together. It is during this extended blurring of the two phases of "explore" and "explain" that Sandra and Alberto engage in discourse that peaks at a level three. They do the work of exploration immediately followed by the work accomplished in a typical "explain" portion. Their only audience, however, for the "explain" portion is one another.

There are six instances of coded talk that occur between Sandra and Alberto during the time the researcher spent with them during the explore portion of this lesson. In the table below, I illustrate the levels of argumentation achieved in each of the six instances of talk. I then follow with a detailed analysis of five clips, examining what factors contributed to the achievement of argumentation levels.

**Table 7.6: Six Instances of Argumentation Documented at Sandra and Alberto's Table**

| Objects of Interaction/Problem to be Solved | Argumentation Levels Achieved | Commentary |
|---|---|---|
| Two clamps with rubber band stretched across, car. | 1, 1, 3 | Negotiating text, use of gestures, words, writing, object manipulation. |
| Balloon attached to wood block, car. | 1 | Words with object manipulation. |
| Wood block pushed into cabinet wall. | 1, 3, 2 | Words, object manipulation, gesture, writing |
| "Does it matter it the arrow is going out of or going into the diagram?" | 0, 1, 1, 0, 1, 2, 2, 1 | Words, gesture, writing, talking with researcher. |
| Writing conclusion to the whole activity. | 1, 1, 1, 1, 3, 1, 0, 0, 1, 1, 1, 2, 1, 1, 3 | Working with discourse moves of researcher. |
| Attempting to phrase how the receivers "changed" as a result of interactions with sources. | 1, 2, 2, 1, 0, 2, 1, 0, 2, 3, 1, 1, 1 | Linguistic objectification – goal is to lead student to more authentic language. Final claim objectifies science into concrete language shared by scientific community. |

I draw upon these six instances in choosing five clips that illustrate the highest levels of argumentation from lesson four, and/or serve to best illuminated instances of patterned resemiotization within the data.

<u>Sandra and Alberto – 1, 1, Clip Eight</u>

In the first discourse sequence in Table 7.6, Sandra and Alberto have set up two clamps with a rubber band stretching across it. As the teacher comes around, Sandra asks: "Isn't your hand the source?" The teacher answers: "Yep," and Sandra looks for further clarification asking: "And the energy is when it pulls it," as she pulls the rubber band back with her hand (see Figure 7.42).

**Figure 7.42: Teacher as "More Capable Peer"**

The teacher again replies "Yep," and walks over to assist another group. Realizing that they are on their own at this point, Sandra and Alberto begin their work together without the presence or intervention of any other "more capable peer." In the transcript that follows, we can see Sandra negotiating the text out loud and using a combination of words together with object manipulation and gestures to arrive at her final level one claim that "energy's when you pull it." In Figure 7.43 below, I document the interaction between the different modalities Sandra uses in her first two level one claims.

| Verbal Statements | Modality Work | Argumentation Level |
|---|---|---|
| S: Okay, we have to do this first. So, the source is the hand. The hand. | S reads portion of lab out loud. Waves hand. | 1(claim without evidence) |

**Figure 7.43: Interaction of Modalities with Speech in Construction of "Claims"**

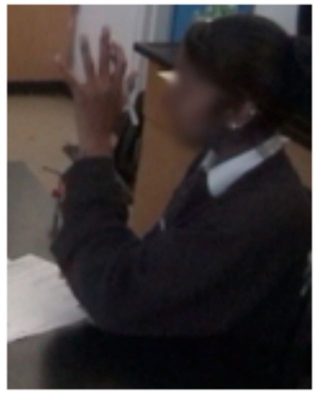
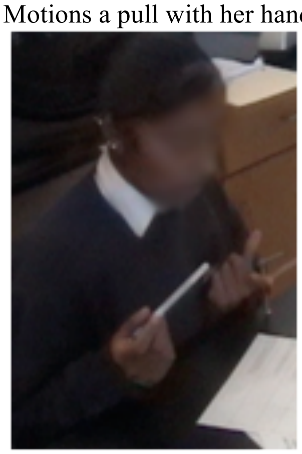
| Verbal Statements | Modality Work | Argumentation Level |
|---|---|---|
| I think that's what we put.<br>Energy's when you pull it.<br><br>It makes the stretch. | <br>Waves hand.<br><br>Both write.<br><br>Motions a pull with her hand;<br><br>motions a horizontal stretch with her hands;<br>Smiles a big grin and shakes her pen against her flat palm to pool the ink.<br>Gesture and speech occur simultaneously. | 1(claim without evidence) |

**Figure 7.43 continued**

*Summary and Discussion*

<u>Patterned Resemiotization and the Timing of Gesture with Speech</u>

These first two instances of level one argumentation are comprised of the simple claims: "the source is the hand," and "energy's when you pull." However, to arrive at these claims, we see Sandra use a mixture of interrelated words, gestures, writing, and object manipulation. In Figure 7.43 above we see her use gestures from a wave of the hand, to imaginary "pulls" on a rubber band, to "stretches" of the rubber band, to achieve her simple claims. In fact, a closer look at the chronology of contributing modalities reveals the following symphonic sequence: words- writing- gesture- object manipulation- words- object manipulation- writing- words- gesture- words- gesture- words –words with gesture. The appearance of verbal phrases or words are always punctuated by one or more kinesthetic or visual modalities before the appearance of more words; and the pattern repeats.

> Words- writing- gesture- object manipulation;
> Words- object manipulation- writing;
> Words- gesture;
> Words- gesture;
> Words with gesture.

Sandra processes her thoughts through verbal, visual, and kinesthetic modalities. It seems the input from multiple modalities enables Sandra to process her thinking and to ultimately locate and lay down her final thoughts in the realm of the verbal modality. However, what is striking is that as her thinking becomes clearer, she continues to verbalize, but begins to replace the object manipulation with gesture. By the time she is "ready" to fully articulate her claim of "energy's when you pull it," she has preempted this claim with a proud smile, and the gesture that accompanies her final claim about energy is synchronous with her words. Until that final certain statement, all other gestures we see have preceded her verbal remarks. It is only in the final remark she utters, that the gesture is well-timed with her speech. This is consistent with Crowder and Newman's (1993) claim, discussed in Chapter 2, that during the sense-making stages of thinking, speech and gesture are asynchronous; however, in thought that has been rehearsed, speech and gestures are well-timed and exist very often simultaneously.

Lesson Four, Clip Nine, Level Three

Later during the same exploratory session, Sandra and Alberto negotiate the text to figure out what to do with the objects of the next activity.

**Figure 7.44: Sandra and Alberto Negotiate Text**

Alberto begins by blowing up a balloon with an air pump. Table 7.7 below documents the interplay between modalities that peak in a level three argumentation. In Table 7.7 below, S signifies Sandra and A signifies Alberto.

**Table 7.7: Interaction of Words, Modalities and Argumentation Levels During "Explore"**

| Verbal Statements | Modality Work | Argumentation Level |
|---|---|---|
| S: So, this is the object- | S: sets car to far side of her | |
| S: and just push it like- | S: gestures a smooth flat surface in front of her. | |
| S: Slide it on the table and push it- | S: points to balloon in Alberto's hand. | |
| A: Like this? | A: slides car across table. | |
| S: So it slides. So, the source is the thing- | S: hits pen on the pump. | |
| S: -the air pump with the balloon | S and A: both write. | |
| S: - and the energy is the push- | S: slides her hand horizontally across the table, | |
| S: - and the receiver is the car. | S: taps car with her right hand.<br>S and A: write in silence. | 3 (series of claims without evidence) |

In this example, we again see the interplay between words, object manipulation, and gesture. The discourse coded as a level three is comprised of a sequence of phrases uttered by Sandra, each immediately followed by gesture, then more words, and finally physical contact of her pen with the car that has just watched been manipulated by her table partner, Alberto. In this example, the sequence alternates from words to gesture, words to object manipulation, or words to writing before the claim is finally encoded in writing as follows:

> Words-object manipulation; words-gesture; words-gesture; words- object manipulation; words-object manipulation; words-writing; words-gesture; words-object manipulation; and then finally writing.

This interplay between touch, gesture, and verbal language seems to be a crucial mixture in the final outcome of cementing claims that can be encoded into a final written form. Again, we see the patterned use of resemiotization with the use of words punctuated by alternative modalities.

### *Resemiotization Mediated through "Talk Moves": Clips Ten, Eleven, Twelve, Lesson Four*

Clips ten through twelve illustrate examples of resemiotization as mediated through the "talk moves" of a more capable peer. This is similar to the data in clips one and two, except that instead of the teacher orchestrating the semiotics and student voices, I, the researcher, engaged the students in "talk moves."

*Context for Clips Ten, Eleven, and Twelve*

The last three examples of argumentation at Sandra and Alberto's table involved the intervention of myself, as the researcher. As I filmed Sandra and Alberto, it became clear that there was a regular use of multiple modalities contributing to their attainment of "answers" for their work up until the point I chose to intervene. Once the duo had run through all ten of the required scenarios involving interactions between the various objects in their boxes, they reached the point where they had to begin to synthesize information from all ten scenarios and participate in some higher level critical thinking exercises if they were to proceed.

The next interactions document the discourse as Sandra and Alberto attempt to write the conclusion to their lab. To accomplish this, they need to first decide what they did, then give a summary of their results, and finally make a final claim about what occurred in this particular set of lab activities. Just prior to this clip, Sandra and Alberto have re-read the requirements for writing their conclusion and appear to be stuck. I decide to intervene and use the I-R "chaining" discourse style, previously described in Chapter 6 as one of the "teacher practices" that could potentially foster student-student discourse. My words are bolded in the conversation to highlight the minimal input I provided in the turn-taking of the talk. Here is how the conversation unfolded in clip ten:

**R: So, what did you guys do?**
S: We did, I think we did…
A: We um, found the source (picks up the air pump) and the receiver, and then um…
S: How did the receiver change.
A: Yeh.
S: I think in this lab, we did events where we know how the source causes the receiver to change (both write this). The source…(writes this as she

> says it, then stops to read her paper again, twirls her pen). In this lab, we- did events about the source causes the receiver to change. Our results depended on how the word problem was, if either it was pushed or, if either the source was pushed or pulled. (LEVEL 1) I think- what's the key question? (Turns her paper over to look for it, then finds it and reads it). What is the proper way to show a force visually? (thinks for a long while staring at the paper). I know the answer. To show a force properly you show if a source pulled or pushed (gestures up and down for emphasis of push and pull) the receiver, and then after, and after the event happened, you put what changed, how did the receiver changed. (LEVEL 1)
> **R: That's the answer to the key question?**
> S: I think that's it. Now I'm barely- summary of the results (turns paper over to re-read). In my results, in *our* results, we had um, I don't know (shrugs her shoulders and tilts her head from side to side, then smiles, and tries again). In our results-
> **R: What did you find out?**
> S: We find out how-
> E: Each different problem had different, different types of forces. (LEVEL 1)

At first, there is a low level of argumentation achieved at level one. Sandra uses the following chronology of modalities in searching for her answers: words, writing, words, reading, words, reading, words, gesture, words. Again, we see the patterned resemiotization with words punctuated by alternative modalities. In this case, there is little contribution from modalities other than from the written or verbal realms. Interestingly, she is not happy with her resulting claim. She ends by shrugging her shoulders, tilting her head from side to side, smiling, and then finally claiming that each problem had "different types of forces." But, she still seems dissatisfied and stuck. As the researcher, I decide to take a turn at playing "the more capable peer" to see how I might empower her to use further resemiotization to arrive at an answer she would be proud of and own. As the conversation in clip eleven (below) proceeds, I initiate the I-R "chaining" and toss Sandra and Alberto successive prompts designed to push their thinking.

**R: What did you find out?**
S: We find out how-
A: Each different problem had different, different types of forces. (LEVEL 1)
S: How each energy diagram goes through a force (claps hands together) (LEVEL 1) - how an energy diagram helps (gestures), wait. In our results, we found out how an energy diagram helps you find a force diagram, which in a force diagram (looks up toward ceiling and uses gesture) our results was that, um, either the (taps finger on the edge of the table) receiver was pushed or pulled (slides finger across table), and that caused the change in (taps finger on edge of table) in the receiver. (LEVEL 3 – series of claims). So, like the results was (pulls on rubber band attached to clamps) the change in the receivers (smiles with surprise on her face). (LEVEL 1) Isn't it?
**R: So, give me an example.**
S: An example is when we pushed the air puck (gestures a push) with the balloon attached and it moved towards the car (gestures a movement with both hands to her right)- (LEVEL 0- observations only).

**Figure 7.45: "It Moved Towards the Car…"**

A: And the air from the bottom made it (touches table and moves hand back toward himself) move towards the car- (LEVEL 0- observations only).
S: And it made the car move. (LEVEL 1) So- if it would have been a different car, it would have bumped or like something pushed in (gestures a slow push with an abrupt stop) (LEVEL 1), so that would be a change because the car would have looked different.
**R: And, Alberto, you said something about different types of forces. What do you mean by that?**
A: Cause in these forces, not all the forces had the same pull of push (LEVEL 1). So for these forces-
S: We had different answers.

A: Yeh, we had different answers.
S: We need to make like a little sense of that (brings both hands together as if to clasp an imaginary ball in front of her to crystallize an idea)

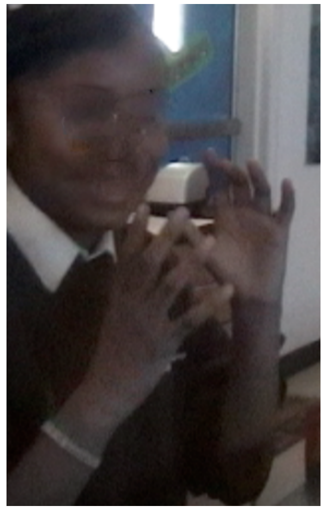


**Figure 7.46: Sandra Crystallizing an Idea**

R: **Yeh. Good. So, in each example the forces were not all the same? Is that what you're saying?**

S: So, I think that (again tapping index fingers on edge of table as she thinks) the answer to that is that in our results, we got different answers.

**R: From each other?**
S: From each word problem because it had a different source, and a different energy. (LEVEL 2 - claim with evidence)
**R: And so what did that do to the receiver?**
S: It [the energy] changed it? But, um- it changed the receiver. (LEVEL 1) I think that's our results! (surprised voice).

In this reasoning session, we see both Sandra and Alberto move once again through a series of modalities, this time in response to the purposive I-R "chaining" of myself. Here is the pattern embedded in the transcript above:

Words-gesture; words-gesture; words-gesture; words-gesture; words-gesture; words-gesture, then a level 3 argumentation is achieved.

This is followed by:

Words-object manipulation- words –researcher input;
Words- gesture; words, gesture; words- gesture; words, gesture; words – researcher input;

Words- researcher input;
Words- gesture- researcher input;
Words-gesture-researcher input;
Words- level 2 argumentation- researcher input;
Words – Sandra claims with surprise "I think that's our results!"

Even though this sequence terminates in only a level one argumentation, it is the empowerment Sandra expresses that is striking. She is on her way to making some significant sense of the lab activities at this point. To get here, she has resemiotized largely through the kinesthetic modality. She has used either gesture or object manipulation to process her ideas, with the help of the I-R prompting of the researcher. In the transcript immediately following, opportunities for resemiotization are again made possible through the I-R "chaining" discourse style inserted by the researcher.

**R: Did all of your word problems have something in common about the receiver?**
S: (looks back at paper) They moved. (LEVEL 1)
**R: Every single one of them?**
S: They changed. They had something different. They moved because the cars were moving, and the rubber bands (smacks/pushes a flat hand on edge of table) stretched out (performs a stretching motion with her hands), and then the rubber bands came together (brings her hands together) and we had two cars moving, and then in one of them we had a block bounce off, so- they all changed (LEVEL 3).
**R: What do you mean by 'they all changed?' What does that mean?**
S: They changed their like, their distance (eyes dart from place to place). (LEVEL 1)
**R: They changed their distance?**
S: Distance.
**R: What changed their distance? The receivers?**
S: Well, not their distance, but the um- they changed their- (searches for words, begins to rock back and forth as she contemplates, frowns), yes, no – they didn't change their distance (LEVEL 1). They changed their um- the way they were, cuz, if the car wasn't moving (gestures both hands in parallel from side to side across the table), well, what changed was that the car moved (LEVEL 2).

Here we see that Sandra has begun to engage with the researcher in the process of using resemiotization to realize linguistic objectification. She is literally telling the researcher with her words that the receivers all changed their *distance*. That is quite literally what her words are conveying. However, her gestures reveal not a change in distance, but more accurately, something else. Her hands are attempting to convey a change *in shape* for the rubber bands, as she performs a stretching motion with her hands, and a change *in position* for the car, as she moves her hands in parallel from side to side across the table. My goal, when I elected to move beyond the videographer to also assume the role of the "more capable peer" was to pave the way for Sandra to express in words what her hands were already saying. Here is the next sequence of resemiotization embedded in dialogue from clip twelve:

> **R: Okay.**
>
> S: And if, um- the um- if the rubber bands were normal and you like stretched it (gestures a stretching motion back and forth in front of her), it goes wider (LEVEL 2).
> **R: Okay.**
>
> S; So, it changed their- (long pause) their form of being? (LEVEL 1) (Begins to twist the rubber bands in tight circles with her left hand as she thinks).
>
> **R: Oh?!**
> S: Yeh! Now, I have to change my answer (Puts her hands to her chin in prayer like formation).
> **R: This is getting very interesting! So, the receivers changed their form of being?**
> S: Yeh (expression of pride on her face) Yeh. (Leans back in chair thinking).
> **R: Well, let's take them one by one. The rubber band-**
> S: It stretched out (gestures stretch motion) (LEVEL 0 – observations).
> **R: But changed its? What could we call that?**
> S: Okay, we have a rubber band, right? (removes the rubber band from the clamps and stretches it out). Their size! (Delighted) It changes their size! Because it was smaller (lays rubber band flat on table), but once you stretch it (picks it up and stretches it), it gets like (LEVEL 2)

A: bigger
S: Yeh, it gets like a little bit bigger. So, for the first one (holds up rubber band) it changed their size (LEVEL 1).
**R: Okay-**
A: The more you stretch it, the more bigger it gets (LEVEL 0 - observations).
**R: Okay. And what about the next example? How did that receiver change?**
S: (Looks down at paper). It changed because the car was still, it wasn't moving, and all of the sudden when the rubber band hit it, it moved like forward (gestures a thrusting movement forward with her right arm). (LEVEL 2)
**R: Okay, so how did that receiver change?**
S: Um-
**R: Did it change its size like the rubber band did?**
S: No, it changed its distance, and so in the next one it did too, because the air puck moved the car backwards (gestures), so it also changed its distance. And in the fourth one, in the fifth one, (picks up the wood block) when the block bounces the wall, um- it changes the distance too. Because first it's moving, but it stops it, because it has to keep on moving, but then it bounces back, so it changes its distance too (LEVEL 3 -series of claims).
**R: Good! So, how can you put all that together for your results, what you found out about the receivers?**

S: That receivers changed their size or distance (LEVEL 1). So, my results for – I think I have my sentence. My results for this lab-
**R: Good, _____! Do you agree with that, ______?**
S: My results for this lab is that the receiver changes their size or distance depending on how the source with the energy hits it? (begins to write) (LEVEL 1).
**R: Very good. I'm proud of you guys. That's a very sophisticated answer.**

S: Thanks (both write in silence for awhile). My final claim is that the receiver changes depending on the energy from the source (LEVEL 1).
**R: And how does it change?**
S: It changes by moving its position, size, or shape. It's just like the results.

Through a purposeful interaction between the researcher and, mostly, Sandra, linguistic objectification occurs by the end of this sequence. The pattern of resemiotization in this portion of the transcript is as follows:

Words-gesture; words-object manipulation; words-gesture- **researcher input**.
Words-gesture- **researcher input**.
Words –gesture- **researcher input.**
Words- object manipulation; words-object manipulation; words- object manipulation; Level 2 argumentation.
Words- object manipulation; words-**researcher input**.
Read-words, gesture- Level 2 argumentation.
**Researcher input**- words- gesture-words, object manipulation- words- level 3 argumentation.
**Researcher input**- words-writing- words.

*Summary and Discussion*

Two things seem clear from the transcripts in clips ten-twelve, involving the dialogue between Sandra, Alberto, and myself, the researcher. The first noteworthy finding is that the appearance of verbal phrases, or words, are always separated by one or more kinesthetic or visual modalities before the appearance of more words; and the pattern repeats. And the second idea is that the interplay between the touch, gesture, and verbal modalities seems to be a crucial mixture. Resemiotization of the learning through these modalities is a necessary process in order to achieve a final outcome of cementing claims that can be encoded into a final written form. This, again is the black-boxing I embed in my proposed model for guided-inquiry in Chapter 6 (Figures 6.2 and 6.72). If opportunities for linguistic objectification are present, this black-boxing will occur in language commonly accepted and practiced within the scientific community at large. This is depicted in pathway one of the model. If such opportunities are not present, the black-boxing of the science that occurs can include misconceptions of science and/or science expressed in "pseudo-scientific terms," as depicted in pathways two and three in the model. This is illustrated in many instances throughout the data collection period in

Carla's classroom wherein students work together manipulating objects. The last clip below illustrates this point.

*The Black-boxing of "Pseudo-science" – Clip Thirteen, Lesson Four*

Data from the final clip suggest that if students do not already possess a sufficient foundation of the scientific concepts and linguistic terminology involved, without a more capable peer, their exploration can potentially result in non-scientific notions are not embraced by the larger scientific community.

In this last clip, two female students work together to identify the source, receiver, and energy in a system consisting of rubber bands stretched across two clamps. One pulls back on the rubber bands between two clamps. Here is talk that transpires in the absence of any input aside from the partners themselves.

> S1: When you pull the rubber band (reading from text). The rubber band? Okay…(turns to the set-up of the two clamps with the rubber band). Your fingers pull the rubber band (pulls the rubber band as she says this), and give it the- (allows the rubber band to snap back into place), the- (looks up in thought) the elasticity-(looks at her partner, then looks away) to (looks at partner and smiles) hit the air. Yeh? (Waits for partner's response) I mean gives it the elasticity (pulls back on the rubber band again with her fingers as she says "elasticity") Yeh. Yeh. (slightly tugs at the rubber bands). So, (writing now) fingers pull the rubber band and gives it, and, gives it elasticity to put back in place. LEVEL 0- only observations of what is occurring are articulated. This is the fingers (drawing), fingers (hears her name called across the room). Que? (in Spanish) Que? The rubber band, elasticity, (looks at her partner's paper). Back in place? No se.

In this clip, we do not see the students able to check their thinking against the "talk moves" of a more capable peer, as in the examples of Sandra and Alberto with the researcher, and as in the many cases in Dave's classroom when the students work with Dave to resemiotize their thinking within the careful structure of his "talk moves." If students do not already possess a sufficient foundation of the scientific concepts and linguistic terminology involved, very often their exploration might still include the process of resemiotization through object manipulation and gesture; but without a more capable peer to bounce their ideas off of, the learning does not go through perceptual nor linguistic objectification. Though there may be a black-boxing of science, it is in language not understood by the scientific community at large. It remains in a "pseudo-scientific" state as we see in clip thirteen when the final claim is actually that "the fingers *give* elasticity to the rubber bands."

Though in other cases in the video data, partners are able to arrive at sophisticated scientific claims in partner work, this depends on the nature of the activities. Clip thirteen, in essence, attests to Kirschner et al.'s (2006) argument that inquiry approaches fall short of instructional goals. Without the proper supports in place, Kirschner is correct.

### *Chapter Summary: Revisiting the Model of Guided-Inquiry*

This chapter presents ten findings concerning the mechanisms by which the middle school students in this study construct scientific arguments. These ten ideas prominently concern the work of resemiotization. In particular, these mechanisms are situated within the model in the two green boxes labeled "resemiotization" in Figure 6.2. Looking again at the model in Figure 6.2, we see these two green boxes lead to three different outcomes. In Chapter 7, I have used thirteen video clips to illustrate how the work of resemiotization in these boxes unfolds and how these three outcomes are achieved.

In pathways one, two and three, the act of drawing upon multiple modalities to process and reprocess information is shown to be instrumental in students' ability to construct "first drafts" of their thinking. These "first drafts" are often constructed from a hybridization of words, gesture, and references to text encoded in artifacts around the physical classroom. During the "sense-making" stages of thinking, speech and gesture are often asynchronous; whereas, in articulated thought that has been rehearsed and of which a student is confident, speech and gestures are often expressed simultaneously. During such "exploratory talk," it is also found that resemiotization often occurs in a patterned formation with initial ideas processed first through object manipulation, then replaced by gesture over objects, then in gesture with words, and finally in words alone.

These "first drafts" of student thinking are also often necessary formations before more sophisticated (higher levels of) argumentation structures can be achieved, and before students reach consensus on final claims. In pathway one, the "talk moves" of the teacher were instrumental in orchestrating student resemiotization to facilitate the realization of perceptual and linguistic objectification, grounding students in a common view of the scientific phenomena and appropriating academic language to reference these "shared realities."

Higher levels of argumentation are seen to result from instances when there is a failure of certain modalities to explicate scientific ideas. When this occurs, students are seen to draw upon other modalities such as object manipulation, and use these modalities to formulate "exceptions" to opposing arguments in their attempts to re-explain claims to their peers.

In pathway one, resemiotization was mediated through "talk moves" of a "more capable peer" to advance student thinking. In the data, the "more capable peer" is either the teacher or the researcher.

Pathways two and three reveal that resemiotization does not always guarantee the attainment of science learning as expressed in ways likely to be authenticated by the scientific community. As seen in the model (Figure 6.2 and Figure 6.72), in pathway three, resemiotization that occurs during the "explore" phase of a lesson often is not articulated with "talk moves" of a "more capable peer." This was mostly found when there was no "explain" portion of the lesson and students were left largely on their own to process and reprocess their thinking. The data from this study indicate that when this was the case, students sometimes did not achieve linguistic objectification, and arrived at a "black-boxing" of science that was articulated in "pseudo-scientific terms." In pathway three, we find that resemiotization alone is not sufficient to lead to successful black-boxing of science in authentic terms. In situations where students do not possess sufficient background in the science, and do not have the benefit of a "more capable peer," the use of resemiotization alone can potentially lead to non-scientific conclusions, expressed in "pseudo-scientific language" that does not bear scientific credibility, as in the student statement: "Your fingers pull the rubber band and give it the elasticity to hit the air."

## Chapter 8- Conclusion and Implications for Incorporating Successful Models of Guided-Inquiry in Middle School Classrooms

*Clarifying Goals for Science Instruction*

***"All…students will graduate with the skills, motivation, curiosity, and resilience to succeed in their choice of college and career in order to lead and participate in the society of tomorrow."***

***-Mission Statement of Large Urban School District in Southern California***

To look critically at science teaching and learning, we must first be clear about our goals. The mission statement of the charter school in which this study took place states as its primary goal: "to accelerate academic achievement for ALL students through a college preparatory culture and curriculum" (school website). What is missing is a larger vision for the purpose of this college preparation at all. Why should students *want* to go to college? Why should students commit themselves in middle school to the habits of mind that will lead them to college admission? What work in the real world will college prepare them to do? Students need to see relevancy; they need a rationale for the purpose of college and its connection to solving the problems of an imminent tomorrow; and they must also be able to locate their place within this conception of the future.

We find this larger vision in the text that opens this chapter. Here, the mission statement of the large urban school district closest to the charter expresses its primary goal for students as preparing them to "lead and participate in the society of tomorrow." A society of tomorrow necessarily presents challenges and problems requiring solutions not yet invented- the creation of renewable energy sources, solutions to global climate change, and medical cures for diseases thus far not understood. These are the challenges that make education pertinent to youth. These are the challenges of tomorrow for which educators need to design instruction today.

This study seeks to provide suggestions for such instruction in science. In particular, it identifies features of guided-inquiry likely to lead students in developing the skills to attain such goals. This view of learning is very different from the more traditional perspective of science teaching and learning as the memorization of facts from an existing knowledge base. Unfortunately, the science curriculum in most school systems still focuses narrowly on such "final form science" – the collection of scientific findings that populate textbooks (Michaels et al., 2008). In approaches that do advocate in the name of more modern calls for "inquiry," science investigations often take the form of "activity mania" in which students complete activities that lack purpose and input from teachers. The latter is the type of instruction Kirschner et al. (2006) criticize in their arguments for the superiority of direct instructional approaches to science learning, at great cost to the elegant contributions of inquiry-based approaches. Neither direct instruction alone nor "activity mania" approaches to inquiry are ideal.

### *Effective Approaches to Science Instruction*

A synthesis of the research on the learning of science and the practice of science informs educators that in order to promote proficiency in science we must afford students opportunities to both understand the scientific claims of others, and also to generate scientific evidence of their own (National Research Council, 2008). To accomplish the former, there is a definite place for direct instruction. Students need to understand scientific concepts and the links between them; but, they also need to know how to use that knowledge. To this end, effective science instruction must also focus on the skills to build and refine models and explanations, to design and analyze investigations, and to construct and defend arguments with evidence. But what are the factors that enable students to participate productively in science? How do we guide educators to create the environments and contexts necessary to engage students in practicing productive social interactions with their peers? How do we facilitate argumentation in the classroom? These are the questions investigated in this study.

*Calling for a Model of Science as "Practice"*

As noted in the introduction to this study, some teachers remain resistant to "inquiry" models of instruction, citing a lack of content rigor and a lack of structure in their critiques. It may be that rather than looking to "inquiry" as the term to evoke "best practices" in science teaching, that we think about science as a social "practice." This is the context into which I situate the findings of this study. A view of science as "practice" involves doing something and learning something in such a way that the doing and the learning cannot truly be separated (Michaels, Shouse, Schweingruber, 2008).

By setting aside the notion of science as inquiry for a moment, to consider science as "practice," we accomplish four important things. First, we calm the opposing critique of Kirschner et al. (2006.) As explained in Chapter 2, Kirschner et al. (2006) argue that minimally-guided-inquiry approaches to science might mirror the process of how scientists conduct work in their discipline, but such approaches are incompatible with what we know about human cognitive architecture and incompatible with how science *should be taught*. In thinking about science as "practice" we can capture a superior characterization of what constitutes science and effective science instruction, rather than engage in an argument over the advantages and disadvantages of teaching content and process separately (Michaels, et al, 2008). Second, the notion of "practice" evokes the notion of doing something repeatedly in order to become proficient at it; third, "practice" connotes learning something so thoroughly it becomes second nature; and finally, learning science is tantamount to "practicing science" in the same way medical doctors or lawyers "practice" their respective professions. To engage in scientific practice means to be embedded in a complex social framework with particular participation structures; to use the discourse of science; and to work with the tools and representations of science. The research questions investigated in these chapters explored the confluence of these factors.

*Summary of Findings*

This study identified four models of guided-inquiry instruction as enacted in practice in two middle school classrooms (Figure 6.2). Students' opportunities and abilities to achieve various levels of argumentation were influenced by a combination of factors stemming from three dimensions: teacher practices; physical structures of the classroom environment; and classroom systems, including routines and procedures. The degree and manner in which each of these dimensions influenced the quantity and quality of argumentation varied in each classroom. The four pathways for guided-inquiry identified in this study were a direct result of the complex interactions of these systems, practices, and environmental structures. One of these pathways (number one) was recognized as a paragon of guided-inquiry instruction in that it provided ongoing spaces for students to construct high levels of argumentation and resulted in the articulation of scientific understandings and the learning of new content that mirrors those ideas embraced by the larger scientific community. This model pathway is one that moves beyond the dichotomy between content and process skills, instead embodying the notion that such a split is inconsistent with what we know about how scientists conduct work in their field; this pathway illuminates the notion that the process of conducting science and science content are inextricably linked.

The exemplar identified in this study (pathway one) also underscores the idea from previous research that learning experiences need to develop from first-hand, concrete experiences to the more abstract ideas of "final form science" (National Research Council, 2005). And, it adds to that research insight into *how* students construct arguments to arrive at technical terms for their ideas that are rooted in these first-hand, concrete experiences. By using resemiotization in this study, students were able to construct sophisticated arguments to articulate their scientific understandings. This study uncovers and explicates the process whereby students amalgamated gesture to partial words to articulate claims using evidence within the learned discourse of scientific argumentation, and in the context of inquiry-based classroom settings. The findings in this study corroborate Kirschner et al.'s view that inquiry is best when "guided," and best when there exist spaces for students to resemiotize their learning in meaningful contexts with more knowledgeable others.

Additionally, higher levels of student argumentation correlated with increased opportunities for the ongoing re-representation of scientific phenomena across different media, through leveled knowledge states, and leading to clearer scientific understandings, a term Iedema (2001, 2003) defines as resemiotization. Within the analysis of his classroom, Dave's practice was construed as a distributed "cognitive web" (Gibbs, 2006) across multiple modalities including the use of verbal talk, gesture, visual diagrams and demonstrations involving the manipulation of physical models- all used to evolve maturing conceptual understandings of science.

*Implications for Teachers*

One of the striking findings in this study was that the teacher in whose classroom pathway one was identified was unaware of the complex interrelationships documented in Chapter 6. Although Dave was able to talk knowledgeably about his deliberate use of individual elements of his practice, such as "cognitive derivation," "charting," and elements of the 5E model used to guide daily instruction, he was not consciously aware of their synergistic effects on student talk. Yet students in his classroom consistently demonstrated their proficiency in participating in a scientific community dependent on these interactional systems. And, interestingly, these students were aware, much more so than Dave, about the necessity of using objects during the class discussions.

This suggests that teachers may be not be fully aware of the factors that affect their students' abilities to collectively practice productive social interactions with their peers in the context of formulating arguments based on claims and evidence. If, as teachers, we do not know *how* we arrive at results, we are not able to refine and advance our practice; neither are we able to teach others the ways of our craft. Though I do not believe Dave was ignorant of what constitutes effective inquiry instruction, I do believe he was not aware of the powerful synergy of the interactional systems he was able to co-

construct with the students in his classroom. He was also not aware of the ways in which these practices and systems successfully evoked the use of student gesture. In fact, in this study, gesture was found to be a critical component to the formation of scientific argument. It would seem, then, that professional development opportunities that focus on an understanding of the semiotics and modalities involved in the formation of student talk would be a fruitful topic for exploration. In general, the study of gesture as a mode of communication is not something that has been a point of focus in the literature on scientific talk and argumentation; neither has anyone yet placed it on the map of professional development for teachers. The data from this study suggest the time has come to do so. In thinking about promoting gesture as a key component in processing science, it is beneficial to recall that science is, in fact, a social enterprise. As such, it is governed by a core set of values and norms for participation, of which we are obligated to make teachers aware.

An additional implication from this study lies in teachers' interactions with administrators at the school site in negotiating the physical classroom environment. The findings from this study reveal the powerful role of the classroom environment in students' ongoing learning. And yet, the purposeful manipulation of the classroom space is not an affordance available to all teachers. While the teachers in this study were fully supported by the administration in their efforts to creatively use the physical classroom in novel ways, in many school sites, this is not the case. Rather, a more traditional view of seating arrangements favoring single desks in rows is the norm. This study adds awareness to the importance of considering the pedagogical implications of the physical environment, and of raising this issue not only with teachers, but also with those who support their efforts in the classroom – their administrators. This is an important consideration that must also register with those who plan and build the facilities in which learning takes place.

While the past several decades have witnessed advances in ways of thinking about science teaching and learning, classroom buildings are still too often designed to facilitate lectures and demonstrations. Oberlin College is one institution creating change in this arena. Over the past decade, Oberlin College's Board of Trustees approved and carried out the final designs for a science center specifically designed for contemporary teaching methods (Paine, 1999). This effort speaks to Oberlin's position as a premier institution for educating future scientists. The new facilities have been built to accommodate collaborative learning efforts, creating spaces for research and teaching to occur in the same locations. The center's architecture blurs the distinction between classroom and laboratory, much in the same manner as Dave's three seating arrangements facilitate the same type of seamless exploration and explanation of scientific phenomenon.

But to affect such change on a larger scale, the need for redesign must be thoroughly understood by many more in the position to affect change. Traditionally, educators are effectively excluded from architectural decisions of educational facilities. Implicit in this view is the assumption that architecture does not influence the flow of ideas, nor affect the interactional dynamics in which learning is embedded (Orr, 1993). Rather, architectural decisions are based upon location, aesthetics, and operational costs. We have not yet moved to a view of academic facilities as pedagogical, as facilities that encourage or discourage certain types of human interactions. This study presents a significant basis for such a view of physical space, and the impact of environment on learning.

### *Implications for Teacher Educators in Institutions of Higher Learning*

Aside from professional development for experienced teachers, the findings from this study have important implications for teacher educators working with beginning science teachers. In my own position at a large public university in Southern California, I can think of no place in the sequence of courses for new teachers where paralinguistic features of language are explored in connection with the learning of content. As might be expected, introductory education courses at this university explore learning theories such as behaviorism, cognitivism, and constructivism, and heavily emphasize sociocultural learning theory. In fact, Dave is an alumnus of the education program at this university. As such, we see he is highly influenced by ideas firmly rooted in sociocultural theory. And yet he remains unaware of the powerful components of his practice that stem from such theories as distributed cognition and embodied cognition.

It would seem teacher educators, like myself, would have much to gain by including rich discussions of these theories during science methods courses, over an examination of teacher practice in video. In addition, discourse in the classroom is not, as yet, a topic that "fits" into the short span of ten meetings of the science methods course at the university where I am a lecturer. It is not even a topic that "fits" into the three-quarter sequence of practicum courses teacher candidates take during their credentialing year. This study provides substantive reasons to include discussion of such theories of embodied cognition and distributed learning into science methods courses. It also creates a sense of urgency to include in such courses an examination of teaching videos for the purpose of analyzing the ways in which student talk is influenced by the “talk moves” of teachers in inquiry-based settings.

It would also be beneficial to explore ways in which a model of embodied cognition could be drawn upon in guiding new teacher candidates to re-evaluate the use of more traditional forms of assessment. This would include the addition of more informal types of assessment in their lesson plans. One possibility for informal assessments might allow for students to access lab equipment during class discussions and during time set aside for lab write-ups- settings in which models and manipulatives are traditionally absent. Implications for formal assessments could exist in the sense that teachers could be encouraged to allow students to use the same models they learned from in laboratory settings, on application-based assessments following units of study. A view of embodied cognition could radically change certain taken-for-granted science classroom practices at the secondary level.

One additional implication for teacher educators in institutions of higher learning concerns the need to look closely at the variability of skills in the teacher trainee population. Teacher educators will be presented with prospective teaching candidates who may present a range of skills and understandings about students. Dave is a unique and extremely talented educator. As this study has demonstrated, his teaching practices derive from a core belief of building on students’ strengths, rather than focusing on deficits in skills, language, and content knowledge. The affective teaching practices he draws upon have been shown to contribute to students’ opportunities to articulate their emerging scientific understandings. Too often, those responsible for educating new teachers focus on pedagogical content knowledge without necessarily addressing the affective aspect of teaching. I believe the findings from this study underscore the importance of cultivating affirming affective practices in all novice teachers, especially in those for whom such methods do not come naturally.

*Theoretical Implications*

This work contributes greatly to our understanding of the applicability of a distributed view of cognition, and refutes the counterargument against this theory espoused by at least one of its critics, Margaret Wilson.

Throughout this work, I draw upon sociocultural theory. From the design to the analysis, Hutchins' theory of distributed cognition served as a lens through which to view the dynamics at play in the two classrooms documented in this study. So too, embodied cognition proved a fruitful theoretical lens through which to analyze the way in which the physical classroom environment contributed to students' learning. In Chapter 6, I use the six claims analyzed in Wilson's "Six Views of Embodied Cognition" (2002) to analyze selected clips. In her consideration of the six views, Wilson finds the fourth claim to be "deeply problematic." Claim four states that the environment is part of the cognitive system, such that the mind alone is not a meaningful unit of analysis. Wilson rejects this claim, asserting that some examples of research on distributed topics "stretch the bounds of what we would recognize as cognition at all" (p. 631). Wilson posits Hutchins' (1995) study of "the organized behavior of groups" as one such example. She goes on to claim that it remains to be seen whether or not a distributed cognition approach can truly provide "deep and satisfying insights into the nature of cognition" (p. 631).

And yet, this study documents a real lived example of distributed cognition at work in a classroom setting, where learning relies on a distributed model. The forces that drove cognitive activity in these classrooms did not reside solely inside the mind of any one individual. Rather, they were truly distributed across many individuals and across the components of the environment itself. The interactions of physical structures, routinized systems, and teacher practices at play in each classroom constituted a larger interactional system that "learned" only by virtue of the complex interplay at work by each constituent. Each element or member of the larger system, whether person or inanimate object, played a crucial role in the intricate connectivity of knowledge as it was transposed and modified across object(s) and person(s). At times, inanimate objects such as charts and whiteboards quite literally "stored" knowledge until students were ready to integrate the pieces of information they held into their own developing schemas of understanding. This work is replete with instances that exemplify a distributed model of cognition at work. The many transcripts repeatedly reveal this theory to be a very useful tool in explaining the way complex interactional systems can be constructed to draw upon the strengths individual members bring to the larger group.

Wilson would argue that such a system "trades off the obligate nature of the system in order to buy a system that is more or less closed" (p. 631). In her discussion of what constitutes a "cognitive system," Wilson espouses that systems are defined by their organization, and by the manner in which the elements of the system functionally relate to one another. Either they are "facultative," or temporary systems, organized for a particular occasion; or, they are "obligate systems"- that is, permanent relative to the lifetime of their parts. Wilson claims that distributed systems would change each time a member moves to a new location or begins interacting with a different set of objects. By such a view, then, Wilson would define distributed systems as facultative systems only able to retain their identity for short periods of time. Such systems would be readily constructed and readily disbanded. Because of their temporary nature, such distributed systems cannot, in her view, constitute closed, obligate systems of a more permanent nature. To back this view, Wilson uses the example of hydrogen. Many scientists have come to understand much about the way in which hydrogen behaves in different interactions with other chemicals, and the causes of the behavior of hydrogen have been built upon a combination of the nature of hydrogen itself as well as the context. But, the goal of understanding hydrogen itself still, Wilson argues, came from narrowly defining the hydrogen atom as a system alone.

This argument, however, does not hold up in examining the dynamics at play in Dave and Carla's classrooms. Chapter 6, in particular, expands our understanding of the application of distributed cognition in that it documents a moving beyond attributing roles to people and objects alone. It also identifies and assigns roles to routinized "systems," at work in classroom settings for the entire five months of the data collection period. All members of this system could be considered to be members of a stable, relatively permanent larger system that constituted a "cognitive system" that learned. Indeed, I believe the work of uncovering and exposing the processes at work in developing the final-form science of Latour's "black-boxed" notion of the scientific enterprise, would not be possible without the theoretical lens of distributed cognition. This work both informs our understanding of new application of the theory, and is also informed by the theory itself in a mutually constitutive manner. This study provides an example of a distributed view of cognition that posits a strong counterargument to Wilson's refutation of the theory.

### *Future Research*

This study also raises important considerations for future research that could further illuminate the relevancy of sociocultural theory in educational settings. One main vein of Vygotsky's (1962) sociocultural work holds that people learn first on an interpsychological plane, then internalize new knowledge on an intrapsychological plane. In order for this work to speak to this particular aspect of sociocultural theory, further research would be needed to examine how knowledge reached as a whole by the group in dynamic social interaction, is translated to the individual knowledge states of the students. A collection of individual assessments following whole group work could address this issue, as could a view into state accountability test score results. The latter could potentially speak to the degree to which these knowledge states are retained over longer periods of time. These methodological possibilities raise important considerations for the implications of Vygotsky's work.

### *Final Thoughts*

America wants and expects our schools to be educating our youth for a tomorrow we have yet to truly understand. Such measures as No Child Left Behind and Race to the Top are clear testaments to the tightening of the reigns on accountability in our public schools.

In October 2009, U.S. Secretary of Education, Arne Duncan, challenged schools of education to transform themselves and to help teachers reclaim the social justice function of their profession. Acknowledging the existence of achievement gaps, Duncan insisted education is “the great equalizer.” He also acknowledged that teaching has become more difficult than ever, stating that teachers must be familiar with a range of learning styles and disabilities and be able to tailor their methods accordingly. But this is not new. It has always been the case that children have different strengths and weaknesses. I would argue what is different is our future. What is different is the job market our children will face. What is different is that we need to prepare our children differently for a tomorrow unlike any yesterday we have ever known.

In the sciences, this means not settling for the memorization of objectified already “known” science. It means looking carefully at the outcomes we desire and revisiting standards and redesigning courses to incorporate critical thinking skills in the hopes of guiding our students to face the world’s problems of climate change and renewable energy sources with creativity, integrity, and wisdom. This brings me back to Duncan’s call for change in how teachers are trained. He is correct. We need to promote change in teacher education. By the year 2017, the Department of Education estimates the nation will need 1.7 million new teachers. Schools of education have the potential to make a significant and critical impact on the way new teachers are trained, and in turn, on the way we educate our youth.

This study adds to our understanding of how structures, systems, and teacher practices support and constrain inquiry-based instruction in middle school science classrooms. Though there is still much work to be done in redesigning science education to meet the needs of an uncertain future, the recommendations in this study contribute to the growing body of research and practice geared toward the revolutionizing of science education in U.S. schools.

## Appendix A - Teacher Interview Questions

1. What are your primary goals for your eighth grade students in your science classroom?

2. One major goal identified by many of the latest science reform initiatives is to create scientifically literate citizens who can engage in inquiry to solve problems. How do you address this goal in your own teaching?

3. What are some of the tools you need as a teacher in your classroom to meet the goal of creating scientifically literate students?

4. One of the purposes of inquiry-based instruction is to provide students with opportunities to "think" like scientists. What does it mean to think like a scientist?

5. How do you know when one of your students "thinks" like a scientist? What might that look like or sound like in a small group or whole classroom discussion in your classroom?

6. When a student is struggling with articulating his/her understanding of a scientific phenomena, what are some of the possibilities for this struggle?

7. What are some strategies you use as a teacher to assist a student who is struggling to communicate his/her own understandings of scientific ideas?

8. Are there strategies you share with your students that they can use on their own to assist them in communicating their own ideas when they are struggling to do so?

9. Gompers Charter Middle School has a diverse student population with nearly 80% of those classified as English learners. This must present a challenge to teaching an inquiry-based approach to science. Are there certain strategies you have found to work better for English Language Learners?

10. Could you run me through a typical day in your classroom?

11. Is there anything else you would like to share with me about the way you guide students in communicating their own understandings of scientific phenomena during small group or whole class discussions?

12. Thank you so much for taking the time to assist me with my research.

## Appendix B – Interview with Teacher “Dave”

**R= researcher**
**D= “Dave”**

R: So I have ten questions, just so you know how long. So the first question is what are your primary goals for your 8th grade students in your science classes?

D: Umm wow, seriously. Primary goals is that the kids walk out of the classroom knowing the standards-

R: Right,

D: -knowing all the information in the standards but more in tune with the idea that they can think about the information in a logical like scientific-type of way.

R: Mm hmm,

D: So even if they don't remember this specific information, they will be able to look at a problem about any piece of information, and just like extract like given information in like a problem. They will extract given information and then be able to um say ok let me think about this, this is what they are giving me this is what I know. This is what I know. This is what they are asking for. Let me go through this process and just be able to think about things and come up with their own ideas, use their imagination. That would be a nice thing if everyone could walk out of the room with, I guess.

R: Yeah, kind of having a framework for how to think about science.

D: Yeah.

R: Like your “guesstimate.”

D: Yeah, like that, only in a conceptual way, um like the thing I always think about is umm when I was a kid. I used to sit down and I would look at things and I would look at like a leaf falling from a tree and I would look at it and want to know why did it do that?

R: Really?

D: Yeah. I used to think, why does it do that? Why did that happen? Like I was telling the kids the other day, why is that the signals turn red, green, and yellow in the order that they do? What is the purpose? There is a purpose for that. What is the purpose behind it? You know?

R: Oh yeah. Red light, then green on the bottom.

D: Why is it that it goes red, green yellow and then go up? Why is it that the left turn lanes go before the straight through lanes?

[interview is interrupted by another teacher interrupting, then continues after the teacher leaves]

R: Okay. I think we can get started. But, um, you were on a roll.

D: I know. That's how I always go. That's how my 5B was today. I was on a roll. I was just teaching. Like you try to get really - like you realize when you're happier and you're being goofy as a teacher, the kids are usually more goofy and they're more relaxed and they enjoy it a lot more. But then some kids when you're goofy feel like, "oh I don't have to as serious now," and then they get too goofy, and then you have to go back to being a disciplinarian.

R: I know.

D: And so it's hard to keep switching those hats on and off and eventually you get tired of it and say I'm just going to be a disciplinarian all the time. And then the lesson kind of suffers.

R: Awww.

D: That's what today was kind of like. It, uh, it actually turned out to be a better lesson than I thought it would be, but-

R: Were you reviewing today?

D: Yeah, we were reviewing. But I had the kids redo homework that they've already done as a group and then we put them on a rubric and graded them as if it were a test.

R: Oh that's cool.

D: So they got to see how I would grade their questions and what parts were missing and how to make a good answer and how to break down multiple choice questions.

R: So this week is review, right?

D: Just today. And then Wednesday and Thursday is the test.

R: Oh. Now what are you guys doing on Friday?

D: I’m probably going to do a potluck, um, make up work day. ‘Cause it’s only an hour ‘cause it’s a noon day.

R: A potluck like bring food?

D: I have the kids bring food.

R: Oh that’s nice.

D: And then, um, and we’ll just have – and I’m going to give them make-up work packets on Wednesday and then they can just work on their make-up work.

R: Oh that’s nice.

D: Get it done before Christmas.

R: Yeah, that’s good. Okay, we started with this, but I didn’t know if there was anything else you wanted to say. But, the first question we started with was, that we left on, what are your primary goals for your eighth grade students in your science classes?

D: Right. And I was talking about how I really want them to learn how to think.

R: Yeah and I think you stopped off with – you said that when you were a kid you used to wonder about strange things.

D: Right.

R: And you were talking about the traffic light.

D: Yeah, the traffic light.

R: I don’t think I got to hear the end of the traffic light.

D: Right. I mean there’s all sorts of weird things. But being the youngest child, I was always dazzled by what my older brothers could do. You know, like, my dad could be like, “we’re going to Long Beach,” and my brother would be like, “take the 10 over to the 15 to the 605,” and I’m just like, “how do you know that?”

R: Oh, uh-huh.

D: So anyway, so I used to watch how things happened and be, like, really dazzled and my, and I figured out like, why do these things do things the way they do? Like the traffic light, for instance. You know, like, why is it that the left turn lanes go, and then the straights go, and then the left turn lanes go, and then the straights go?

R: How else would you do it?

D: And that's the question? That's what you ask yourself. You're like, well, why would you do it that way, you know? And you're thinking, well-

R: I guess the turn lanes could go and then the other turn lanes could go and then the straights.

D: Right. But then what's the problem with that is that then the pedestrians are sitting there waiting while all the turns are going, so then you mix it up. I mean, you just think of it that way. And then you look at certain signals and they don't do that. And you're like, well, why is it that some signals do it and others don't? And you're like, well it's a very busy street so they want to get the – this - all these cars all out of the way so that these cars can go because until that signal turns green there's a backup. You know, there's just things like that.

So, you start looking at things like that and you start wondering like-

R: Why is the traffic light like that?

D: I don't know. That one I haven't figured. But you can come up with guesses. And so, like, as a kid, you know, I came up with some crazy hypotheses on, like, why things are the way they are.

R: Um-hm.

D: And I realized that being stubborn, I'm going to stick with that hypothesis or that theory on something until somebody proves it otherwise. I was a very stubborn kid.

R: Um-hm.

D: And so, um, I figure kids are the same way I was, you know. They all have ideas on how things work. Like, for instance, when we were talking about gravity. I don't need to teach them that there's something called gravity. They've heard the word, they know the word.

[Interruption over the intercom]

D: And so, they know what gravity is. So it's a matter of me not just teaching them, "this is gravity." It's more of proving that the way that I want them to think about it is the way that, um, the way I want to think about it is the way I'm going to show it. I want to prove it to them. I'm not going to just – I don't believe– I don't believe they should listen to anything I say and take it as, "well, you said it, so it must be true." I should have to prove everything to them because they- 'cause they should be as stubborn as I am, because their theories are just as sound to them as mine were when I was a kid.

R: But how do you prove things that – you know, there are some things in the physical world that you can't really – you know what I mean? How do you prove to them things like in a frictionless world? I guess you do with that video. I mean, but-

D: I mean – Yeah, I mean, there's certain assumptions they have to give me, like when I say, "This is exactly what – even though this is a cartoon – this would be exactly what a frictionless world…" That's an assumption they have to give me. But, you know, I would expect them to come back and say – I would love for them, in fact, to come back and be like, "well, if there was no friction than 'this'" or "da da da da da" or "I don't think that's true." And I'd be like, "well, why?" You know, you're already getting the thought process going then, at that point. You know, I don't – I hate the fact that kids go into classrooms and get told to do things, they do 'em, and then they consider themselves smart because they just did what someone told them to do. It's like, that's not going to get you anywhere. That's not how the job world works, you know? People who advance in jobs, are the ones who can look at a situation, think outside the box, come up with something real and new, and apply it, and then they can think, "wow, you're an amazing worker.

R: So I can't remember – you did say the answer to this on the last tape – do you remember what you said? What are the primary goals? For them to think for themselves?

D: I think to know the standards – to know the information from the standards, but be able to think about the information in a certain way.

[another intercom interruption]

D: Um, yeah, so I want them to know about the standards. 'Cause obviously I want to teach what's standard information, but I want to be able to think about the information. And that's what I'm just starting to work on with my classes right now.

R: Okay, the second one is: One major goal identified by many science reform initiatives is to create scientifically literate citizens who can engage in inquiries and solve problems. How do you address this school in your own teaching?

D: So scientific literacy?

R: Well, to create scientifically literate citizens who can engage in inquiry to solve problems.

D: Oh. Right. Yeah.

R: So how do you address that overarching-

D: Well, scientific literacy – I think the literacy aspect of that question is just a matter of putting – putting a word to something you've already seen. I don't have to teach them, like, I mean, like, they know "push" or "pull." But instead of having to say "push" or "pull" every time, let's use a new word. Let's just use "force." And we can take these five words and throw them out and just insert this one every time you think "push" or "pull," let's just use the word "force." That's – to me that's all scientific literacy is. You know, like, um, that's the same thing as with any literacy, is like, instead of saying, like, "I'm able to read things and understand what they say," I can say, "I can comprehend this book now." It's just a new word that, that really just, kind of, puts all these other words and puts it together.

R: Um-hm.

D: So, as far as the literacy aspect, I think it's just a matter of saying, "you know that thing you used to call… well, we're going to call it this now." And, and actually I, one of the things I learned in this class I just took was that - I can't remember the number, but I think it's like you need to use a word 30 times or so before it even sinks in, as a word you could use again. So-

R: That explains why – I remember looking up words in a dictionary and going, "oh, okay," and for my immediate purposes of the sentence in the book, I got it. But then I'd see it again the next day and I'd be like, "oh man, I can't remember…" you know?

D: Like, like I took a spelling, uh, a vocab test, I think it was like senior year of high school. And one of the words that was on the vocab test – I think we took one, like, every week.

R: Yeah.

D: And the only word I could seem to remember of them was the word, "verbose."

R: [laughs]

D: And the reason I used verbose, was that I would go around – I thought it was tremendous irony to tell the kids that I wasn't very verbose.

R: Oh, that's funny.

D: And kids didn't get it. But then I learned the word by constantly making a joke out of it. And I don't remember any other words, but by using it as a constant joke, now I know what the word meant.

R: Yeah.

D: And it's the same with the word, like, a young boy – all the young boys learned the word "to masticate," because they'd make jokes about it all the time. And you'd eventually know, "no man, it means 'to chew.'" You know, like, just simple things like that. Like, by constantly using it, it becomes a word in your vocabulary.

R: Yeah.

D: So, how I try to teach the literacy in here is just to constantly keep hammering them with both sides of the literacy. Like one time I'll come up to them and I'll say like – they'll be like, "I don't know what the force is." "Well, what's the push or the pull?" And then they come up and go – or I go, or next time I might go, "what is a force?" And they'll go, "a push or pull." And I'll say, "okay, do you see any of that?" And next time I come up I'll say, "okay, what are the forces?" And then next time I go, "is there any pushing or pulling?" You know, you just keep mixing 'em up, so that they see those words as being interchangeable.

R: You do that intentionally?

D: Yeah, I do that intentionally.

R: I didn't know you did that.

D: Yeah, when you talk to the kids, you do that intentionally, so that, you know, they do the A to B to C connection with the words and they realize that these are all equal so I can use these interchangeably.

R: Oh that's neat. I didn't know you did that.

D: I try to do that.

R: I think a lot of teachers don't do that. I think that a lot of teachers think that once they teach you, like the word "allele," or something like that, and you say, "that little letter or that big letter," they keep saying, "allele." No, from their end it's just the repetition of the science word and I don't think they help by scaffolding it - by every other time maybe using the kid's word, you know?

D: Right. I mean. Like with magnitude on a force arrow. Like, you know, at the beginning, I teach, you know, I teach them the definition – we wrote it down. “Magnitude.” Sometimes I say, “how strong a force is, is the magnitude.” Sometimes I just say, “how long the arrow is.” You know, or “how big the arrow is.” You know, you use those interchangeably. “How big the arrow is, is the magnitude and the magnitude is how big the arrow is.” And we just keep going around in those circles until it becomes, like, “duh” to them. And that’s honestly the feeling I’m getting a lot from the kids this year is the “duh” attitude. They’re like, “this is easy. Duh.” Um, good! [chuckles]

R: Why do you think that is, as compared to other years?

D: I think, because the, um, I think the lessons this year are more to the point. I think that I’ve – what I’ve tried to do with these lessons is really say, “I just want them to know this by the end of the day.” And then you base everything you say and everything you do and everything you have the kids do around, “does it lead to that?” Which – and that was a principle I learned with a collaborative lesson study. Was the idea of, like, just, “what do you want them to walk out the door with today?” And just hammer them, hammer them, hammer them! [claps to emphasize “hammer”] Come at it from this angle. Come at it from this angle. Come at it from this angle. You know, we may do a demonstration about it. Then we might let them do an experiment about it. And then we’ll, uh, take some notes on it. And then we’ll use these words in this way. But, at the end of the day, this is all that I care that you know.

R: And is that what you put for the key question?

D: That’s usually what my key question is. Is usually, “this is what I want you to know by the end of the day.” You know, and that’s it.

R: Um-hm.

D: And so, I used to think that that was going to take forever to do it that way and that I didn’t have enough days in the year to go through lessons in that order. But, by coming at the, um, the curriculum, or the standards in a more conceptual manner than a mathematical manner, it becomes quite simple to go step-by-step that way. It’s, it’s, it’s been really fascinating for me. I’ve always felt like I’m going to run out of time. I’m like, “man, all I did” – like, two weeks ago I was like, “man, all I taught them today was that there’s this thing called friction. It’s a force. It goes in the opposite direction. And causes you to slow down. And that’s it. That’s it. Those are the four things.” And I was like, “that’s it. I spent an hour and a half on that, just that.” But now I can see the benefits of it when I talk to the kids. They’re like, “oh yeah, that’s friction. Oh yeah, that’s this.” And you don’t – like days like today where I realize that just that hour and a half focused on it really helps the kids because there were a couple ladies today, who, um, weren’t there for that lesson. And they were just like, "friction, what?" Like, and, you know, there's kids next to them like, "you know, friction!" Like it's just so simple for them.

R: And even if you tell them the definition it doesn't-

D: Right.

R: It doesn't mean anything, or it's not going to stick with them.

D: Right. And so, then, I find out that, even for people who weren't there for the lesson, I have to do a demonstration for them, too, to teach them what I'm talking about. And so, yeah, those are the kinds of, like, that really has just made this year so much simpler as far as the information. I honestly think – I always just look at the standards every week and wonder, "am I really teaching them what they need to know?" But-

R: You are. You double check.

D: Yeah, I double check and I'm like, it's all there. It's all there. It might not be – I think the problem too is that, um, I don't know about everybody's learning, but I know my learning with science in particular was all mathematical-based, especially a physical science. It was all mathematical-based. You know, you looked at, oh F=ma, and then, now that we know this F=ma, let's – how is it going to affect motion? And how is the force going to do this? And how big the object is, ia going to determine – and you look at it mathematically.

R: And you just chugged numbers?

D: Yeah, you would learn, like, oh, if the mass is 10, and if you increase the mass to 40, how is that going to change the numbers and the equation and, oh, that's how I learned my comparisons.

R: But you never learned to conceptualize?

D: I never learned to conceptualize. I didn't learn conceptually in college. And I never – there was a kid in my physics class in college who was nothing of a conceptual and I was nothing of a mathematical. And we used to argue about things, but we were actually telling each other the same thing but we were coming at it from different points of view. [chuckles]

R: That's interesting. Okay. Three: What are some of the tools that you need as a teacher to meet the goal of creating scientifically literate students?

D: What are some of the tools I need, or what are some of the tools I use?

R: Uh, both! [pause] Actually, that's a good point. Yeah, how about tools that you use? And if there's anything – I know you recently got your doc cam so that's kinda cool, too, but – so that might have been something that you felt you needed before. But, yeah, what are some tools that you use – to do inquiry or to, um, meet the goal of creating scientifically literate students?

D: Ummm. I think it's, it's a lot of modeling in how you write. There's, there's – I was doing a lot of dot cam last year and then I started off this year on just doing it on a whiteboard. But then again doing it – actually I do it mostly on a whiteboard still now. And uh, just modeling the idea of, of, like, I'm just going to throw these words in here like "force" and "friction." I'm just going to, you know, give it a go. And the kids, I don't know, that's something that's really hard to say 'cause the kids just kind of grab it and I don't know – I haven't really sat down and thought about why they do grab hold of it so well. But they just grab the words – like they grab "speed" and "distance" and "time" so quickly and when we get to specific scientific words like "instantaneous" – like I really spent time breaking that word down.

R: And how did you do that?

D: Um, you just break it into parts and you, like, like I, you come at things like if you're a thirteen year old child. I mean you just look at you're like, "okay, here's this huge word." And you talk like that. That's how you talk to them. You just, you talk at how they probably think. "Alright, here's this really big word and I don't know what it means. But I'm expected to know what it means so let me look at this. Okay."

R: Yeah, I like how you do that out loud.

D: Yeah, it's a, it's a shared reading tactic. And you just say, "well, I know 'instant.' And so I've heard of 'instant' with 'instant coffee' and 'instant rice' and 'instant noodles'" and, you know, so, "'instant lube' for cars"?

R: Did you ever notice, um, I think it's [redacted], yeah it was [student name redacted], that you asked – I can't remember what you guys were talking about and you actually weren't asking about whether it was a constant or instantaneous force – I don't remember what you asked but it wasn't about that and he went like this: "And it's an instantaneous force like that [snaps] like that [snaps]" and I was like, "awwww, that's exactly how you had talked about it." I thought that was so cool. You know, he really learned from that modeling.

D: That's the idea is like, like, take what they know and mold it in to what you want them to know. Don't, I mean, you know, the whole empty picture idea – they're not empty at all. In fact, a lot of our kids, a lot of *our* kids here are very full of tons of theories and ideas that are wrong, which is even more of a difficult challenge ‘cause I don’t – it’s not just a matter of them going, “I don’t – I’ve never heard of a force before.” No, it’s them going, “I’ve got all these kinds of forces,” and now I’ve got to help them sort them out and categorize them and tell them which one’s wrong, tell them which one’s right. So, it’s more of a complex thing when you think it in that idea. But, yeah, I mean, you know, they hear their moms, you know, “I’m constantly going to work.” And “I’m constantly late.” So, oh, well they know that. So let’s use “constant.”

R: Okay, um, four: one of the purposes of inquiry-based instruction is to provide students with the opportunity to quote “think like scientists.” What does it mean to you to “think like a scientist”?

D: I think it means, like, to think like a scientist, or to think logically, is just to say, to look at something and say, “hmm, what do I now know?” So you just kind of look at your previous knowledge of whatever you’re looking at and then you say, “okay, so, what am I wanting to do?” or “what’s my problem here?” and so now, “here’s what I know and here’s my problem,” and so you take – then you use those two together and you say, “okay, I’m going to take a guess here,” which we say is a hypothesis, but you just take a guess. And then, based on that guess you try something out. And then you try it out and whether it works or not, you say, “oh, that worked,” or “that didn’t really work.” And then you stop and you think, “why didn’t it work,” or “why did it work?” And then, based on that, you go, “I have to try this again” or “should I try it a different way” or “should I mix things up?” I mean, it’s just a logical process of trying and failing, trying and failing, but not, not repeating the same faults every time, but modifying it a little bit and saying, “what’s different this time?” And so, you know, I think in order to get kids there, you have to, you have to expose them to situations where they’re going to have previous knowledge and find out that they were right, and they’re going to have to take previous knowledge and find out they were wrong. So that they can experience that it doesn’t matter if you were right or wrong, it’s just how you move on from there. And hopefully they take that into life situations too, ‘cause then that could really help them.

R: Okay. So right along those lines – number five: How do you know when one of your students thinks like a scientist? What might that look like or sound like when they’re in small groups or whole class discussions?

D: Um, the easiest way to tell is when they go through the process out loud. And they say, “well, okay, is the car speeding up or slowing down? Okay, well, let’s see, that arrow right there is longer, and we know that a longer arrow means more force so then it’s going to go, like, a little faster so it’s speeding up. That’s what it’s going to do.” And they go through that. Some kids will do that.

R: Hm-hm.

D: Um, some kids will just give you an answer. "Speeding up." And, and, and you've got to say right back at them as soon as, as quick as the answer they give it to you, you've got to come back with, "well why?" And they go, "because it is." And you just got to, you just got to pick apart their brain and say, "what?" – I mean you really would like to just go, "what made you think that? Where did you get that from?" And sometimes you even go that far. You go, "where do you see that? How do you know that?"

R: But you never actually let them just give you an answer without probing them first?

D: Unless, unless they've demonstrated in the past that they have that knowledge and that they go through that process, like in the class you come to with, like um, like, [redacted student name]-

R: Oh yeah.

D: I know that he's gone through – I've witnessed him going through that process. So if he gives me the right answer, I know that he took the right process. Um, which, I mean, is not always true. But then there's other kids, like [student name redacted], who will talk it out. And then, um, or [student name redacted] – he will talk it out as well. But then a lot of the girls just want to get the spotlight off of them and just throw an answer out there. And they learn that you're going to come right back with, "no, you're not going anywhere. You're not just going to get rid of me. Why? Why is it that way?"

R: I notice that [student name redacted] is normally very thoughtful before she gives you an answer. Do you notice that? She's really – like, she'll, you know – the other girls are like [impression of giggly girls], but she's like, she's really, you know, she gives very intelligent replies usually. I'm really impressed with her.

D: Remember when I talked about, uh, [teacher name redacted], and how she had a very regal manner?

R: Oh yeah.

D: Back in that paper I wrote for your class. Um, [student name redacted] has a hint of that as well. Some kind of regalness to her. And, uh, that's not bad. And I like the fact that she takes time to think.

R: She gives it some serious thought. She's not like making fun or saying, "I don't know!"

D: I've got a bunch of kids that are doing that now. They're like, "well…" And they honestly – and the thing I love about it is they know they're not going to let something come out of their mouth until they understand why they know that, because I'm coming right back with that question. "Why?" "Where'd you get that?"

R: And if I gave you an answer just to get the spotlight off of me, and then you say, "why?" and I say, "I don't know," you would say?

D: If they – I go – or they go, "well, it must be 'a'." "Why?" "I don't know." "Well then, you don't know if it's 'a' so let's see if we can figure this out. What are you thinking? What's going on? What do you know?" And a lot of kids get pissed. [laughin] A lot of kids get mad with that. But – and the thing is you got to take it right up to that level of frustration, but don't push them over the top. Don't be like, "well, I'm not getting an answer from you unless you tell me why." Because then they're going to be like, you know, "blah blah blah and I'm not going to ever answer a question of yours again" [sarcastically]. You take them up to that frustration level and you say, "it's difficult, huh? Let's see if we can get somebody to help you out." And so, then, now they're probably curious and now they listen. You know, again, not all the students do. But, um, I would say that most of my knowledge of what they know doesn't come from the class as a whole discussion. It comes from walking around the tables. Walking around the tables during the experiments is where you're going to find out everything.

R: Wow. I didn't know that.

D: It's where you're going to find out everything because hopefully you set up your lesson to where they have to create some kind of product based on what they thought. And so, say for instance, like, even when we were doing gravity and I said, "create a force arrow diagram of the parachute man falling to the earth." And so they drew the parachute man and drew an arrow down. You can literally come up and point at it and go, "why did you come up with that?" And now it's one-on-one, it's less threatening, they're not in the pressures of other kids and they go, "well, because he's going down." "Okay, so did I ask you to draw what he's doing, or did I ask you to draw the forces?" Or, you know, whatever. You can really probe them. And it's less of a, um, intimidating environment. And so, by doing that, you can see which kids know and which kids don't. And so then, with that, you can go into the discussion and say, "okay, now I know which kids know and which kids don't, so let me focus on, um, which kids don't and let me use the kids that do to help the kids that don't."

R: Oh, but you don't have to – you already have that kind of-

D: I already have an idea of who knows what's going on in the discussion.

R: Oh, I didn't know that. That's cool.

D: And so, you know, like, you could look at a student who's struggling with the information and you say, "okay, why, you know – what force arrow do you think this is?" and they're like, you know, "ummmmm…" "Like, just give me one." And they're like, you know, "I don't know, friction." And say it's supposed to be gravity. You can go to the student over there – or first you say, "why did you come up with that?" And maybe they say, "I don't know." And you go, "okay." Now you pick a certain student that you know knows what's going on. And so you say, "what do you think?" And they say "gravity." And so you say, "why?" And then they say, "Because gravity's always pulling you down and the arrows going down." Okay. Then you go back to that student and you say, "okay, so, did you hear what they said?" "Yeah." "What?" – if you've got enough time, and, you know, you say, "what did they say and why do you think they said that?" And then they can now – so they really grab onto that person's understanding and take it in for themselves, at least for the moment.

R: Yeah, your students, when I did the focus group interviews, they really, um – I didn't have this in my set of questions, but they were talking about, um, learning from an inquiry process and how much they liked it and then I just decided to throw in there, "well, what would happen if you, um – what if your teacher just had you do, you know, the "explore" part at your tables, and you didn't come together in the post-experimental meeting area here? What would – what would that be like?" And almost like simultaneously, they were all, "oh, no no no, that wouldn't be good because that's where we really learn!" They were really-

D: I told them, like, this is the most important part of the lesson. [laughing]

R: Oh yeah, they were really adamant about that. I was like, "oh, okay." Alright, um, when a student is struggling with articulating his or her understanding of science, what are some possibilities for why they're struggling and what are some strategies that you use, um, to help a student articulate what they're thinking?

D: Um, if a student is struggling with what's their answer – first thing is you can't-

R: What I'm really asking you is not like if a student is struggling to understand. What if a student is struggling to articulate their understanding?

D: Right. More often than not, especially with the inquiry model, it's not that the student doesn't know the answer, it's more likely they can't explain what they're thinking. And, I would say that's most, like – I, that's one thing I love about inquiry is I can look at every student in the meeting area and, you know, I say, "What do you think's going on?" Then they, they have something. And that's why we do the "claims," is so that it can help them have something before they say anything. But, they have something in their head. They saw what the experiment did. They weren't just sitting there. If they were, they'd still be watching. So they have some idea in their head. So I would say 98% of the time it's because they don't know how to explain it the way they think that I expect them to explain it.

R: Um-hm.

D: And so, that usually means, struggle with the vocab, struggle with, um, the terminology of, like, just general science. Like, instead of saying that, um, you know, "well it just put something here," they're expecting to say, "it acted," or you know what I'm saying, just general terminology of science. But, um, so I'd say most of the time they're struggling because of vocab and scientific literacy. And so, the tool I use the most is, "well, what did you see? Just tell me what you see and use your own words. You know, don't use my words." "Well, I saw that the block moved left." You know, "okay, instead of left, can you say 'forward' if it's pointing that direction?" "Okay." You know, you just help them go through it, and then, um, you can kind of help them. I don't want to say, help them say what they want to say – but help them find the words for what they're trying to say to you. And then the other thing is you can't, um, you can't let them feel threatened when they're struggling to articulate it because then they're not going to feel like sharing at all until they have the perfect answer. 'Cause that's the way most kids I see – at least that's the way I was. I'm not raising my hand until I know exactly what I'm going to say and I know that it's right. And that takes some time. So why would I get up there and be like, "well, I don't know, maybe…" You know, they need to feel comfortable and safe.

R: And how do you make them feel like that or do you just tell them that it's okay? Or do you think that you've created an environment that they just know they feel safe to share or?

D: You have to, um, you have to validate the wrong answers. You have to, uh, you have to really, immediately jump on anybody else whose snickering or laughing or making the student feel that they're not up to the task. You really have to do something about that. And that's usually said at the beginning of the year.

R: Yeah, I haven't really seen any of that.

D: Eh, it happens in some of the other classes. But then, they're also friends, so you've go to know whose friends are whose and what is an okay comment from a friend and not-an-okay comment from a stranger and you've just really got to get into the politics of that. Um, but most of all you really have to just validate wrong answers. Nobody likes to say, "wow, I really think that this and this and this are going on" and then have the teacher be like, "umm, no. Moving on." Like, I mean, gosh.

R: Yeah, you write all the answers down.

D: You, you write – and especially with an inquiry model because we don't even get to the right answer until discussion. So, what does it matter? You know, if you draw a force arrow for gravity pointing straight up, you know, I'm more curious to know, "why did you do that?" as opposed to "well, you're wrong." Like, you know, we'll get to it. And a lot of kids – and a lot of kids, um, when we do an engage, and I write down the answers they give me about, um, I think we did one on gravity, and we said, "is it a constant force." And somebody actually said it's an instantaneous force. And we left it up on the board and we went to discussion and um, and then like, after we did the discussion, they saw that it was probably a constant force and they were like, you know, who cares? Now that you know the right answer, who cares?

R: Because you don't put their names up there by the answers, the original answers. So no one probably remembers who said which thing, right?

D: But the person who did does.

R: Yeah, but they're used to seeing it happen over and over again, right?

D: Right.

R: So they're familiar with the process, right?

D: Right.

R: So it doesn't really, yeah. That's good. Okay, um, let's see here. Okay. Are there strategies that you share with your students that they can use on their own to assist them with communicating their ideas when they're struggling? So if they're not with you, is there anything in particular that they know that they can do?

D: When communicating, its – I think most of that would come in – there's nothing I would say explicitly other than the modeling of, you know, I try to approach, like I've said, I try to approach all the problems as if I was a thirteen year old student. And so, you know, maybe I'll look at something one day and be like, "I don't know what this does," and be like, you know, moving it around and saying, "well, it does this and does this and that," and, and just gather information. Just – I think that would be the thing that I try and teach them is just gather as much information as you know, and then put all that information somewhere and say, "okay, now that I know all this, what can I say?"

R: So you don't explicitly teach them, but you're thinking maybe somehow implicitly they pick up on things that you do when you're modeling.

D: Yeah. Yeah, they do.

R: Okay.

D: Yeah, they tend to repeat that kind of stuff a lot.

R: Okay. Um, I think there's two more questions. So, your school has a lot of classified English learners, right?

D: Um-hm.

R: Um, are there certain strategies that you think are better for English learners when following an inquiry-model than for other students in particular?

D: I, uh, I've had discussions about that idea, you know, what kind of modifications do you make for English language learners as opposed to the so-called mainstream students and I'm like, I feel – when you approach something like science with a conceptual attitude, you almost – I mean my belief is that you can come at the problem – like, you don't have to have a whole bunch of previous knowledge, other than you've lived for a certain amount of time, to walk into this room and be ready to learn. That's all. You need to have, like, walked around this area for a few days and see things move. That's it. Like, I can teach you the rest. And so, since there's not a whole lot of prerequisite knowledge, then we can start from the ground up and teach all the strategies as if I was teaching a class of nothing but English language learners.

R: Um-hm.

D: Like, you know, um, good strategies are good strategies for all kids. Why would you take them away, like – yeah maybe a kid would learn how to use the word "instantaneous" if I didn't teach them how to break it down. But why not teach them how to break it down? It takes almost no time, and plus, it's a good strategy for him to learn. So, you know, I think, I just incorporate English language learner practices and I don't see how that would hinder any learning of students that might fall into other categories. So, let's just do that from the get-go.

R: Okay, perfect. And then the last question, um, could you run me – this is kind of a long question – could you run me through a typical day in your classroom?

D: In class?  Like, an in-class lesson? Um, and the rationale behind it, or?

R: Yes.

D: Okay. Um, we come in and, uh, begin working on the prelude and the prelude used to be, back when I wasn't that good, [laughs] – the prelude used to be just a question that would spot them for five minutes and get them to just-

R: So you could take role.

D: So I could take role [laughing].   But now, the prelude, the prelude's evolving into two forms. It's usually review, so that way they, you know, it's usually review in, let's see, how do you put this? It's a review of a piece of information that is necessary for today's new learning of information. But not at the level that it was taught the day that I taught that piece of information – probably just one degree lower.

R: Ooh. Very interesting.

D: So that, let's, like, let's say that the day before today's lesson, you, uh, were learning about friction. And I know that by the end of the day, we're going to talk about constant force and backward motion and things like that. Well then I need to re-institute the idea in the kids' heads of what a constant force is. But I'm not going to teach constant force at the level that I taught it the day that I taught it. I'm going to probably take it at that level and just move it back a little bit so it seems easy. Something that the kids go, "oh, duh, constant force. I got that." So now they're coming in – now they're finishing the first five minutes doing re-grasp, re-hashing – I can't even think of the word right now – but re-grabbing the information that I need them to know before I even teach them something new all on their own. So that, I didn't have to teach the prelude – the prelude was just them going, "oh yeah, duh!"

R: And it seems like it then, it also sort of, um, you start with a confidence builder.

D: Yeah, and it's a confidence builder, too, because then, now they're like, "okay, I've got constant force. So, now when he starts saying 'constant force' today I'm not going to be all 'wooo' [makes a sound of confusion].

R: Well, that's neat.

D: So that's the prelude. That's supposedly where the prelude should be at.

R: And that's your idea, right? Like, the taking it and just making it go down a level from the previous day's learning?

D: It's the spiraling idea.

R: But that's not a [redacted school name] idea. That's your thing?

D: No, no. That's just my thing.

R: That's great.

D: The more I think about it, and I'm coming to learn this more and more myself, is that inquiry only works with spiraling. You can only – the day that I taught them – like going back to that same example – the day that I taught them constant force, even though my goal was to have them with this before they left the room, they probably didn't bring that back the next day. So then, I've got to re-spiral back into that. But, if I don't spiral back to the lower level, then- if I don't spiral back just a little bit below that level, then they're not going to feel comfortable with the information because they didn't bring it back with them the next day. So the question's gotta be a little bit below their level to build their confidence and to build the knowledge for the day's lesson. So that's just the prelude. Um, then the "engage" is bring them up to par and it's kind of, it's kind of with workshop model of saying, like, "here's what we're doing today." And you kind of just outline the day, and you say, "alright, so now that I – this prelude has supposedly jogged your memory a little about what we're doing. Let's look at some whole new situation." Ideally, an "engage" should be that – a new situation or new words – sometimes with notes I do that. Or, take the information we have and look at it a different way, maybe. Something new, something that is supposed to be like, "huh?" and then they just kind of, they look at it or they observe it or they do something with it or maybe do a little game with it or something with this new style of stuff and then they guess at it. And they just guess, guess, guess. And there's where they're bringing out their own now previous knowledge on today's lesson. So they brought out previous knowledge from the last day's lesson and the previous knowledge about this new topic, and so now they've got both of them sitting, like, I don't know, like the foam on top of the water and so now it's like, "okay, now that I've jogged this and I've jogged this, it's time to take both of these and go through this experiment," which is our "explore."

R: Um-hm.

D: While giving them a key question of what to look at. So here's what I want you to try and look at today now that you have all this information before you. And the experiment should be laid out so that it explicitly shows what I'm hoping them to learn. So they do the experiment and they, and they have all this knowledge and they, and again they feel like it's "duh" at this point because they've had all this knowledge already put to the forefront, and so now it's like, well of course it's going to be this and of course it's going to be that, because that's the knowledge. And then, then you come to after the, uh, "explore," you go to the, um, back to the meeting area in a circle and, um, they do their "claims." And the claims is simply them saying, "I saw this stuff go on and now I need to try and, in my own way, connect it to that question that he posed before we did the experiment."

R: In the "engage?"

D: Yeah. You don't just re-give them the question though because that's just too much at once. You scaffold that thought process for them. And say, maybe break up that question into four little mini questions about that specific object. And so that helps them now have ideas for the answers but not the full answer to the question yet. And then you discuss it as a class and say, "what are your little pieces and what are you little pieces and what are your little pieces? And maybe let's put all these pieces together and now we have an idea of what happened. And so then we talk about the key question and we bring that in and we say, "now that we've done it, put our ideas together in our own brain and put our ideas together as a whole class, what do we now believe the key question is?" And if everything's been set up right, that key question now becomes pretty obvious. And so that's cool. And then we do a conclusion, which is basically a way for us to say, "okay, this is everything I did today. What was the purpose of it and let me get it, set it – set it in stone in my brain and say, 'I did this and I did this and this is what I found and this must be my final answer.'" And then you just walk out with the final answer. Hopefully that's what it's supposed to be.

R: What did you mean by the water and the foam? What were you saying?

D: Well like, like I was saying, like um, like when you have something in solution, it's hard to grab it, because it's all mixed in with all the other stuff. But if you can make it like the foam on top, it's really easy to just sweep it off the top and grab it.

R: And that was referring to?

D: The previous knowledge and information from the prelude and the "engage."

R: Oh, that's awesome.

D: It's really easy to say, like um, this is what I need because it's sitting there floating on top. I don't have to dig for it. It's right there. "Oh, of course I need – of course it's a constant force. And of course it's going to be like the goo. And of course – " whatever. And you just – you sweep all that information and apply it right to here.

R: Oh, okay.

D: And now it's like "duh." It becomes just a "duh" process.

R: Um-hm. And that's what you get the kids saying this year?

D: Yeah. I hear the kids just being like, "well, of course."

R: Now this isn't one of my questions – that's the end of the questions – but I wanted to ask you two things. So, one, the other teacher, you know, that you lesson plan with – it's unique to you, right, that you break up the key question into mini claims, like mini scaffolded questions for them to develop their claims with right? That's not, because I don't think I see that in the other class but I'm not sure.

D: Um, we plan it together to do the claims that way.

R: Oh, you do? So you do break up the, um, you know how when you have the easel in the post-experiment meeting area and you might have, like, three questions and they're going to make claims on those three – you do plan those questions together?

D: We have. That's been a recent thing.

R: Okay. And then my other question is what made you, um, uh, this wasn't one of my interview questions, but what made you guys go away from CIPS again, besides that it didn't meet with the standards?

D: I actually, it didn't, it's not that it didn't meet the standards, it just met the standards too slowly.

R: Okay.

D: Um, and I actually like the thought process of CIPS – I still like that process. But I believe in, and I'm not sure about this, but I believe that CIPS was designed for at least fifty minutes or an hour class daily.

R: Okay.

D: And so, um, with, with our schedule here, um, it, the CIPS lessons don't neatly fit into our schedule. So you were getting caught up in, maybe one day, you do, uh, the prelude, the "engage," the "explore," and maybe you'd begin the discussion. Well, how are you supposed to come back to a discussion two days later? And with kids who are having difficulty remembering their homework two days later.

R: So, the pacing was just too slow so you kind of kept some of the – you did keep some of the ideas?

D: Yeah, I kept a lot of the ideas. A lot of the experiments are really good in how they think you through things. But I kept the ideas of the experiments and, um, actually with our forces experiment, they just, they chose to teach force as a transfer of energy.

R: Um-hm.

D: And I decided to go with that same conceptual flow. So I started out the kids on energy diagrams before we got into force, which, again, has made it really easy. They seem to grasp that concept very well. And so that was a CIPS idea for that. Um, no, I like the way CIPS goes, it's just too slow and not enough standards daily to meet the needs by the end of the year. That's all.

R: For your scheduling purposes.

D: Yeah, for our scheduling purposes.

R: Um, is there anything else that you want to share about, um, the way that you guide students in communicating their understandings about science in small or full-class discussions?

D: Um, I just, I like – the way I want them to go is I just want them to, like I said, to think things through and um – I guess, I guess I try to stress the importance of, it's okay if you don't get it, but share it. You know, why are you not getting, why don't you believe what I believe? I'd like to know. I'd like to know what you're thinking because you're opinion is just as important as the teacher's opinion. We're all seeing the same thing. You know, like, it's not that I have all the answers and you're just going to get the answers from me and you're going to walk away. Like, why are you thinking what you're thinking, just like you should have to ask me, why am I thinking what I'm thinking. The only difference is that being and adult, I may be able to articulate my thinking better. But that's it. They can, they know the answer. They see all this stuff happen all the time and you really just have to tap into their real life experiences. Uh, and that comes with knowing the kids and knowing the neighborhood and things like that. But, you just have to tap into what they see every day, you know, most – I mean, I'll admit, most of my, uh, force diagrams end up about sports equipment or cars and trucks and planes. I mean, I'm a boy, that's what I am [laughs]. I think about that sort of thing in my head so, you know, I mean I hope it doesn't hinder the girls too much – they don't seem to mind. But I mean, that's like, that's what's in their life right now, you know. They see cars. They know about cars, they see the planes fly over the school. They see dump trucks. They see buses and they see, uh, soccer balls and footballs and basketballs. And they see that stuff all the time. So, you know, it would do me no good to talk about an accelerated proton or to, you know, like, imagine a comet racing through space, like, that's not going to help them a whole lot. Especially when they don't know what that is. So, it's really easy to teach them the concepts with the, uh, the real life, uh, the reality I guess you'd call it, that they have in front of them. So, that, and just, you know, demonstrate exactly what they're saying. I love, I love it when they, like, that day with gravity, and I was dropping things at the same time and they're like, "well, because of this and blah blah blah," and I'm like, "okay, let's find something that's not like that but still heavy."

R: That was awesome. That was really, really good.

D: Yeah. I mean that's just-

R: You went with every suggestion that they had. "Okay but that's because blah." "Well let's do – what do we do?" [laughs]

D: Exactly. What should we do?

R: And they tell you.

D: And on a day like that, you don't want to stop talking because you really want to hammer home the point.

R: It's really too bad that you don't have science every day though. You know, because English and Math both meet everyday, right? Same amount of time that you do, but every day.

D: Actually a little more. About ten or fifteen minutes more.

R: That's too bad. Oh well.

D: But, it's okay because I'm working with the math department now to start doing an inquiry style of learning there too.

E: I know you said that. That intrigued me.

D: Did it?

R: Yeah.

D: Well, because – it's got to be modified definitely because, remember how I said that with science, conceptual science I felt like you could come in with bare minimum knowledge and I could teach you everything?

R: Um-hm.

D: I don't feel that's the way it is with math. Math is, math is like, uh, book stacks to me. Like, you stack the books – every new concept you get stacks the books.

R: Oh, builds on – right, right.

D: Builds on top of that. And so what I'm working on with the math department right now – and I'm having to pick and choose my friends because, I mean, just with the inquiry model and science is pissing some science teachers off. I mean, they just don't get it. They think it's complex and a waste of time. Can you imagine the math people that are, like, set in stone with the way they should teach things?

R: No, I can't. That's why it's intriguing to me.

D: I was talking to them about how to spiral information and, like, for instance, like, let's say-

R: You should share your prelude idea with them.

D: I have. I have. I've shared it with a couple of them now and they really like it. They're just not sure where to go with it. I told them how to use it in conjunction with the study skills class they've got for math. Because I was saying, look, let's say that today you're going to teach kids how to use "y=mx+b."

R: Right.

D: Alright. Then you say, "what information do you need to have before the know y=mx+b?"

R: Um-hm.

D: Alright. Well, why don't we do this? Why don't we have the homework from the night before be on the, um, the really simple concepts that they need. Like, for instance, um, putting 2x and 4x together. Or, how to move one variable from one side of the equation to the other side of the equation. So do that as your homework. "They're going to think it's easy." Great! You know, because now they come in knowing, remembering how to do that stuff. Then, you're prelude, may be as, one step a little bit harder because you're assuming they did their homework, so let's do, um, you know, I don't even know, something about, uh, I can't even remember - see that's the thing, I'm not that knowledgeable with math to go as – but, you know, you just look at what you need that day and you say, "I need them to know these five things before I even teach them this." Okay, well let's – two days before that, one day before that, the homework, the prelude the day of, blah blah – and so I think that if I was going to talk about book stacks, like, today's lesson is stacked this high, your prelude is stacked about this high, your homework was stacked about this high, and then the study skills class in the afternoon is stacked about as high as the homework maybe just a little bit below it. And so they're getting this constant, you know, and they're, and somebody said to me, "but if they don't have these book stacks, they're not going to do well in here." Well, that's not a problem because as you're stacking this one more, your prelude will eventually get to the point where your doing y=mx+b. And then you'll keep going. Then your homework will get to y=mx+b. And then the study skills class will get to y=mx+b. So those kids are going to see it four times during the year. So maybe they didn't learn it the first time, but you hit it again and again and again in all these different areas and they're just like, "duh, duh, duh, duh, duh" the whole time and then by the time you do it the fourth time they're like, "dude, this is a piece of cake."

R: See now, you know what's funny? I don't know if you see this – so really the interview's over – but I was just going to say that, um, so a couple times in your own, like, um, what you were just sharing with me, you referred to, like, putting something in stone. And then, you know, the foam and the water – that's why I wanted to make sure I understood that. Because when I think about your classroom, the word that came to my mind was, um, that you have these, um, you have these – okay, I don't know exactly how I want to say this, but the word "sedimentation" came to my mind. There's, like you have so many systems around your classroom that serve as like, um, not only a second teacher, but it serves as, like, a support or a scaffolds and enables them to do the inquiry. And, it's like sedimented in, like, different formations around the room, you know? I mean, if I'm going to use that metaphor like sedimentation or whatever. But what I see, if I were going to draw your classroom, like on a piece of paper – you have the whiteboard, you have now the doc-cam, you have your preludes and your homework, and then you have usually, so you have these other charts up there, and then you have this string of what we have learned back here as references, you have important terms all across here, you have table of contents, the concepts page, how to talk along here, all those things. Then, at the back now you have these, you know, um-

D: What you're being graded on basically.

R: Yeah, exactly. So you have all these, you have all these systems in the way that I visualize your classroom. There's nobody in here right now, so it just looks like "huh?" right? But when you're kids are in here, each of those "systems" you use as like this interactional media of, um, oh, like, let's say I drew your classroom on a piece of paper. It's almost like when they're in a certain part of the 5-E model, you have, I could like actually take one of your representational media, which in your "engage" part would be your whiteboard, and I could circle the whiteboard and then your rows, because your kids are in a row, right? And that is, like, interactional space A.

D: Oh I see what you're saying.

R: You see what I'm saying? Okay, in the post-experimental meeting area, I would circle your easel and this circle. And that's different interactional space where there's different forms of communication and different modalities that are drawn on. Then there's, um, the tables, yeah. But in each place, there's, depending on what it is that you're talking about, I could circle, like, the table and then maybe like that. Maybe some of your kids are like referring to that while they're working here. Or maybe in the meeting area, some of your kids – I could draw a circle around your kids and then those – although those things they've internalized.

D: Yeah, isn't that funny?

R: Even in the, like, interviewing they were like, "well, I wouldn't agree with what, uh, [student name redacted] just said." Little [student name redacted] back there. Oh, man, has has totally internalized those [pointing to charts at back of room].

D: I know.

R: And then like these, you know, but, you know what I'm saying? Like, if I could draw a circle around different of your – I don't know what else to call them – like representations that you sedimented around the classroom in a way that – they're like these systems of communication, but you have to use each one at a critical part in the 5-E model. And I think, I think, having watched a lot of inquiry classrooms, that that is like, if you want to teach inquiry as a PD, that's how you should present it. Like, you need to set up these systems in your classroom that make the classroom kid friendly. So do you realize that you do that? I mean, you seriously have these different systems set up and it's very – like being in your classroom as an observer for all, you know, since September – it's very obvious to me that that's how you do it. Now whether you're conscious of doing that?

D: I mean-

R: It's pretty amazing. And it works.

D: It's like, I put things up for, like, like for instance, there's a lot of information that we've done this year that's not even written on a poster. And so I ask myself, why do I need to put that in a poster or does it belong on a poster?

R: These ones?

D: Yeah, the charts. The charts should be tools. Like the speed one is like a tool. And so then I ask myself, "Well, what is the purpose of this tool?" This tool is so the kids can look up here at any point in time when they're in need of help, to help them with speed. Well, why would I put that at the front of the room when they're never going to be at the front of the room needing help? They're going to be at the tables needing help so it needs to be closer to the tables. You know?

R: And that’s the reason why the word “sediment” came to my mind because these are the results, these are like the sediments, the deposits of things that you’ve talked about. They’ve germinated here in like all this, you know, “I agree,” “I disagree,” “I think,” “I- whatever,” and then eventually they become, like, codified, or whatever in these charts.

D: They should be. Yeah, our key questions.

R: Exactly. Exactly. So then they become references for future learning. Like, okay, this is what I’ve learned now, if this is, if A=B=C=, you know, if all these things are true, then I can tackle the next thing, kind of. It’s really cool. But, see, this doesn’t exist – all of these things, to me, are like supports for inquiry. And I think that if a lot of teachers who are resistant to inquiry understood, like, “oh, okay, I guess I just have to learn how to do it.” It’s not just presenting the right lab and then asking kids what they think. There’s a lot more to it to do it successfully. That’s kind of what I’m trying to document. Does that make sense?

D: No, that makes sense. I mean because I do – like this is my, like it’s funny that you asked for a dictionary today. I don’t have a dictionary. I don’t have encyclopedias.

R: Oh, that’s just because I was looking up something for-

D: No, I know. But I mean, it makes me think, like, I don’t have a dictionary. I don’t have encyclopedias. I don’t even have a science textbook available to the kids. It’s hidden in the cupboards. This is their textbook.

R: I know.

D: This is their textbook.

R: The classroom is their textbook. Exactly!

D: This is their reference tool.

R: But don’t you think that that’s a key – that this is really, really key to inquiry?

D: It has to be. Yeah.

R: And a lot this I’ve seen you develop over the past years. I mean, I’ve seen some of it over – but all if now is kind of like I think that his is why you have this hum going on in your class of like, “duh,” because they have everything they need to succeed in this style of learning.

D: Right.

R: And your classroom really facilitates that. It must sometimes make you feel like, “what am I here for?” [laughs] But that’s what I think is so cool about your class, because from a sociological perspective, this is kind of a microcosm, like on a global, on a global system of schools or whatever, you know, in a lot of different, um, social structures. You have so many different, um, systems in place that make it work.

D: Yeah.

R: It’s really, really cool. So, anyway, I’m going to turn this off.

## Appendix C - Interview with Teacher “Carla”

**R= researcher**
**C= “Carla”**

R: Alright, so number one, there are twelve questions just so you know. What are your primary goals for your eighth grade students in your science classroom?

C: My primary goals for this year are for them to learn the scientific method for an inquiry-based classroom and to learn the basics of physics, chemistry and astronomy.

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R: Very succinct.   Okay two, one major goal identified by many science reform initiatives is to create scientifically literate citizens who can engage in inquiry to solve problems.  How do you address this goal in your own teaching?

C: I do inquiry-based lessons every single day. I give hands on demonstrations with hands on learning for the students.  I also have the students writing at least a three to four page lab write up on every single lab that they do in class, which includes complete sentences and paragraph form, where they are including literacy into their science learning. Definitely we use hands on, you can touch it, feel it with the literacy portion, but instead of using the textbook, we use hands on learning, and they have to write their textbook portion.

R: Number three. What are some of the tools that you need as teacher in your classroom to meet the goal of creating scientifically literate students?  You can define tools however you want.

C: Some of the tools that I would really like is that I would like a computer per lab group to teach the situation that is unavailable.  That way they could be doing a webquest to figure out their answers on their own. One of the tools that I do use on a regular basis is that we use calculators in class so that they don’t get boggled down with their math.  Many of them don’t understand the math so I don’t let that be an impeding situation for them. I allow them to use a calculator so that they can still get the scientific concept, like speed, velocity or force, but without having to be stuck on multiplication or division, which that is really very important in so many of the students’ lives.  And another tool that I use is just the basic science equipment and keeping the equipment similar to what they would see in a real science lab in college or in high school or in the industry, and not dumbing down the equipment.  I would try to buy equipment that is similar to what they use in the real science industry and I use the real scientific terms for it, not  baby terms.

R: So like what are some of the equipment you would like to have?

C: Instead of using a triple beam balance using a digital balance.

R: Oh.

C: Um, when we get into pH, I will actually have real pH beakers given to us by the biotech companies so they can actually use a real pH meter, like they use in the industry.

R: Uh huh.

C: Trying to create real scientific materials. I would like to use in speed, something to record the speed digitally, but we just don't have the computer strength to do that. I am working on getting those tools for the school.

R: So four one of the purposes of inquiry-based instruction is to provide students with opportunities to think like scientists. What does that mean to you to think like a scientist?

C: To think like a scientist for me is to experiment. To try and to fail. And science experiments in schools are set up for this- for students to succeed every single time they do an experiment. In the real world, scientists fail more times than they actually succeed. And sometimes their experiments don't work, and I want to get them to see why it is not working.

R: Ooo, I never thought about it that way. That's awesome.

C: Umm, scientists think that it will work one out of five times.

R: I remember doing chemistry labs. We would study whatever we thought it was that we were learning, and then we would do the lab to prove an example of the law we just learned, or the principle or whatever it was you were studying, and if my numbers didn't come out right and I knew that didn't match what I was supposed to get, I would freak out and start calling my friends. We would be just so upset because we knew that it wasn't the right answer.

C: Students will fudge their answers.

R: Exactly, I did that.

C: They will fudge the numbers to try to get the right answer. And that is not right, you cannot fudge the numbers.

R: It doesn't, that doesn't give you confidence in wanting to do science.

C: No, FDH doesn't like that.

R: What do you mean? They don't like that?

C: FDH doesn't like fudging numbers, you have to have your own numbers.

R: Okay perfect. Number five. How do you know when one of your students thinks like a scientist? What might that look like or sound like? In a small group or a whole class discussion.

C: They have, they send you a gift. Sometimes someone will pick up on the answer.

R: Okay.

C: And sometimes someone else will be like, that is not right. This is what should have happened and they come up with a "this is what should have happened in your experiment." They come up with a wrong answer and how it should have been right. And what they should have done differently. And also the students start talking with each other, and they start trying things, just to try it. The labs are written for them with time to mess around with the supplies. They need to experiment, to be able to experiment on their own, and with the guided practice that I give them. From their own questions, they need to look at it and do it themselves. I have had students send pencils against the walls trying to test forces.

R: Oh my!

C: But it was very, very controlled, and they would learn more from sending stuff and have it hit the wall than what I would do. And they would learn more from not being on task as some people might say. However they were totally on task because they were like, "ooo, what about this?"

R: Right.

C: They came up with it on their own.

R: Would you say that if they were sitting in a circle and somebody got an answer and someone else said, "Well what should have happened is…" How do they know what should have happened? You know what I mean?

C: Well some of them have previous science knowledge.

R: Okay, so they know, oh something should or should not happen?

C: And some of them, I will have told them, "yeah that is exactly what should have happened in your lab." So they will know.

R: So what it might sound like to be thinking like a scientist, is thinking outside of the experiments like you said?

C: Yeah, thinking outside the given questions. Think further. Try to come up with your own plan. Scientists are curious, and make mistakes, tinker with things, until they reach a solution.

R: I have seen your kids doing that, like tinkering.

C: Yeah, and mess with it. I don't get mad at them. They will be falling out of the chairs and making pretty much chaos at the minimum.

R: Yep.

C: Controlled chaos.

R: And actually that is hard to do as a teacher.

C: It is a big step. I can let it be noisy and just tell people to, you can be noisy sometimes, yet I have the ability to control the kids. Within three seconds have them all quiet again. Controlled chaos.

R: Right. Okay. Six. When a student is struggling with articulating his or her understanding, like when you are in the meeting area or whatever, of a scientific nature, what are some of the possibilities for that struggle?

C: Lack of scientific knowledge, lack of being able to express their scientific ideas. Modern English. And I have them use pictures and demonstrations, or use a partner to try to get the words out. And sometimes I will hear them, and I will try to lead them to where we are going. They really struggle because they haven't had science. And elementary school teachers don't teach science. So they don't have that knowledge to be able to base their answers off of something prior. They come up with examples. Sometimes they are not the most politically correct answers.

R: [laughter]

C: But they work. They get us to the end point. That everybody knows.

R: Great. Umm, what are some of the strategies that you use as teacher to assist the student who is struggling to communicate? I think you already kind of started talking about that already. You have them draw pictures, work with a partner-

C: Right, draw pictures. I have them write paragraphs on what they have done. They have to write a paragraph of what they have seen and draw a picture of what is a source or what is a receiver. Lots of visuals, with the words underneath. If they draw the picture, then they can look at the picture and then they usually say it out loud. And I am like, “write down what you just said.” And for them to actually write down what they are really saying, they don’t get that connection to writing down immediately. That they said the right thing, but for some reason they don’t know to write down what they are saying. I think some teachers count them off for not having the exact right answer. In science there is no exact right answer. Many answers.

R: So how do you grade their notebooks?

C: Every child is different. They don’t have their names on their labs, or the outside of their notebook. I do all of my grading without looking at names.

R: Wow!

C: I do not look at the names when I grade.

R: That’s neat.

C: Who they are as a person has nothing to do with their grade in this class. It is based on conceptual knowledge. And I don’t look at the name until I have to record the grade.  I grade like I grade tests, page by page. And after the first page, I have no idea whose test it is because I graded all the page ones. That is the only time I ever knew their name. And usually I make that first page a matching or multiple-choice, where it is a very fast grade.

R: So what are you looking for?

C: The conceptual knowledge- did they get the concept. Were they able to fulfill their purpose? Fulfill the standard?

R: Now what if they get it wrong? Do you still give them credit?

C: I give them partial credit for it. If they wrote down something for it, then they will get some points, but if it is so far off base, that it has got nothing to do with it, they get it wrong. And it is not uncommon for them to have 25- 50 percent of the class failing in the beginning of the year, because they are not used to being graded on conceptual learning.  They are used to being graded on effort alone. Effort in here is participation points. Its 15% of your grade,

R: Have you ever- I was in another class and I saw the kids using those low friction cars, and then the cars, well they were different. And I remember they were doing something with a fan, they put a fan? And I knew what the concept was that they were supposed to be learning, but I saw that the way that some of the kids were doing it, well, I wouldn’t have got the concept from the materials. How would you handle something like that?

C: Try to give them really good questions.

R: Okay.

C: If they have to answer a key question, the question has to always relate to the concept. What do I want them to learn?

R: So that is what you are going back to when you grade?

C: Yeah, I give them the concept, in a question and they have to go back and answer that question. So I understand what they want to learn.

R: Oh, okay. Alright. I think we are on eight. Are there strategies that you share with your students that they can use on their own, like when they are working alone to assist them in communicating their own ideas, when they are struggling to do so?

C: I try to get them to look back in their notebook to other labs. I also try to get them just to express it any way they can. If you can’t express it in words, express it in a picture or something to get some points from. Because I know sometimes I struggle to write a scientific concept in words.  It is easier to just try to draw the little catapult hole.

R: Right.

C: So I can look back at it. But really on standardized tests, they can draw little pictures and those little pictures can help you answer the questions. If you can get a visual of what it is, you can see it, you can touch it you can feel it. You are more likely to get it right.

R: Cool. Uh huh. Anything else on that one?

C: No I think that’s about it.

R: Okay, your school has a diverse student population, with many English learners.
This must present a challenge to presenting an inquiry-based approach to science. Are there certain strategies you found work better for English language learners?

C: I have discovered that science is a second language for everyone. Not only for English language learners, so I have used lots of different colors, charting and demonstrations.  These are all SDAIE strategies, to let the students touch it and feel it instead of having to read. Very little new in this class. If I have an English language learner that is emerging, I try to pair them with an English language learner who is also fluent in English. One can help the other. But science is a different language for everyone.

R: And where do they get their ideas from for pictures?

C: Umm, usually from the data tables and from their actual experimentation.

R: Alright. Three more questions for you. Could you run me through a typical day in your classroom?

C: We always begin with a five to ten minute prelude at which time I do housekeeping, passes, check homework, whatever. Maintaining quiet that's the big thing. And then we come up to the meeting area where the students can come up and bring their desks to the front and we go through the "engage." We go through the prelude and we go over homework if need be, and the "engage" is a small activity to get the students thinking about the big concepts of the day. Sometimes they are a little bit far out. But, it's mainly to capture their attention and get them to want to learn. And then from there I try to keep it straight up, five minutes on what they are going to do in the lab. I do not tell them any of the questions. I show them what they are doing and go do it, make them work on it themselves. After that, I do an "explore," which is a hands-on experiment. Hands-on experiments can take anywhere from 30-45 minutes. Sometimes they can go a little longer than that. After that we come back up to the meeting area and "explain," and go over what the questions are for the lab, and what some sample answers are for them, and then we have homework which is usually an extension, and they evaluate their lab procedures and the conclusion. They have to summarize what they have learned. They have to answer a key question. They have to say what they would do differently and say what they don't, they are pretty good about doing that, it has to be a paragraph.

R: And they do that, that is the extended part?

C: That's the "evaluate." The "extend" is the homework and it is usually one or two problems based on whatever that lab was.

R: Oh, okay. So when do they answer the key questions?

C: The key questions are answered in the conclusion in their evaluatory portion. They don't answer their key questions until the very end when they go back to look at their whole entire experiment. If it needs explaining, or if they have questions, they look at their "claims" section and then they have to provide evidence for those claims and evidence helps to explain whatever that claim is for the lab. So they can go back over and look at the lab and what they were supposed to be learning about. Conclusion, they answer usually three to four questions. And I do not give them the answer.  I let them get that themselves.

R: Oh, so you never give them the answers?

C: Never.

R: Ever? Like not even-

C: Well, I might eventually, but they usually pull it out on their own because they will have answered it indirectly in the claims and evidence section and that makes them have to synthesize it. I will write the answer in their reports.

R: If they get it wrong?

C: Yeah, I will write down if they get it wrong.

R: So do they do that alone? They answer their questions alone?

C: Yeah, they answer the key question and the conclusion as an individual.

R: Do they do that at home?

C: They sometimes do that in class, sometimes they get to do it at home, it just depends on the time they have that class and how they want to do that.  I would say more times than not, they are having to do their conclusion at home.

R: Okay, and then when do they do their "explore, " do they put the manipulatives, or whatever they were using back?

C: One person from each table comes and gets the manipulatives, and they are the one that makes sure that the bucket gets back with everything in it. So, I try not to pass things out in the middle of class. It is too hard to pass out a bunch of little different pieces.

R: So when you bring them back to the meeting area after the "explore" part-

C: They would have turned in all of their materials for them and checked them off. I give them a little bit of time between their "explore" to look at the questions first.

R: Oh, okay.

C: So, it's not just cold.

R: At their tables?

C: With their groups.

R: Okay, and when they come up here, do you facilitate them?

C: Yeah, I facilitate and we always sit in a Socratic form, in a circle. I don't like them sitting in rows. I just like it so they can sit in a circular shape. The desks are arranged in a circular shape so you can always see what the other group is doing. So it helps a lot with classroom discipline issues because they can all see each other and everyone knows if someone is messing around. They can tell that person to stop it.

R: Whereas if they are in the rows?

C: If they are in the rows, only the people behind them know if they are messing around.

R: Do you use rows for anything at all?

C: I try not to use rows at all.

R: So when you say meeting area, you mean the Socratic circle?

C: Some of the classes come up and make groups and kind of make a big conglomerate of chairs in the front. I have one class that does that but they are a very small class and I have no discipline issues so they don't really care, and they all turn around to look at each other. But they do go into a circle sometimes.

R: And when you say that you facilitate the explaining part?

C: I just ask them questions, and they all answer them.

R: So you don't use the manipulatives again?

C: I try not to use the manipuatives again because it is just too much stuff out and it creates chaos. They have to communicate the manipulative into words.

R: Okay. Number eleven is there anything else that you would like to share with me about the way you guide students in communicating or understanding some scientific phenomenon?

C: Mainly having touchy feely.

R: Touchy feely?

C: I am a touch it, feel it person. I hate reading from books, even though it's school.

R: Is there anything more you want to tell me about why the touch it feel it, is so important?

C: Because the books are poorly written even in science, and you cannot learn a scientific concept without looking at any real science. Science is not done out of the book. There are big theories with a big T and little theories with a little t, and the way they got those theories was by trying out things. Watching it happen. You can't watch it happen through reading things off of a page.

R: And number twelve is just thank you so much.

**Appendix D-Student Focus Group Prompts**

1. As you know, I have been sitting in on your science class the past few months, and I have had the chance to watch you think about a lot of different ideas about the physical world we live in. And so, I am wondering, what you think about how scientists outside of a place like this classroom go about solving real problems?

2. One of the things I have noticed when I come to visit in your classroom is that Mr./Ms.________ has you explore different ideas at your tables in groups of four. I notice that he then brings you to the rug in a meeting area around an easel and up close to the whiteboard. I have noticed that much of the time the students get a chance to talk about what they are thinking during that time. I have heard Mr./Ms. ______asks questions like "what do you think?" and "how do you know?" How do you go about making sense of things you experience in your science class when your teacher asks you "what do you think?" or "how do you know?"

3. Video-elicitation prompt: Let's think back to activity "X" (show a videoclip of the 3-4 students interacting, discussing, making sense of a scientific phenomena). Could you explain to me what you were doing here? What did you do here to help you "say something" about what you thought was going on? Can you explain to me what you were doing and thinking here?

4. What helps you the most when you are asked to explain what you think about something in your science class?

5. So you said, _______helps you make sense of science. Let's watch the videoclip again. This time, see if you can observe anything else that you think contributes to your understanding of the science involved in this activity.

6. Is there anything your teacher specifically does that helps you understand science better?

7. There are lots of ways to "talk" about different subjects in school. For example, in English you might talk about characters or themes. In math you might talk about counting or solving equations. What kinds of things do you do in your science classroom when you "talk" about science? What does it sound like to "talk about science" with other students in your class?

8. Is there anything your teacher has taught you that helps you communicate your own ideas about science-things your teacher has taught you that help you "talk about science" or say something you feel is right about science that others might not agree with?

9. Is there anything else you would like to tell me about what makes it easier for you to talk about science?

10. Anything you think makes it more difficult for you to talk about science.

## Appendix E- Student Focus Group A

**R=Researcher**

**<u>Student Pseudonyms</u>:**
**Sandra**
**John**
**Gina**
**Alberto**
**Veronica**

R: First question: As you know, I've been sitting in your science class for the past few months and I've had a chance to watch you guys think about a lot of different ideas about the physical world. So I'm wondering, what do you guys think about how scientists outside a classroom go about solving a real problem?

John: They go out and find evidence and like they best work out problems by the, like uh, the evidence, and the items and materials they use. They find different ways to get what they need.

R: Um hm. So can you give me an example of a problem they might be working on and how they would go about doing it?

John: So like, how we can breathe on like, on the moon, so then like the best like solution to that problem would be putting like a huge glass bowl over one area we want to live on and like, we can like put oxygen and transfer from like – we can put the oxygen on the moon and transfer oxygen, uh, from earth onto the moon.

R: Uh huh. Oh okay, good. You guys have any other ideas about how scientists solve problems when they're not actually in a science classroom?

Alberto: They use some type of items.

R: Uh huh.

Gina: Like they use different kinds of materials. Not like the regular class. 'Cause in the regular class they use like paper and pencils, but when scientists do it, like more fun and more harder.

Sandra: I think that they really go through procedures.

R: Uh huh.

Sandra: Because in science, in this class, they give you the steps and everything, but they have to know what's the next step and they don't have it all planned out.

R: Oh, so you're saying that here you have procedures all planned out and they don't. Yeah, that's why it's harder, huh? [laughing]  So, how do they know what to do then?

Sandra: Because they work together in the science lab.

Veronica: And they test different things together like if they want to-

Sandra: They test different variables.

R: Oooooh. Variables!

Veronica: Like did you know that two men that you guys were talking about.

R: No. What two men were you talking about?

Veronica: Something about the scientists.

Gina: Yeah about the trees and Christmas lights.

John: Oh. Mythbusters.

R: I missed the lesson.

Veronica: Oh I don't… [points at John]

John: The Mythbusters.

Veronica: Yeah those.

R: Oh, the Mythbusters.

Veronica: Like those, um, they were trying like different things, like, I don't know what they were but there were like things around their head but nothing was holding it. Like, they weren't attached to their head it was just floating there.

R: Ohhh.

Veronica: So I think they like, say what they want to do and what the experiment's going to be on, so, and they try different stuff, so, until it comes out.

R: Hmm. Any other thoughts on this one?

All: No

R: Okay. So number two is: one of the things that I notice when I come to your classroom is that [teacher name redacted] – she has you exploring different ideas at your tables in groups, right? She has different items out there for you and I notice that when you come to the meeting area, or when you're sitting in the meeting area, um, sometimes there's an easel there and there's stuff on the whiteboard, and much of the time you guys get to talk about what you're thinking when you're in that meeting area – that's the time that you guys kind of talk about what you're thinking. I've heard [teacher name redacted] say things like, "what do you think?" or "how do you know?" So my question to you is, how do you go about making sense of things when you have to share it in that big group, when you're teacher says, "what do you think about?" or "how do you know?" and you're sitting there in the meeting area, what helps you answer?

John: Well, what helps us answer her is the support and evidence we find at our table, and that's what gets us going and that's what keeps us, keeps us, from, like, getting the wrong answer, but, like, really there isn't a wrong answer, and so we need evidence to, like, support our, our, should I say, group work. Yeah, we need evidence.

R: What if you're sitting in your meeting area and you did the activity at the table, but you can't remember, or you're confused, what would happen? What would you do?

Gina: You would get, like, ideas from other people. That's why, like, you need, like, a little group, so you can know, like, what you're doing.

R: So, but, let's say that we were in the meeting area right now and I just said to you, you know, so, [student names redacted], what did you just learn about blah blah blah? Like the other day when you and I were working together, [student name redacted], and it didn't work with those two things – what do you do in the meeting area if [teacher name redacted] says, "well, what do you think, [student name redacted]?" and you don't know? What do you do in that very moment? What do you do?

Veronica: Sometimes I just like answer some question that we think it is, and then everybody is like, "noooo" so that's the only thing-

[talking together]

Alberto: Just think what the answer is like.

John: There's agreeing and disagreeing all around the meeting area.

Sandra: Sometimes you can say, "I'm confused and I didn't actually get it."

John: And at the beginning of the year [teacher name redacted] was talking about, like, the accountable talk.

R: What's that?

John: Like, "I agree with," "I disagree with."

R: Uh-huh. And how does that help you if you're in the meeting area?

John: Yeah, like adding on support to help others.

R: And so, let's say you're confused, or you say something, and I say, "na-uh, that's wrong. I disagree with you because blah blah blah." Then, does that help you change and think of something else?

John: Yeah, it helps me change my thinking. It's like support either way. Agreeing or disagreeing.

R: Ohhh. Very nice. That's kind of cool. Accountable talk. I like that. Okay, so I wanted to show you guys a video clip, um, of you working, okay? But I have to change the tape to do that. So, just a second. And I think it's you two, or you [pointing at some of the kids] I think. Let me see. So, unfortunately I have to turn this off for a second. And I'll put this one back in.

[break– watching video clip ]

R: Okay, ready? Here's the question I wanted to ask you about that. So, here we go. So let's think back to the video that you just saw of the people talking with Sandra and Alberto, and then there was, um, Veronica and Raquel. Okay, and I saw students interacting and discussing and making sense of science. Can you explain to me, um, what did you do in those clips to help you figure out what was going on? What were you doing and thinking?

Gina: I think the pictures help you a lot.

R: What pictures?

Gina: I mean, the arrows.

R: Okay.

Gina: Like telling, like, like, the sentence that explains what they're doing.

R: Okay.

Gina: I think that helps.

John: Could you repeat the question?

R: Yeah. Basically, I want to know, when you're sitting there and you have all those things out, what did you, um, what helps you the most when you're asked to explain about something right there with your group? How do you figure it out? What helps?

John: Like, asking more questions.

R: Okay.

Alberto: It's easier for me to, like-

Gina: The procedures.

R: Okay.

Alberto: The procedures are for us to understand.

R: Okay, so let's pretend that you got together at your tables and all you got was a piece of paper with words on it. What?

Gina: When I-

R: Wait, Veronica was going to talk first. Go ahead.

Veronica: What would we do?

R: Yeah.

Veronica: Alright. I would just ask another, um, person, and other, um, tables or if not – if they don't know, then I ask the teacher to repeat it again.

R: Okay.

Gina: Well, if you're really, really good, it's like being the other same papers with, like, little drawings.

R: No, but what if there were no drawings on it?

Sandra: It would take you more time to, um, to work on it because it doesn't have everything. Like, it has information, but you have to, um, separate it apart.

Veronica: It doesn't have everything you need to work on the experiment.

R: That's what I want to know. What do you need to work on the experiment?

Veronica: You need, like if you have-

Gina: Procedures.

R: Okay.

Veronica: No if you have, um, if you're working on force and energy and the receiver, you have to, you have to, um, have something like, something – you have to have something like a receiver or something not like just anything.

R: What do you mean you have to have something like a receiver?

Veronica: Like, if you have a tennis ball and you bounce it on the ground – you have to have like a, like, um-

R: Like that, okay. [points to something Gina is holding] So you have to have like, um-
J: Energy.

Veronica: No, like-

[John raises his hand]

John: In every, like, energy force diagram, there's always a receiver. Always. No matter what. You can walk and there's, like, a receiver.

Veronica: And there's an energy and there's a force.

John: Like you could talk, and, like, someone could be a receiver.

Veronica: The receiver is another person's ear.

John: Yeah, like the voice blades are like the energy.

R: But let's say that we're going to study something completely different, not like receivers and stuff. What if I just said, okay you know what? We're going to study circuits and electricity. Here's a piece of paper about circuits. Read it and then explain it to me. What else do you need for that to be-

Sandra: You need to know like what you're talking about.

R: And how are you going to know that?

John: You need, like, explanations. You need more than just paper. You need, like, an expert's point of view.

R: But what if you have a piece of paper that explains in words what electricity is and how it works, and it's just words?

Veronica: Maybe we could make something up, like, like the scientists make it up?

R: Like what?

Veronica: Maybe we could ask you to give us, like, different materials and then like, us, we could, like, build really, build like what you're saying.

Gina: Make it into our own way that we can understand it.

Alberto Put your own mind to your hands.

R: Put your what?

Sandra: You can try to figure it out.

John: Just like a picture can, like, occur in your head, like, when you're reading. So when you're reading, there are, like, even if it doesn't have pictures, pictures occur in your head, like, you know what they're talking about. But then, sometimes you don't, and that's when you need an explanation.

R: Okay. Alright. Is there anything that, um, your teacher specifically does that helps you understand science better?

Sandra: She explains the, um, the lab when we're in the meeting area.

Gina: Like, she gives an example with objects.

Sandra: She uses an example with things and she explains how to, how we're going to do everything and then, um, afterwards-

Gina: Ask questions.

Sandra: We share our-

Veronica: What I like about her is that she doesn't just say what we have to do. She's like, if, like, if she's doing the experiment, she does, like, part of it, and then that's what she gives as an engage.

R: Oh she does part of it with the objects. She gets you started on it?

Alberto: She starts with the object to do it on the lab work.

Gina: And it's way easier.

R: Yeah? With the objects?
Gina: Because you've got them right there and you can redo it how much times however you want.

Alberto: You have to learn to be moving it and how you're doing it and stuff.

R: Oh. Why does that help, [student name redacted]? Do you guys think that helps?

Sandra: Because when you draw a picture it's going to be harder because you don't really know how-

Gina: There's no action on it.

Veronica: It's your own way, like, you get it because it's your own way.

Sandra: And other people are going to think about it, um, differently because you don't – it doesn't do what you think it does.

R: Ah, so a lot of science classes, the teacher just gets up there and writes stuff on the whiteboard, and she draws pictures, but she doesn't give you any objects. So, do you guys like that?

All: Yes.

R: You like getting the objects? Why? Can you talk to me about why you like that? What is it – why does it help you understand and be able to say what you think, to have the objects?

Vernonica: Because it helps us to have more pictures in our mind, just – maybe if the teacher just goes up there and writes stuff, maybe it'll give us, like, a little bit of clues, but, like, we won't do it exactly like we would if, um, there was an object. So, um, I think if we had an object, for an experiment, I think that we're going to get it more and have more explanations and more answers to it.

R: Um-hm. Um-hm.

Gina: And we're going to get it more. Like, it's easier to-

Veronica: We're not just going to-

Gina: Do it with objects. Not just with pictures.

R: Um-hm. Okay. Alright. That's great. Okay. Is there anything that your teacher has taught you that helps you communicate your own ideas about science things? So, um, something that she might have taught you to do when you're talking about science? I think we talked a little about disagreeing and agreeing and that kind of thing. Is there anything – so, um, let's say that you're

Sandra: Data.

R: Layer?

Sandra: Data.

R: Oh, she gives you data. Okay. Um, is there anything that she's taught you to do like when you're stuck? Like, "okay, when you're stuck you should do this."

Veronica: Oh, like a strategy!

R: Yeah, strategy. Thank you.

CVer:onica Um, [pause], like she kind of tells us-

R: Do you have to go?

[Sandra and John both had to leave the interview early.]

R: Okay, let me rephrase. So, there's lots of ways to talk in school. So, in English, you might talk about characters in books, right? And in math, you might talk about solving equations, okay? So in science, what kinds of things do you talk about when you're doing science, and what does it sound like when you're talking about science? What kinds of things do you say?

Alberto: We worked on, um, different kinds of forces and how to draw different kinds of forces.

R: Um-hm.

Veronica: And what it sounds like, because when you have math, it's just about equations and everything. Um, and English is about sentences and things like that.

Gina: I have a really quick – because I'm confused. Is it true that math is like science?

R: Ummm.

Alberto: It actually is because we sometimes in science we actually have to be using a type of math.

R: Um-hm. There's one type of math that's really like science. It's called geometry and you have to do things called proofs. And a lot of times in science what you're doing is you're trying to say, you know, this is true because, I know, because here's my evidence. You're trying to prove something in science. And they do that a little bit in math. But math is kind of like the language of science. You need it to solve equations and stuff like that.

So, um, basically the last question I want to ask you is: is there anything that you can think about, you know, after watching that tape and seeing – is there anything that you saw somebody do on the tape that you think is helping them actually talk about science?

Alberto: The objects.

R: When you're done doing the activity at your table and you come to the meeting area, does it matter if you have that same object with you when you come to the meeting area? Does it help you in any way or does it matter?

Gina: Not really. The questions help you, 'cause like it's telling you, like, what are you doing with the object and all that. So you just need the paper and just answer the questions.

R: So you don't need the objects anymore?

Gina: No.

R: When do you need the objects?

Veronica: When you're actually doing the experiment.

Gina: Yeah.

Veronica: When you actually have to solve something or give an answer. But when we're up in the meeting are, we had already tried it with objects, so it's more easier for us to answer the answer, the questions that she's asking us.

R: So you don't need the objects anymore when you're in the meeting area?

All agree: No.

R: Alright. So, um, that's it, unless there's anything else that you want to tell me about how you think you best learn science. Anything about the-

Veronica: With pictures. Like, not actually, like, pictures. But like, pictures like, you know, [teacher name redacted] puts on the wall.

R: Oh, um, on her, like when she draws things for her preludes?

Veronica: No, not when she actually does it.

R: What do you mean?

Gina: Examples.

R: When she actually does physically put them up on the wall? Oh, okay. So, not pictures on paper. Pictures that you get in your mind when she does the objects?

Gina: Yeah.

R: Is that what you mean?

Veronica: Or giving us videos to watch.

R: Why do you think that is?

Gina: Like actually somebody doing something.

Veronica: Like, first they do it and we watch them do it, so it's like we have a little more experience.

Gina: Like we have a clue of how to do it.

R: So I'm confused. So if she shows you a video, right, why do you still need to play around with the objects?

Veronica: Um, because we don't, we're not-

Gina: We really don't get it because they're doing it kind of different.

Veronica: We get a clue, but not, like, exactly the clues to answer the paper that she, you know, she gives us a paper. We get what she's saying but not if we were to have to write it or something, we have to do it with our own stuff.

R: So you don't think you could be able to just watch a video and get a paper with the questions.

Gina: No, I don't think so.

R: Okay. I think that's it. Thank you so much.

**Appendix F-Student Focus Group B**

**R = Researcher**

**Student Pseudonyms:**
**Carlos**
**Mark**
**Ian**
**Alan**
**Daniel**

R: There are seven questions. The first question is: As you know, I've been sitting in your science class and watching you guys and taping you for the past few months and I've had the chance to watch you think about a lot of things about science and the physical world. So I'm wondering what you think about how real scientists outside of this classroom go about solving real problems. Now, the only rule is that you don't talk over each other. You don't have to raise your hand. You can just kind of say what you think, as long as you respect each other. So, the first question is how do scientists outside of a classroom solve real problems? What do you think?

Ian: I don't know. I think they, like, test it out, like you know how we use certain types of tests, um, like, you know, they use environmental stuff. Like, they'll look for certain tests.

Carlos: Yeah, I think they use different trials and stuff like that.

Ian: I think what they do, um, before - they test the experiment, right? What they do is share out their results with other scientists and other scientists decide what's wrong and he'll probably go back and redo it and try to fix his experiment or something.

R: After they talk to other people?

Ian: Other scientists.

R: Other scientists.

Mark: I agree with, um, the three because I think that, that when, that when you, when they do like, trials with other scientists, and they see if the experiment, if it's right or not, and they change the, uh, things, to make it, to see if it, works like this or works better like that.

R: And how do they know how to change things? Based on?
Mark: Their, their experiments.

Ian: And the information that they gather, basically from the results.

Daniel: Of their testing.

R: So [to Daniel], what do you think is different about the way that we do science in Mr. [teacher's name redacted] class or real science, or is there a difference?

Daniel: Just test it out. Try to, like, just try to figure stuff out, um, kind of like real scientists would, like, testing out theories seeing if most of us got the same results, then that's possibly the right answer.

R: Oh, like a consensus – the majority of you. Good. Okay, the second question is, um, one of the things I notice when I come to your classrooms is that [teacher name redacted] has you, um, work with actual objects at your desks and, like, in groups, right? And then I notice that when you come to the meeting area, he, that's like when you guys get to talk about and discuss what you found at your tables, and he'll say things like, "why do you think that?" or "how do you know that?" and you can't just say something. You have to tell him why you think that, right? So, when you're trying to answer that question, what do you use to answer that question?

Ian: Well, what I use when you have to do an experiment or when we do an experiment - what we do is I share out – I record everything I've done and all the information that I've got, and then that way if you were to ask me, um, "well, how can you prove it?", well, I'll be able to say, have the evidence to support it, pretty much like what scientists do. They can't just say my experiment works like this, and this, and this. They have to actually have evidence, or like examples, that show that they're true.

Alan: Like, they always have new experiments for every single thing. Like, if they want to prove a type of theory, they have to have, they have to have claims, they have to have objects, they have to have supplies. That's why you need to do experiments because if they're going to prove there's gravity, they'd have to use all types of experiments to do that.

R: What would happen if [teacher name redacted] didn't give you those objects and he just taught you from the whiteboard and showed you videos? What would be different?

Mark: You wouldn't learn about, you wouldn't learn it like just as individuals than from doing actually the experiment because you're actually thinking you're doing your own things like this and that, and on the video they just told you what they do and all that, but if you do it you understand it more because you're doing the work.

Ian: We get hands on learning, unlike just watching, you know, the video. We actually know, and we can actually fix it if we think it's wrong and do it differently to get different results.

Carlos: Exactly. Like every time a scientist does it, they have their own way of doing it, just like we'll have our own way of doing it. So, like, 'cause if we watched it, if we just watched videos or do what [teacher name redacted] does on the whiteboard, then it wouldn't be us doing the experiments. It would just be us doing what he says.

R: Do you think you learn differently from doing it yourselves?

(All agree yes – start talking at same time)

Daniel: If we do something wrong, we can learn from that and like, try and change it.

R: Uh-huh. But if you saw it on a video, it'd probably just be the right way, and you wouldn't know, like (some agreement from students) – okay, that makes sense. Alright, um, so, let's see, what does [teacher name redacted] do, specifically, that helps you understand science better? So, when you're not at you're tables, and you're just working kind of with [teacher name redacted] – does he do anything specific, the way that he teaches, that makes you learn science better?

Carlos: Yeah, I think he does, he – if we have questions, he'll answer them, like, in an organized way instead of everyone just yelling out or-

R: Okay. Alright.

Mark: He, um, he let's us do the work, like, sometimes when we are working independently, he tells us, "who wants to do the work on the board?" We do the work and then he tells the whole class, "Is this right or wrong?" and then we talk and discuss about it.

R: Uh-huh. Okay.

Ian: The way that [teacher name redacted] does it is that he gets everyone involved. Every single student at least says something and gets to share an opinion during either an experiment, or like our conclusion or anything. And he tries to get everyone involved and more into science. Even if you might not like it. Maybe you might not like science, or he probably gets you to enjoy it because you feel like you're participating and actually doing something good, and that's the way that [teacher name redacted] likes to do it.

Alan: Yeah, ‘cause [teacher name redacted], he is a good teacher. Last year I was a bad kid in my science class but this year with [teacher name redacted] I think I just got a little bit better.

R: Yeah. What do you think [to Daniel]?

Daniel: Yeah, uh, I agree with, uh (points to Alan).

R: You agree with Alan?

Daniel: Yeah, I agree with Alan.

R: Okay, so, here’s another question. You know when you’re in English class and you talk about characters in a book or in math class and you talk about equations, right? What do you talk about when you say you’re talking about science? How is talking about science different than talking about math or talking about English?

Alan: Well, it really isn’t much different. Its kind a little bit more different than math and English, but it’s kind like a little bit combined of both. Because sometimes you are going to have to write and you are going to have the writing skills and sometimes you might have to do equations to find out, like, either what’s the error or calculate, uh, or when we try to find the speed or the distance – the speed is like we divide the distance by the time to find the speed in this problem. To find the time, we divide this one by speed. So that’s why you need the mathematical skills. And then, when you want to give out evidence, we need to be able to write it down ‘cause of course you’re always going to forget a little bit about it.

R: Uh-huh.

Ian: I think that both plays out.

Carlos: I think I disagree with him because he says that it’s math and English kind of put together but I think it’s more than just math and science. ‘Cause it has a little bit more about history, it’s got, like, all different kinds of things, like, um, history, all the other experiments they’ve done in the past and the past history. All of that and then plus what he said like added on to what you need the writing skills and the math skills and all that. So, I mean, I agree with him, but at the same time I disagree.

R: Hmm. Okay. Very interesting.

Mark: I agree with both of them.

R: Uh-huh.

Mark: And I'd like to add a little bit more about it. Um, we also use the G.E.S.S. system, which is adding, dividing, and finding the speed and all that.

Alan: And that's why I agree with [Mark], because that's why we really need to know a lot about math, because we use the G.E.S.S. system a lot.

R: Okay. Very good. Okay, so back to the objects. Let me ask you this. Let's say that we were, um, we did something at the tables with these objects, and we did them in groups and stuff, and you wrote down your evidence in your notebooks, and you come to the meeting area – um, does it matter when you're in the meeting area in a circle, post-experimental meeting area, does it really matter if you have your notebook with you or if you have the objects with you when you go to talk about science? How do those things-

Ian: I feel that if we, how we usually we do the post-experimentals in the big ole circle. We bring our notebooks because we obviously are all going to share out. We're going to have to have, like I said earlier, we're going to have to remember what we wrote down and what we learned and usually in our notebooks that's what we do – we record every single thing we've done and then we compare it with everyone else.

R: Okay.

Ian: And then so- I do feel that it would matter because, you know, some kids might go like this, and then sometimes other kids feel like laughing, but if you have your notebook, you'll hardly ever gonna make a mistake.

R: So, does it matter if you bring those objects with you?

(all agree yes)

R: But you don't really bring those objects with you, right?

Mark: Yes, because [teacher name redacted], he sometimes uses the objects to, um, to teach us, um, what happens if this happens. Like when we were learning about gravity with the block and the parachute man, he put them, he let them go up and we saw if the block fell before the other one (gestures with his hands).

R: So, but [Mark], you did parachute man at your tables, right? How does it help that [teacher name redacted] also uses parachute man at the meeting area? How comes it helps when he does it again?

Mark: Because, sometimes we, like, put the wrong answer, and he tells us, um, how this works and that, and if this, um friction, and if gravity is, um, stronger than friction, with the parachute man, and then we, if we're wrong we change the answer and we know what happens.

R: Ohhh, okay. So let me ask you. (points to Carlos)

(Carlos has to go)

R: Oh man, I had a question for you. Really quick: One day you brought, you had a clamp around your neck. You almost always bring the objects to the meeting area. How come? Does it help you in any way? How does it help you?

Carlos: I, like, as he's explaining it, I kind of use the objects in different ways just to see, just to find out what will happen or how it will happen.

R: Uh-huh.

Carlos: So, yeah, I just kind of try to work with it all at the same time.

R: Oh, okay. Great. Alright. You can go. Thank you very much. I know you have to leave.

(Carlos leaves)

Okay, I think we're almost done here. There's one last question. Is there anything else that your teacher has taught you that helps you communicate your own ideas about science?

(Alan raises his hand)

Go ahead.

Alan: The force arrow diagram and energy diagram. It helps us understand what the objects are doing.

R: Where are those diagrams?

Alan: They're, um, always at the back of the class on the poster. So, if we ever have a chance, we can just look up at them and then we don't have to forget.

R: Do those help you when you're in the meeting area too sometimes?

(all agree yes)

R: How do they help you, [to Daniel]?

Daniel: When we forget, like, what to do, we can just, like, look up there and it reminds us, we like, just remember from what we see up there.

R: [to Mark] Were you going to say something?

Mark: Yes, um, I agree with them and it also shows us the definitions of the, of the, um, like, of the words.

R: Um-hm.

Mark: And so if we want to say something but we can't remember what it is, we can just see the map and we know what the word means and we just use it.

R: Oh, and you can use the word properly. Ah, very nice. Okay, this is the last one. Okay, um, is there anything else that you want to tell me in general about what makes something easier or more difficult for you to talk about science?

Alan: Notes always make things easier because that way you'll be able to remember and you also have a notebook so you'll never forget.

Ian: Well, I think that the way [teacher name redacted] makes it, you know, he makes everything simple, he doesn't really make it so difficult.

R: Okay.

Alan: He gets it to a point where we do learn, but in a simpler way. He doesn't go too fast, and if someone needs help he'll send them back to go do the experiment, but he's always walking around so that way nobody will be crying, no one will be upset.

R: Okay. [to Mark]? Anything that makes it easier, or more difficult, to talk about science?

Mark: The posters.

R: The posters.

Mark: When we did the posters, like, last time we did posters of the arrows, to see what was the friction, what was the principle force, and the, and different things and see which one was stronger than the other one.

R: Uh-huh. So you like the pictures and the posters?

Mark: Yeah.

R: Okay. What happens if you, um, you want to say something and you don't know the scientific word for it but you want to make a point – what do you do?

Alan: That's why we have our terms. Like, he made up charts of scientific words to describe anything as the word and the definition. That's why, um, we never really forget. Plus we have them in our notebooks.

R: Okay. Anything else you want to say about the way that you learn science this year in this class?

Mark: It's more fun.

R: It's more fun? Than in other years?

(all agree yes)

R: In what ways is it different?

Mark: Because this time we get to do more experiments. Last time we just saw videos and write things.

R: Oh really? Last year?

Mark: Yeah.

R: Is that true for you, too [to Alan]?

Alan: It's more active this year. And it's more active.

R: More active.

Ian: And I feel like you get more hands on learning than last year, so we actually get to remember things instead of watching videos.

R: And I just thought of one last question – is it really that important at the end to come together in that circle? Could you skip that part?

Alan: No, uh, like it is important so that everybody can, so you can get to claims and so we can figure out the experiment more better. So like, um, if you forget how to do it, like you did it anyways, that's why it's good to come up there. That way if you get it wrong, if you get it entirely wrong, he'll probably let you take it home and then you can fix it back up.

R: Did you want to say something? [to Mark]

Mark: It helps us double-check our answers.

R: It helps you what?

Mark: Double-check our answers.

R: Double-check your answers. Okay. Did you want to add anything? [to Ian] No? Anything else?

Ian: Could you repeat the question one more time?

R: Yeah. Does it really matter, at the end of you doing a lab or an activity at your tables, does it really matter if you come to the circle at the end?

Ian: I feel it does for three reasons. One, I think it will help [teacher name redacted] because I'm guessing he takes everything that he does in one class and sees which are successful and us coming into that circle, it shows everyone was contributing something which means they did it or they were paying attention.

R: Oh.

Ian: And then, second of all, like I believe [Mark] said, it gives us the students a chance to be able to make their claims or their conclusions, and I feel like it's really a good idea to have all the students come in a circle.

Alan: Also, I have something to add on to it. Yeah, I agree with [Mark and Ian] because that like, if you didn't really get it, like, earlier I wouldn't say you get hands-on experience, if you don't really get hands-on experience, and when you come into the meeting area, he'll show you, like, how you should've did it, how it should be.

R: Ohh.

Alan: So that's why it's important to, so – he let's us try and know, then he gives us the claims to try to tell us what we learned and helps us answer that.

R: Okay, that's it. Thank you very much.

## Appendix G: Agenda for Selected Lessons

**Lesson One**

*Engage*
Fun engaging visual (GOO)
Three scaffolded questions with the goo during ENGAGE
1. "How come the goo only moves when I turn my hand upside down?"
2. "What is causing the goo to move?"
3. "What type of force do I think it is?"

*Explore:* *Gravity Investigation*
**Key Question: What type of force is gravity and how does it affect motion?**
Reminder of class definition of motion: speeds up
slows down
stays the same
Three scenarios and sets of materials presented:
DIRECTIONS
Paper clip and Wood Block

5) Hold the paper clip in one hand and the wood block in the other.
6) Drop both objects at the same time.
7) See which one hits the ground first or if they hit at the same time.
8) DRAW both objects falling to the ground.

Shooter Ball

4) Put the ball in the shooter angle it to the side.
5) Shoot the ball and watch the path as it goes towards the ground.
6) DRAW the shooter and the path of the ball with an arrow.

Parachute Man

4) Throw Parachute Man in the air
5) Watch the speed of the man as he moves towards the ground.

DRAW the Parachute Man falling to the ground.
**Explain:** "the time for us to figure out why it is things are doing what they're doing"
Discussion
Claims – these are scaffolded into four sub-questions

a. Did the paperclip and the wood block hit the ground at the same time? Explain why or why not.
b. How does the path of the shooter ball differ from the path of the wood block?
c. Why doesn't the parachute man fall like the wood block?
d. Does gravity happen all the time?

Conclusion: What did you do? What were your results? Final claim?

**Lesson Two**

Agenda: Friction
Purpose: For students to properly identify, understand, describe, visually display, and apply knowledge of FRICTIONAL forces.
Prelude: A soccer player kicks a soccer ball into the wind. Draw a FORCE ARROW DIAGRAM with all the forces acting on the ball.
**Engage:** Fiction Video (Magic School Bus)

Scaffolded questions:

1) Which way do I think friction pushes or pulls?
2) What type of motion do the kids have on the frictionless baseball field?
3) Describe actions that happen differently because there is no friction.
4) How does friction keep the bus from moving when it's in the book?

**Explore:** Wood Block Friction
**Key Question: What type of force is friction, which way does it act, and how does it affect motion?**

DIRECTIONS

WOOD BLOCK

1) Take the wood block an give it an "instantaneous push" across the table.
2) Pay attention to how it moves (motion) across the table.
3) DRAW a picture of the wood block and LABEL the motion you see.

WOOD BLOCK with STICKY NOTES

4) Set up the sticky notes as you see in the diagram to the right.
5) Push the wood block across them with the same amount of force as before
6) DRAW a picture of the wood block and the Sticky Notes and LABEL the motion you saw.

WOOD BLOCK with SAND PAPER

1) Set up the sandpaper as you see in the diagram to the right.
2) Push the wood block across the sandpaper with the same amount of force as before.
3) DRAW a picture of the wood block and the sandpaper and LABEL the motion you saw.

**Explain:**
Discussion
Claims:

1) What motion did the wood block have after you pushed it?
2) Did it slow down more with the sandpaper?
3) Which way do you think friction pushes?

Conclusion: What did you do? What were your results? Final claim?

**Lesson Three**

Agenda: Balanced and Unbalanced Forces
Purpose: For students to identify balanced and unbalanced forces on an object, accurately, predicting the motion.
Prelude: A ferari goes 18 miles in 2 hours. Calculate the speed. Use G.E.S.S.
**Engage:** Multiple Forces (Hair dryer and ping pong ball, fan car and hair dryer)
**Explore:** 3 stations
**Key Question: What is the motion of balanced and unbalanced forces?**
1) Pass the ball

DIRECTIONS: Pass the ball

a. Have 2 people stand opposite one another
b. Pass the ball pushing from the chest back-and-forth
c. Draw a FORCE ARROW DIAGRAM of the ball for one pass.
Include all the forces acting on the object.
d. Copy and Answer the questions below:
Are these forces balanced or unbalanced? WHY?
What was the motion of the ball as a result of these forces?

2) Parachute Man

DIRECTIONS: Parachute Man

e. Toss the parachute man in the air.
f. Notice his movement as he falls to the ground
g. Draw a FORCE ARROW DIAGRAM for the parachute man falling to the ground.
Include all the forces acting on the object.
h. If the man moved right, does that mean a force occurred?
i. Copy and answer the questions below:
Are the forces balanced or unbalanced? WHY?
What was the motion of the parachute man as a result of these forces?

3) Fan car and hand

DIRECTIONS: Fan Car held backwards by hand

9. Point the fan car towards your hand
10. Push back on the car so that it does not move when the fan is on
11. Draw a FORCE ARROW DIAGRAM for the fan car staying still
Include all the forces acting on the object
12. Copy and answer the questions below:
Are these forces balanced or unbalanced? WHY?
What was the motion of the fan car as a result of these forces?

Balanced – equal forces in opposite directions.
Unbalanced- forces not equal and in totally different directions.
**Explain:** Discussion and Conclusion (what you did, what were results, final claim).
Forces Handout (no claims on white board today; answer station questions as claims.
FINAL CLASS CLAIM (consensus) = Unbalanced forces can speed up or slow down the objects. Balanced forces cause objects to stay the same speed.

**Lesson Four**

Agenda

Purpose: Students will be able to define a force and how a force is represented in a picture.

Prelude: Two cars race towards each other. The first car traveled 457 meters in 4 seconds. The second car traveled 382 meters in 2 seconds. Calculate the velocity of the cars upon impact. Draw an energy diagram for this accident.

**Engage:** Car Crash

**Explore:** Force Arrow Diagrams

**Key Question: What is the proper way to show a force visually?**

Procedure:

- Use the descriptions in the data table to simulate the scenarios presented.
- Draw an energy diagram for the interactions
- Draw a force arrow diagram

**Explain:** Claims and Evidence

| Claims | Evidence |
|---|---|
| What object is usually drawn in a force arrow diagram? | |
| How can you tell if a force is a push or a pull in a diagram? | |
| Does it matter if the arrow is coming out or going into the diagram? | |

**Evaluate:** Conclusion

Write a one paragraph conclusion. Remember to include:
*Summary of what you did.
*Summary of your results.
Final claim of what occurred during this experiment.
Answer the key question.

**Extend**: Bowling Ball and Pin Force: Create a force arrow diagram of a bowling ball hitting a bowling pin.

**Lesson Five**

Agenda
**Purpose: Students will be able to predict the types of motion based on a force.**
Prelude: What do I know about forces?
**Engage:** Thanksgiving Project
**Explain:** Forces
**Explore:** Force Posters
**Evaluate:** Poster Presentations
**Extend:** Constant vs. Instantaneous Forces

**Lesson Six**

Agenda
Purpose: Students will be able to identify and define frictional forces.
Prelude: What is friction? What causes it to occur?
**Engage:** Car
**Explore:** Friction in sports
**Evaluate:**
**Extend:** Putting It All Together

# Appendix H – Lesson One Transcript

Black - transcript
Red font = coding from 5-point rubric
Green= commentary
**Actual student names replaced with pseudonyms.**

[Starts out with the Prelude]

T: We're going to have a short "engage", a short engage. But, there are three very important questions. Our "engage" is titled G - O - O - O - O. Goooo. I'm going to put three questions up here. I want you guys to copy them down and I want you to leave some space in between them because we're going to answer the questions.

S: The key questions?

T: No, these aren't the key questions. This is a bad, bad marker. "How come the goo only moves when I turn my hand upside down?" Okay, so that's one thing. Second question - leave some space - "What is causing the goo to move?" Remember we learned, we learned now, we learned now that things don't just move on their own. There has to be some kind of force. And the force causes some kind of motion. So now we've got, "what causes the goo to move?" and then the last one is, "What type of force do I think it is?" "What type of force do I think it is?" "Type" is the key word there. What "type" of force - it's not what force, but what type of force.

Alright. So, as you're getting those down - I'll give you a couple of seconds to get those down.

Alright. So, I went down to the store and I got something called "The Tar Pits" - prehistoric creatures tracked through time. So you get these little prehistoric creatures but that's really not what we're all about. We're about the goo today. We're about the goo. So, so you take the goo.

All: Ewwwww! [laughing and chatter]

T: Okay. So, other than it shaking a little bit because my hand can't stay perfectly still, is the goo moving? No, not really. I mean, it's moving a little bit. It's shaking, but it's not moving too much. Okay, this is when my hand is flat like this. Now I'm going to turn the goo upside down and see what it does [turns hand over, goo drips down].

All: Ewwwww! [laughing]

T: So I'll take another piece of it and rewind. So, again, when it's in my hand, it's not moving a whole lot. But then when you turn it upside down, it all of a sudden starts moving, like, really fast. What is it doing even when it's not, like, falling to the ground?

S: Shaking.

T: But what is it doing? Look at it.

S (multiple): Stretching [one student moves her hands in a stretching gesture].

T: Stretching. Okay, so, so I got this goo. Here, I'll pass it around - don't rip it apart or else it's gonna get messed up. Shhh!  Alright everybody stay with me. How come - and I've got four tickets for this one - how come the goo only moves when I turn my hand upside down? Ian?

Ian :The force of gravity is pulling on it.

T: Oh wow he's throwing up a whole bunch of things. Okay, so he says, "the force" shhhh - I hope we're getting this down. Is this going to be a distraction? [talking to some kids who were playing with the goo]

[Ian] thinks that the force of gravity is pulling it down. Okay, well why is it, why is it when it's in my hand like this - you guys are saying there's gravity as a force pulling down - how come it doesn't pull it down like this? Thelma?

Thelma: Because your hand is stopping it from going down.

[Teacher takes goo away from kids who were being distracted by it.]

T: Okay, so Thelma said, "the reason it doesn't move until I turn my hand upside down," gentlemen [directed at distracted kids], "is because my hand is in the way when it's right-side up." Okay. Interesting ideas, interesting ideas.

Alright, second question - what is causing the goo to fall to the ground? What is it-

S: The way- [interrupting]

T: that's taking that and making it do that?  I'm giving it to people with their hands up. Alan?

Alan: The weight.

T: The weight? Okay, I'll put that down. It could be the weight. Alright, uh, Thelma?

Thelma: Um, gravity.

T: Okay, gravity. I don't know exactly what gravity is. Can you explain that? What do you mean by that?

Thelma: Gravity is, um, something that comes from the earth that kind of pulls everything down.

T: Okay. "Something from earth that pulls things down." Okay. Shhh. Any other ideas besides weight and gravity? Anything else that you can think of. Ian.

Ian: Your hand is pushing it up [student gestures with a hand slowly rising upward, palm flat]

T: Okay, but my hand is not pushing it, that's the thing. I know, I know- [a student talks over him] You take this goo and I hold it in my hand and I'm not, like, throwing it or anything. I'm just holding it, like, I'm holding it with my fingers.

S: There's something in it that allows you to do that.

T: Okay so you think something inside of it-

S: Yeah.

T: Okay, something inside. Okay. So those are some good ideas. There's some good ideas on what could be causing this goo to move. What type of force - because we know it must be a force moving it, some kind of force - it could be weight, it could be gravity, it could be something inside causing a force - what kind of force, and I'm going to give out another four tickets - do you think it could be? Uh, somebody who hasn't answered yet.

S: Gravity?

T: Okay, but what type, what type - we've learned about a couple types of force - if you have to look at the poster, that's fine. That's what they're there for. Mark? [several students turn back and look at the posters at the back of the room]

Mark: Constant

T: You think it's a constant force? Why do you think it's a constant force?

Mark: Because it speeds up.

T: Constant force - I'm going to put b slash c for because - it speeds up. That was Mark. Alright, somebody think otherwise?

S: Instantaneous force.

T: Okay, why do you think maybe it was instantaneous?

S: Because it happens, like, in an instant, and after you drop it, it doesn't really - it can't fall anymore.

T: Alright, instantaneous because it happens once and then not anymore.

Gus: What if it was both, because you see when you put it down, a part of it falls down in an instant and the other part is constantly stretching until it falls down again [he gestures as he explains this idea, using stretching motions with both hands to explain his thinking].

T: So you think it could be both instantaneous and constant at the same time?

Gus: Yeah.

T: Are we sneaky like that? I don't know. I'm going to put it down though. It's a very good idea. "It could be both constant and instantaneous" - and I've got to spell it right - "at same time because..." [wrote the rest without saying it]. Anybody else think something else? Okay. Alright. Well this is some stuff I want you guys to think of. Why is it that the goo falls to the ground? What is causing the goo to move? That's okay, that's okay. This is just something for you guys to think about. Alright. Underneath here, I want you to put, "Explore." We're going to do an "Explore" today. Our "Explore" is entitled "Gravity Investigation." Alright. Our key question today - and I've been writing the key question over there from now on [points to side white board] - it's got a nice little box just for itself - the key question is, "What kind of force is gravity and how does it affect motion?"

[00:13:12.19] [KEY QUESTION]

What type of force is gravity and how does it affect motion? [says slowly as he writes on the white board] And what were the things I told you guys to think about every time you hear the word "motion"?

Gus: Speeding up, slowing down, staying the same.

T: That's right. Every time you see the word motion, I want you to think of "speeds up, slows down, or stays the same" [says this as he writes it on the white board]. Because we said when mo- when things, anything in this universe has one of those three types of motion. It's either speeding up, it's either slowing, or it's going to stay exactly the same speed. And if you're stopped and you're not moving at all, which one of those is it?

S (many): Stays the same.

T: Stays the same speed. Good. Alright. So, what we're going to do today - did you have a question?

S: It’s constant force.

T: So you're agreeing with Mark that it's a constant force?

S: Yeah.

T: Okay, well, we're going to see. We're going to do some other things today too. Alright, what you guys are going to get, um, you guys are going to get a couple different items today. You're going to get a wood block - you've seen that before. Nothing special. You're going to get a small paper clip - not a big deal. The first it says [refers to the document camera] as he explains and models with the wooden block and paper clip] is you're going to take the paper clip and the wood block and you're going to hold them out in one hand each and then you're gong to drop them both at the same time and you want to see which one hits the ground first. Or if they hit the ground at the same time - you've got to see what happens. Then I want you to draw a picture - I want you to draw the wood block and I want you to draw the paperclip and I want you to show what they're doing. Okay, so you're drawing today. And what kind of - do I expect color on these pictures?

All: Yes.

T: And where should you get this color from? Colored pencils, okay? Then the next thing says the shooter with the ball. Alright, this is a new ziplock bag - comes with a ball, comes with a shooter. Push the button, shoots the ball. Alright [models with the ball and shooter].

[chatter and noise]

Hey. Shhh. Totally inappropriate.

We're using it a little differently today. If you look at the instructions it says, "Put the ball in the shooter and angle it to the side." Like this. "Shoot the ball." You ready? You going to catch it for me? [shoots the ball] And see what path it takes. So I want you to draw how the ball is moving. I want you to draw. Is it a straight line? Is it curved? Is it straight down? Or what is it doing? Then I want you to draw it. Draw again. Two drawings.

Third thing is you're going to get parachute men today. Parachute soldiers, in fact.

S: Can we go outside?

T: I may let you go outside if everybody is going to stay under control.

S: Can we go on the roof?

T: You're going to get parachute men - No - throw them up in the air, and I want you to watch his speed. So you throw him up in the air [throws him up in the air] - this parachute man didn't do very good.

S: He died.

T: Someone said that if you wrap it in the parachute and then throw it up [wraps it and throws it again], it works a lot better. Alright, then again I want you to draw the parachute man and what he is doing when he's going down [teacher interacts with the document camera and the parachute man].

Alright, so, you're going to get these items.

S: Are we getting goo?

T: You're not getting goo. Goo is just our "Engage" not our "Explore." Um, what is it - shhh - hold on, I'll let you guys look at it later - what am I expecting for you to have done in your "Explore" section today? What am I expecting to see in your "Explore" section today?

S: Three drawings.

T: Three drawings. With or without color?

S: [looks at document camera] With color.

T: That's it. You're going to have about 15 or 20 minutes to get this done. I want you to get the drawings. I'm very serious about that.

S: And do we have to write what happens to them?

T: Just label them. So, obviously you're drawings are going to look better than this, but if you have a man [draws on the white board] and this was his parachute and you say parachute man. Because I might not be able to tell what you're picture looks like. So you might have to label your drawings. I'm thinking I might have to put this [goo] in the back - this is just too much of a distraction. Alright. The thing that's most magical about the goo is that it comes back into one solid piece [playing with the goo]. Apparently our gentlemen in the class are having difficulty with this [a couple of the boys have stood up to come play with the goo]. Alright, go ahead and go back to your seats.

[00:19:22.14] [Tape skips ahead; skipped the part where the students did the explore with the block, paper clip, and parachute man and ball].

T: One minute.

[00:20:06.14]

T: 3 - 2 - 1 - negative 5 - negative 10 - negative 15. Alright. We're going to come up to the meeting area. When you get up here, your claims are already written over here [points to side white board] I want you to - you don't have to write the question down - but I want you to give a full sentence answer to each one of those questions.

Questions written on the board:

1. Do the paperclip and wood block hit the ground at the same time? Explain why or why not?
2. How does the path of the shooter ball differ from the path of the wood block?
2. Why doesn't the parachute man fall like the wood block?
4. Does gravity happen all the time?

T: Shh. This is what you're writing down. You'll get a chance to share all your answers in just a little bit. Right now you need to put your own thoughts together [teacher walks around the inside perimeter of the “post-experimental meeting area”]. What do you think? Not what does the person sitting next to you think - what do you think? Then the last one is, "does gravity happen all the time?"

S: Yes.

T: We'll discuss it. We'll see.

S: So we don't have to answer all four of them?

T: Yes, you answer all four of them.

[pause while everybody's writing]

[00:24:18.27]

T: Okay, before we begin our discussion today, I want to set a couple guidelines on our discussion before we get started. Four things. We had people first off messing around with things while they should have been listening. And that led to not only you getting distracted and not learning, but people around you getting distracted and not learning either. My job is to make sure that doesn't happen. So, I don't mind if you bring things to the meeting area, but you've got to be mature about it [the teacher does not require students to bring the objects from the explore with them to the meeting area, but he doesn't prohibit them from doing so either, if they use them in productive ways to think through the issues]. You've got to be able to not play with it when you should be listening and learning. That's the first. Second, is we are not going to ridicule, insult, or comment on other people's ideas.

S: Or actions.

S: Isn't that a rule?

T: Yeah, that's, uh, rule number, what is it?

S: Four.

T: Four. If you don't know what to say, you can look up here and pick one of those (points to rules on side board) If one of those doesn't fit, then maybe you shouldn't be saying it at all.

[some chatter and laughing after a student gets his finger stuck while playing with one of the objects brought with him to the meeting area from the explore portion of the lesson]

T: That's exactly what I'm talking about. Shhhh. I'm not laughing. I'm serious. This is the most important part of our experiment. Ladies, I need you to join us. This is the most important part of our experiment. This is the part, this is the time when you actually figure out why it is things are doing what you see them doing. Okay, we're going to talk about it but you have to listen. Okay, do we understand each other? I have the right to give out consequences should you break any of those rules?

All: Yeh

T: Shhhh. So, the first thing we did [teacher picks up the same objects students used in their explore session], was we had the wood block and we had the paperclip. Alright, how many people felt like the wood block hit the ground before the paperclip? [about two people raised their hands] CLARIFICATION OF OBSERVATIONS How many people felt like the paperclip hit the ground before the wood block? [about 2 people raised their hands] CLARIFICATION OF OBSERVATIONS How many people felt the two of them hit at the same time?

[most all others raised their hands] CLARIFICATION OF OBSERVATIONS
Really?

Carlos: Isaac Newton says they do [Warrant, no claim, Level 0]

T: Okay. Well, let's test it out. Alright, so I've got the paperclip, I've got the wood block, I let them go [he drops them].

Carlos: See, so I'm right.

T: Okay, did they hit at the same time?

S (a few students): No. (OBSERVATION, Level 0)

S (some others): Yes (OBSERVATION, Level 0)

[Even watching the very same event, students do not agree on their observation of the time in which the wood block and the paper clip hit the ground. Teacher attempting to reach consensus on perceptual objectification. Dave's students in their interview say this is helpful for their teacher to reenact the lab experiences with them using the same objects they used]

T: Okay, which one is heavier?

S (most): The wood block. [CLAIM, Level 1] [based on previous "spontaneous knowledge" of the wood and paperclip]

T: Then why isn't the wood block falling faster than the paperclip?

S1: Oh, I know, I know.

S2: They're falling at the same rate. [CLAIM, Level 1]

Gus: Cause that's solid and this one's like, whoah…That one has a surface, makes it when it's going down it's like holding it a little and the paperclip, since it's, like …

S3: Has holes…(evidence, Level 0)

Gus: Yeah yeah, it goes right down. [uses gesture to accompany his words] [UNCLEAR EVIDENCE expressed between words and gestures. [THE OBJECTS ARE FALLING AT THE SAME RATE BECAUSE______BACKS WITH EVIDENCE THAT IS MOSTLY IN GESTURE TO DEMONSTRATE THE EVIDENCE HE IS DOCUMENTING THAT JUST OCCURRED BEFORE HIM, with an implicit claim that the objects fall at the same time] LEVEL 1

S4: Like the little things (gestures to make the elongated ends of a paper clip (evidence, Level 0)

T: But you didn't say this one went faster. You said they hit at the same time. [teacher repeats student claim – teacher seems to think Gus is showing through gesture that the paperclip is going faster].

S1: Because one's got wind and one's not. [implicit claim, weak evidence, Level 1]

S: That's why. So the bigger one maybe goes fast, but since that one's smaller, it's going at the same time [uses a lot of gesture to accompany his speech and represent the "wind"] [Implicit CLAIM= objects hit at the same time. WITH EVIDENCE =bigger object goes faster, but smaller one does an action he represents in gesure, gets streamlined down to the ground at the same time as the wood block] THE OBJECTS FALL AT THE SAME TIME, BUT NOT CLEAR WHAT THE WARRANT IS THAT LINKS THE EVIDENCE TO THE CLAIM].

T: So you're saying that this one's got a big surface, so the wind's pushing against it, but it overcomes that because it's heavy?

S: So, if it was open- (leading toward making an exception but doesn't quite articulate it and doesn't finish sentence)

T: And this one doesn't have much surface-

S: Because of the air-

T: but it's light, so they travel at the same speed? [teacher clarifies what the student is saying through gesture and speech, and formalized the gesture into more static language- assists in perceptual objectification by repeating the task and in linguistic representation by assisting with the transfer of gestural and verbal evidence into verbal evidence only. Then the student can repeat it below.]

S: So that one's big and the air is holding it back and that one's small and the air isn't holding it back so they level up and they fall at the same time [uses gesture to accompany his thoughts] [CLAIM WITH EVIDENCE AND WARRANT, LEVEL 2= THE OBJECTS FALL AT THE SAME TIME, BECAUSE THE SIZE OF THE OBJECT AND THE AIR HOLDING IT BACK "LEVEL UP" (EVIDENCE) AND THE WARRANT IS THAT AIR HOLDS BACK OBJECTS IN PROPORTION TO THEIR SIZE.

LEVEL 4 achieved in yellowed area above: there is a series of student claims made with evidence and warrants. Together the students and their teacher co-construct a claim based on evidence and a warrant.

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[00:28:06.13]

T: Then which one should fall faster - this box is a lot lighter than this and it's got a surface similar to this one? [teacher provides a discrepant event to push student thinking and challenge student claim that objects fall at the same time]

S: They'll both fall at the same rate. [a couple of studentes state this, one is Carlos] [CLAIM BUT NO EVIDENCE, LEVEL 1= THE TWO OBJECTS WILL FALL AT THE SAME TIME].

T: Well, no, he's saying that the surface with the wind makes a difference, so let's try it out. [drops the box and wood block] – teacher provides a counterclaim here that he is verbalizing but that came from another student - saying that the wind makes a difference in rate of fall.

Carlos: Yeah, I know.

S: I think 'cause it's smaller, the wood is smaller, [points at objects the teacher is holding] and they're like the same as that one, the the... [doesn't finish sentence] [EVIDENCE CITED, BUT NOT CLEAR WHAT CLAIM STUDENT IS ATTEMPTING TO MAKE, LEVEL 0]

T: Okay, well let's try, uh - these are about the same - not really too much wind is going to get these two, alright? [drops them] [teacher is providing an idea for students to get them thinking; careful teacher guidance to build consensus based on perceptual objectification]

Carlos: I told you. [Carlos is confident, but does not articulate an argument]

S: At the same time. [CLAIM, LEVEL 1= THE OBJECTS FELL AT THE SAME TIME, USING OBSERVATION OF AN ACTION PERFORMED BY THE TEACHER RIGHT IN FRONT OF THEM]--TEACHER IS SCAFFOLDING THE CLAIM PROCESS WITH THE STUDENTS BY WORKING THROUGH SEVERAL EXAMPLES OF THE CONCEPT.

T: So it seems like it's not mattering what two objects I pick up. They're all hitting at the same time. Why is that? Why do you think that? What do you think guys?

S: Because gravity pulls on everything equally. LEVEL 2, CLAIM AND WARRANT [WARRANT] [THE TEACHER HAS STATED THE CLAIM

ABOVE= NO MATTER WHAT TWO OBJECTS HE CHOOSES, BOTH WILL FALL AT THE SAME TIME.]

T: Gravity pulls on everything equally. Okay. so you're saying - when you say the word pull, you're saying it's a force then? [asks student if this is his claim]

S: Yes. [IMPLICIT CLAIM= GRAVITY IS A FORCE; WITH WARRANT AS STATED BY TEACHER. Warrant is that we know forces either push or pull (as stated on back chart in classroom---teacher helps the student scaffold this claim with evidence and warrant; TEACHER SUPPLIES THE MISSING INFORMATION THAT IF GRAVITY "PULLS" THEN IT IS A FORCE. STUDENTS LEARNED THIS PREVIOUSLY] Here we see the co-construction of a Level 2 argument via student (makes claim), teacher (supplies warrant), warrant is embedded in physical environment (to which the students turn to look for verification of collective classroom learning from the past)

T: So he's saying gravity's a force and it pulls on everything equally? [RESTATES CLAIM OF ONE OF THE STUDENTS]

S: Yup. What if it's pulling on, like, for example, if it's pulling on a crane, say it's 1000 pounds and the other one's like 100, so which one is more likely to fall down first? If they're pulling on it equally? (STUDENT INITIATES QUESTION!) STUDENT INITIATED QUESTION #1.

T: So let's see if there's something heavy I can drop. [looks around]

S: You. (Some students laugh)

T: I don't have anything that's that heavy.

S: You and me!

S: Get that monitor over there.

T: Get that monitor [laughing]. Okay, how about this, how about this? Alright. Little ball, heavy book [drops them]. [teacher tests out a student idea, initiated by student request.

S: I win! Do it again. Do it again.

T: Alright, you want to see it again. I'll do it from really high.

S: Stand on a chair!

T: You want me to stand on a chair? [drops them while standing on a chair]

[chatter ensues]

T: Shhh. Okay, so what we just said was that gravity's a force - Alonzo - we said that gravity is a force and it's pulling on everything equally. [TEACHER RESTATES CLAIM BY A STUDENT THAT HAS NOW BEEN BACKED BY SEVERAL SAMPLE DEMONSTRATIONS PERFORMED BY THE TEACHER IN FRONT OF THE ENTIRE GROUP. THIS CLAIM HAS BEEN TESTED AND HAS WITHSTOOD DIFFERENT POSSIBILITIES OF SCENARIOS WHERE A COUNTERCLAIM COULD HAVE DEVELOPED] Okay, let's look at our next situation. The next situation was the shooter ball. Now, when I drop the wood block, what is it's path?

S (a couple): Straight down. [STUDENT OBSERVATION]

T: Straight down. So the arrrow would be straight down. [gestures straight down] Alright, when I hold this is at an angle - uh, is somebody going to catch this over there?

Carlos: right here, right here [Carlos gets up to catch it]

T: - okay, when I hold it at an angle, what happens to - okay ready? [shoots the ball] - okay, so what is the path of the ball? [teacher reenacts a task previously performed during the explore phase to get class consensus on perceptual objectification]

S: A rainbow [OBSERVATION STATED METAPHORICALLY RATHER THAN GEOMETRICALLY. INTERESTING.] Level 0

T: Alright, the wood block went straight down [teacher repeats observation from task #1] [pauses to get the ball back from one student. Also, not happy with two of the students who have been very chatty, takes away one of the objects that Carlos has brought with him from the explore session because he is being distracting with it]. Alright, the wood block goes straight down. The ball does not go straight down, nor does it go the way I'm shooting it. I'm aiming toward that energy diagram poster in the back of the room. So when I shoot it, [students interact with environmental action…students follow the trajectory of the ball with their eyes across the carpet] it kind of starts out that way - it kind of starts out that way but then it starts going down [teacher states observation from task #2]

Carlos: It goes down [student observation achieved through verbal and gestural means, Level 0] (Carlos gestures with a hand motion angling down with his hand and fingers flat; this is Carlos).

T: Okay, why does it start going down? Why doesn't it go straight at the energy diagram- that's where I'm aiming? Mark?

Mark: Because it at first it falls, then gravity- [uses gesture to make his point] – CLAIM WITH A WARRANT, LEVEL 2

T: Okay, so let's think about this then. So you're saying gravity has something to do with this. And we say gravity pulls it down. Now, does gravity just pull it one time, or does it pull it the whole way?

S: It's constantly pulling it until it falls [gestures down with his hand] [CLAIM= GRAVITY CONSTANTLY PULLS ON THE OBJECT UNTIL IT FALLS, LEVEL 1. Claim is achieved through words and gesture].

T: Okay, so you're saying that gravity not only pulls things down, but it actually pulls the whole way, the whole time? [TEACHER REINTERPRETS THE STUDENTS' CLAIM THAT GRAVITY PULLS THINGS DOWN "UNTIL IT FALLS," AS "THE WHOLE WAY THE WHOLE TIME"] Okay. Let's look at other situations. Alright. Let's see if I can do this properly. Uses verbal equivalents. [takes parachute man and wood block]. So I'm going to try and get these equally in the air and then they're going to come down. See which one comes down first. [tosses them in air]

S: The wood block [student observation, Level 0]

S: You didn't do it right. Let me throw them.

Carlos: He has the broken one.

T: You want to throw them? [gives one to one of the students] Alright, we want to try to go about equal height. Alright ready? [they both get ready to toss their objects]

S: The wood block still. [student observation, Level 0]

T: The wood block still got all the way to the ground first. So why is it that the parachute man doesn't fall - everything I just did fell and hit the ground at the same time - why is it that the parachute man doesn't fall to the ground at the same time? [STUDENTS ARE CONFRONTED BY THE TEACHER WITH A DISCREPANT EVENT THAT CONTRADICTS THEIR CLAIM THAT ALL OBJECTS WILL FALL AT THE SAME TIME WHEN DROPPED FROM THE SAME HEIGHT]

[00:34:06.12]

S: Because the air hits the parachute.

T: The air hits the parachute. Okay, so, what air? I don't see anything. [TEACHER CALLS TO THEIR ATTENTION THAT YOU CAN'T NECESSARILY "SEE" ALL EVIDENCE BUT HAVE TO USE YOUR "SPONTANEOUS KNOWLEDGE" OF SOME THINGS. IS THAT STILL SCIENCE? WHAT CONSTITUTES EVIDENCE? ARE THE STUDENTS CLEAR ABOUT THIS?]

S: You breathe it.

T: Ahh, so there is something in the air. And what are those things? Does anybody know?

S: Particles.

T: Thelma.

Thelma: Because, um, the parachute helps hit that kind of stuff from going down so fast [uses her hands to explain her thinking] [CITES EVIDENCE AND A WARRANT TO BACK PREVIOUSLY STATED CLAIM THAT THE PARACHUTE MAN AND WOOD BLOCK DON'T FALL AT THE SAME TIME, SO NOT ALL OBJECTS FALL AT THE SAME RATE]. LEVEL 2

T: Okay, so the air is hitting the parachute, and you're saying it's hitting the parachute like this?

Thelma: No, um, when the guy is falling down, he doesn't go, like, all the way down, he just, he has the parachute to keep him from falling to the ground fast [again uses her hands to accompany her words] [DESCRIPTIVE EVIDENCE, NO CLAIM, LEVEL 0- uses gesture and words]

T: Okay, but I'm saying what is it about this parachute?

S: It slows him down from falling. [CLAIM, Level 1= THE PARACHUTE KEEPS THE MAN FROM FALLING MORE QUICKLY]

[many people talking]

T: Daniel.

Daniel: When he's falling, the air's going up into the parachute, pushing it up so that he falls slower. [CLAIM= PARACHUTE MAN IS SLOWED BY THE AIR THAT GOES UP INTO THE PARACHUTE; EVIDENCE=parachute man is going slower. WARRANT= air pushing the parachute up makes it go slower, LEVEL 4]

T: So there's stuff going up into the parachute like this?

Daniel: And gravity's pulling him down too so he's going down slowly. [CLAIM THE STUDENT IS GETTING AT= GRAVITY AND AIR WORK AGAINST ONE ANOTHER AND COUNTERACT ONE ANOTHER AFFECTING SPEED]

T: So let's see if we can visualize that happening. [tosses parachute man again] So he's still falling, he's just not falling as fast. What do you think about that? [teacher tests out student theory visually with the objects they used originally during observation-helps students process through the science in multiple modalities]

S: I agree with Daniel, that when the air - the air is being like, like in a hot air balloon – it keeps it up [something else I couldn't make out] SAME CLAIM AS DANIEL'S= Parachute an is slowed by the air, and air keeps things up (warrant), Level 2.

T: So does anybody know what that's called when the air slows things down? Have you ever heard of a term that describes air slowing things down? [teacher asks for the official linguistic objectification for the phenomena they have now established as fact- all action, gesture, talk is about to be resemiotized into language, reflective of the students' new knowledge state]

[some students mumble]

T: I think the word that you're looking for is the word "drag." [writes the term on the white board] Also known as "air resistance." [again writes this into his notes, HELPING THE STUDENTS PUT ACADEMIC LANGUAGE TO THEIR IDEAS = linguistic objectification] You might want to get this into your notes. If I write it down, it's probably pretty important [example of "blackboxing in science"]. Or "wind resistance." [writes this on the board] We're going to learn a little bit more about this next class. But right now I just want you guys to see that there is something that's pushing against the parachute that makes the parachute go slower [this is the claim and evidence and warrant all wrapped into one – LEVEL 4] So normally the man - if I were to cut the parachute off of the man - he's going to fall at the same time as the wood block, at the same time as the paperclip, at the same time as the book - it all falls the same. Because - who was it? - was it Isaac - that everything gets pulled equally by gravity. [RESTATES CLAIM BY IAN, EXPLAINING THAT IT IS THE PARACHUTE THAT CHANGES THINGS] Okay, that's what Ian said. So, final question - the thing we're trying to figure out is, "does gravity happen all the time?" Or does it happen every now and then? What do you think Omar?

S: It happens constantly. [CLAIM, Level 1= GRAVITY HAPPENS ALL THE TIME---NOTICE THAT STUDENTS ARE ONLY ABLE TO MAKE THESE CLAIMS IN RESPONSE TO CAREFULLY SCAFFOLDED QUESTIONS THAT THE TEACHER ASKS- at this time, teacher practice leads students' ability to engage in inquiry].

T: It happens constantly. [TEACHER ACKNOWLEDGES AND REPEATS THE VERACITY OF THE CLAIM]

Do you see how this talking is disrupting me from talking with Juan? [talking to a disruptive student]

I'm sorry, say that again Juan.

Juan: It happens constantly, so, um, [can't really hear what he says] [CLAIM= GRAVITY HAPPENS CONSTANTLY]

T: Okay. Mark, and then Thelma.

S: Um, it always happens because if there was not gravity we would, like, go up in the air [uses hand to gesture rising into the air] [CLAIM= GRAVITY HAPPENS CONSTANTLY; WARRANT= IF GRAVITY STOPS, WE WILL GO UP IN THE AIR, Level 2]

T: Okay, so you're saying if there, like, were moments when there was no gravity, we would start floating up or something? Okay, I think Thelma had a comment next.

S: Um, it happens kind of like normally, unless like, you're filled with helium, like a balloon. And then helium, it makes you go up. So, um, so gravity always happens unless you're filled with helium. [CLAIM= GRAVITY ALWAYS HAPPENS UNLESS YOU ARE FILLED WITH HELIUM, WARRANT, Level 2.]

T: That's good. I like the fact that you described the helium idea because there are things that go against falling down that actually go up in the air. Well, kind of like, what causes that to happen? She mentions helium - we're going to learn in chemistry why it is helium does that. Okay. So, gravity happens constantly. So what Mark is saying is that it doesn't matter what time of day or what day of the year or what year it is - if I hold this pen and I drop it, it will always fall to the ground. Is that what you're saying? Gravity is always happening. So if it's always happening, what kind of force is that? [teacher provides scaffolded question for students to make next claim – "teacher practice" of using scaffolded questions]

S: Constant. [CLAIM= GRAVITY IS A CONSTANT FORCE] Level 1

T: It's a constant force. [TEACHER ACKNOWLEDGES and REPEATS THE VERACITY OF THE CLAIM]

S: And it's always pushing it down. It's pushing us down right now. [CLAIM with evidence= GRAVITY IS ALWAYS PUSHING US DOWN, Level 2

T: So, if something is a constant force, and this is our key question, how does it affect motion?

S: It doesn't. [CLAIM= GRAVITY DOES NOT AFFECT MOTION, Level 1

T: No, what motion? Remember, there's three things for motion: speeds up, slows down, or stays the same speed (reminds them of collective class memory encoded in physical environment on charts- physical environment leading here). What do constant forces do to motion?

S [several]: Speeds up. [COUNTERCLAIM, Level 3 = GRAVITY SPEEDS UP MOTION]

T: Okay.

Carlos: No, wait, it stays the same because it keeps going and going and going [Carlos uses a flat hand moving slowly horizontally as he makes this claim] [ANOTHER COUNTERCLAIM= GRAVITY CAUSES MOTION TO REMAIN CONSTANT, Level 4--ARE STUDENTS CONFUSING THAT "GRAVITY IS CONSTANTLY PUSHING" AND THE FAULTY IDEA THAT "GRAVITY CAUSES MOTION TO REMAIN CONSTANT"?) DIFFERENT MODALITIES MIGHT BE IN CONFLICT HERE....WORDS, GESTURES, CONCEPTS....

T: Think of another idea where we saw a constant force. What was one example of constant force we did? [teacher reminds students of past demonstrations and explorations they have done that have become encoded in the physical environment in the form of charts)

Carlos: The fan and the car [Carlos gestures again with the same flat hand moving slowly horizontally across the air]

T: The fan and the car. And what did the car do?

[some chatter]

S: It stayed at the same speed. [EVIDENCE= CAR STAYED AT SAME SPEED WHEN FAN WAS ON IT]

T: Hold on. Okay, did it stay at the same speed? [class needs to get clear again on perceptual objectification- students don't always see the same things, nor remember the same things from experiments unless we encode them somewhere. However, before pointing to the chart where this information has been encoded, the teacher attempts to achieve perceptual objectification before looking at the inscription in the chart]

Daniel: It was picking up speed when the fan was blowing the air [Daniel- with "correct" observation of what occurred previously, Level 0]

T: It was picking up speed - so you're saying it speeds up.

S: [another student makes a claim and uses gestures to explain his narration]- Level 1

[more chatter]

T: Mark - do you want to add anything?

Mark: [couldn't really hear what Mark had to say, but he uses gesture to explain his point]

T: Okay, I have that car and the fan. Let's take a look at it. [teacher goes and gets the car and fan from a previous "explore" lesson, linking past learning to the current learning goals of today] So, the question is, when I put this fan on the, when I put the car like this, what is it's speed? (reenaction of event)

S: Nothing (observation=Level 0)

T: Nothing. Zero speed. (teacher acknowledges and repeats "correct" observation for class consensus of percpetual objectification.) Then I turn the fan on. We already said the fan is constantly pushing. So then it goes. Now did it speed up, slow down or stay the same speed?

S[several]: Speed up (observation- Level 0)

T: Okay. so then our - we determined from that lab, and we actually wrote it on a poster up there [refers to the back line of charting posters hanging at back wall- encoded in physical environment as collective class learning] - constant force causes things to speed up. So if gravity is a constant force, what does gravity cause things to do?

S: Speed up. (CLAIM= Gravity causes things to speed up, Warrant is because gravity is a constant force and constant forces cause things to speed up, Level 4, this is a counterclaim to original claims made earlier in the transcript, and can therefore rise to a Level 4) – notice all the different components that went into making this LEVEL 4 argumentation! (teacher practice of re-enacting a previous event, building on a previously made student claim, which itself was composed of multiple contributing modalities, gesture, physical environment).

T: Speed up. [writing] "causes objects to speed up." [Teacher acknowledges and repeats students claim, a repeated process.

S: Can I ask you something?

T: Yeah, go ahead.

S: What about with the parachute? What if it didn't cause it to speed up? (STUDENT INTIATED QUESTION #2!)

S: Yeah it did.

S: Nooooo. When you threw it up, it went up, and then it went down. (Observation)

T: That's a good observation. So let me ask you this though. If gravity's always happening, right?

S: yes.

T: You guys said that. And is gravity happening to us?

S[several]: Yes.

T: So how come, like, if I'm standing here right now, I'm not speeding up, I'm not going anywhere?

S: You're not flying up though. (Observation, Level 0).

T: That's true.

S: It's holding you down. [CLAIM= gravity is holding teacher down, Level 1]

T: But no wait, we just said that gravity's a constant force and constant forces cause things to speed up. How come I'm not speeding up?

[00:41:40.06]

S: Because, um, it's kind of like a magnet. A part of a magnet, and then the um, gravity is like the whole magnet, that connects you to it. [Implicit claim= gravity is holding teacher down, but teacher is not speeding up even though we know that gravity is a constant force and constant forces speed things up by class definition, because teacher and ground are like a magnet (magnets hold things together). Implicit Claim with weak warrant, Level 1.

T: Okay, so maybe magnetic - something magnetic going on in there. Okay, Mark.

Mark: Because the earth rotates, so the earth is moving always, but you're not moving, but the earth is moving (uses gesture to explain his thinking) Implicit claim with warrant only, Level 1.

T: Ohh. So it has something to do with being on the earth. What happened when I took the goo - we're back to the goo idea - remember, what happens to the goo when my hand is underneath it? [teacher grabs goo and holds it upright in his hand- teacher revisits previous demonstration from earlier in the lesson]

S: It doesn't move because your hand is the surface. [CLAIM with evidence, Level 2)

T: It doesn't move because it's already stuck to the surface. So only when you turn it upside down that gravity now pulls on it? So is gravity pulling on it right here? (teacher scaffolding of question to further student thinking- teacher practice).

S[several]; No. (IMPLICIT CLAIM= gravity is not happening all the time, Level 1, but this contradicts their earlier claim that gravity DOES happen all the time!

T: But I thought you said gravity's always happening? [teacher reminds them of their earlier claim]

S [several]: Yes. It is [counterclaim= gravity does happen all the time, LEVEL 1 with claims and counterclaims, but no evidence].

T: It is pulling on it.

S: But you're stopping it with the surface. [student observation, LEVEL 0]

T: So if one force is pulling it down but it's not going anywhere, what must be happening? [teacher scaffolds a question to further student thought – teacher practice]

S: It's always happening but maybe it's not always- CLAIM, no evidence, Level 1

S: You're the force. [CLAIM, Level 1].

S: It's not moving. [student observation, Level 0]

T: Wait, say that again. [teacher asks for student to repeat Claim)

S: You're the force. [CLAIM, Level 1]

T: I'm the force. What force am I?

S: The holder.

T: Which way is my force going? [teacher asks for observation and gets it below]

S [several]: Up. [observation, Level 0)

T: So let's think about this. If there's a force pulling it down right now [CLAIM] and it's not going anywhere [OBSERVATION] and you're saying I'm the force, [CLAIM] I'm pushing it up. I must be equal to the force of gravity right now because this isn't moving [CLAIM WITH EVIDENCE] If it's too heavy for me, I'm not stronger than gravity [REBUTTAL] If I can lift it up, that means I am stronger than gravity. LEVEL 4- TEACHER ARTICULATES AN EXTENDED ARGUMENT FROM ALL OF CLASS INPUT- he then asks the students to go back to their seats and do the same, empowered with all they know).

[chatter]

T: You guys said it was constant. We already got that. Alright, so, what you're going to do now is you're going to go back to your seats. You're going to go back to your seats and you're going to write your conclusion. Your conclusion has a lot in it today. What did we do? You did a lot of stuff. Parachute man, wood block, paperclip, shooter with the ball inside it. What are your results? What did you find out? Well, I found out that the paperclip and the wood block do what?

S: They fall at the same speed.

T: They fall at the same speed. And then your key question is, "what kind of force is gravity and how does it affect motion?" And the answer to that is what you guys came up with. Then, when you're done with your conclusion, I want you to draw force arrow diagrams for the parachute man, the wood block, and the ball from the shooter. That is your homework.

S: I finished it.

T: So, go ahead and go back to your seats and get started.

[00:44:37.00] [End of the transcribable tape - the rest of the video had some shots of the posters around the classroom]

***<u>SUMMARY OF TRANSCRIPT LEARNING AND HOW IT OCCURRED:</u>***

**CLASS CONSENSUS: GRAVITY IS A CONSTANT FORCE THAT SPEEDS THINGS UP (ARRIVED AT FROM THE INPUT OF SEVERAL STUDENTS USING A COMBINATION OF WATCHING THE TEACHER REDO CERTAIN PORTIONS OF THE EXPLORE, USING THEIR WORDS, SOME ACCOMPANIED BY GESTURE, THINKING THROUGH NEW QUESTIONS THE TEACHER POSED WHEN THE CLASS WAS GOING OFF-TRACK, AND REFERENCING THE CLASSROOM ARTIFACTS IN THE ROOM).**

## Appendix I – Lesson Two Transcript

Black = transcript

Red font = coding from 5-point rubric
Green= commentary
**Actual student names replaced with pseudonyms.**

[00:53:01.23]

T: Alright, so, first question is what motion did the wood block have after you pushed it? This is just on the table by itself. So, draw a line, put the word "claims." Draw a line, put the word "claims." So, what kind of motion? Again, did it speed up? Did it slow down? Did it stay the same speed?

[pause while students are writing their answers]

Second question - did it slow down more with the sticky notes? So, when you pushed it across the sticky notes-

S: It didn't even get to two, or three I mean.

T: The sticky notes?

S: No, like when the thing you pushed - you push it - it didn't even get to number three sticky note.

T: So you're staying the sticky notes slowed it down more then?

S: Yeah.

T: So, the sticky notes slowed it down more, the sticky notes did not slow it down as much, something along those lines - it depends what you saw. Everybody sees different things.

[pause]

Third one is did it slow down even more with the sandpaper or did the sandpaper make it go faster? What do you think?

[pause while they write down answers - meanwhile, writing on the board]

I'll give you guys about one more minute to finish those up.

S: I don't know the last one.

T: The last one is which way do you think friction pushes? Shhhhh. The only wrong answers are the ones that don't try... or spend time in the meeting area doing something other than what they should.

[pause again to finish up answers]

[00:57:45.20]

T: So, if I was in class doing what I asked myself to do, ah, this is what I would have come up with as a student. Here are my three drawings. But my drawings are missing something.

S: Labels.

T: Well, I've got a label of some type, but-

S: Force. [interrupting]

T: Thelma?

Thelma: They're missing the other leg of the table.

T: Okay. The other leg of the table. Alright.

S: The motion.

T: Okay, what else are they missing?

S: The arrow. The force arrow.

T: These are not force arrow diagrams. I didn't ask you to make force arrow diagrams. Alright, Juan?

Juan: Motion.

T: Okay, the motion. So you guys are going to help me with the motion. When I push the wood block on the table by itself, what kind of motion did it have?

S: Speed up.

S: Speed up then slow down.

T: Speed up then slow down? Okay, speed up and then slow down. Anybody else disagree with that? Okay. Uh, next one. When I push the wood block over the sticky notes, did it slow down more or did it slow down less?

S: What?

T: When I push it over the-

S: Slowed down more. [jumping in] LEVEL 1

T: Slowed down more? Does anybody agree with that? Or disagree with that I should say?

S: I would like to disagree. 'Cause ours speeded up. LEVEL 2 – counterclaim after a claim has been made by another student.

T: Okay, so, yours slowed down less then? 'Cause it still slowed down, but it just didn't slow down as fast. Okay, so it slowed down less. Okay. Put "or" right there. Slowed down more or it slowed down less. Anything else? Anybody see anything else? What about when I put it across the sandpaper, Thelma?

Thelma: It stopped as soon as possible. LEVEL 1

T: It stopped as soon as possible. Okay. Stopped as soon as possible [writing that down]. Okay. So going back to our key question today - there's three things we're trying to figure out. We know that this thing called friction is happening. But I'm trying to figure out what type of force it is, which way does it act, and what type of motion does it have, or what kind of motion does it cause? Alright, so right now I need everybody to stop what they're doing and put your hands together like this [puts his hands together palms in]. Alright, now, when I'm cold in the morning and I'm standing out on supervision duty, you can see my sometimes doing like this [rubs hands together].

S: It warms them up. LEVEL 1

T: Everybody should do that right now. Okay, so what are the two things that you notice when you do this?

S: It gets hot. LEVEL 0- observation

T: Your hands get warm and?

S: You get tired. LEVEL 0 - observation

S: You hear a sound. LEVEL 0- observation

S: A sound. LEVEL 0 -observation

T: I hear a sound. Okay. So that sound and that heat are because there's this thing called friction going on. Okay. [linguistic objectification]

S: When two things rub together [kind of at the same time the teacher is talking].

T: But, my question is, what type of force is friction? That still doesn't help me.

S: Push and pull. LEVEL 1- friction is a push or pull.

T: Okay. There's another thing I think about when I think of friction. This was kind of from the video. What was happening on the baseball field?

S: You mean the one in the book?

T: Yeah, no, the one in the movie, yeah, the one in the book.

S: Like they were speeding up but then slowing down. LEVEL 1- incorrect claim

T: Okay, so they were speeding up but were they slowing down? What happened when they tried to stand up or walk?

S: Because there was no friction then they couldn't stand straight because it was slippery. LEVEL 2 (claim with evidence, weak warrant)

T: Okay, so, in the movie, when they tried to put their foot down like this, it would just slip and they would be like [he makes weird slipping sound effect]. Okay, but in real life, when you put your foot like that, you hear, it makes that sound right? [scuffs foot on floor to make scuff sound] Okay, my shoes do it really well. Okay, so that is friction going on right there.

S: I hate that sound.

T: This is going to remind you of friction for a long time to come. Alright, so, if my foot is going this way, which way is friction going?

S: The opposite direction. LEVEL 1

T: Which would be which way? My foot is going towards Alan right now, so friction's going that way [pointing to the board behind him]. Alright, I'm going to move my foot so it goes towards the front of the room. [scuffs his foot in the other direction] Which way did friction go?

S [several]: That way. LEVEL 1

T: Okay, so what can we say about the way that friction goes?

S: It goes opposite to how you move. LEVEL 1.

"Explain portion"

T: Oh Jose, sorry. Why do you say lowest?

J: It's cause it is.

T: Okay, Mark, maybe, what do you think?

Mark: When you are walking, friction helps you to not fall and keep at a certain speed.

T: Okay, that sounds good. What do you think Alan?

Alan: Um, yeah, like, friction, when you run, like, you have [can't make it out] when you're running up a hill, you slowing down, with friction. LEVEL 1

T: Okay, so do you say that friction's always happening?

Alan: Yeah. LEVEL 1

T: Okay. Okay. Good. Good ideas. Good ideas. What do you think?

Carlos: I agree with them because you're always on something, like, you're never, like, flying, because you're always sitting on something or laying on something or standing on something (uses gesture to convey positions as he says them). LEVEL 3 –friction is always happening with very weak evidence (you are always "on" something), but represents a series of claims all in agreement that friction is always happening (third student claim).

S: More evidence to support initial student claim

T: Oh. What is that thing that's always having you on something?

S: Gravity. Linguistic obectification

T: Okay. So, we're going to learn about this more on Thursday, but do you think that gravity and friction have something to do with one another?

S [several]: Yes. LEVEL 1

T: Interesting. Alright, so if we're saying that gravity's always happening, what kind of force is friction then? It's always happening?

S: Constant. LEVEL 1 – friction is a constant force.

T: It's a constant force, good. Friction is a constant force. [writing]. Okay, so that is two of the three things that we were trying to figure out today. I know it's constant. I know that it goes opposite of the way that I'm going. Now the final one - how does it affect motion? What did it do to the wood block? What did it do to my hand? What did it do to my foot? Mark?

Mark: It slowed it down. LEVEL 1

T: Yeah, it slows it down. It slows it down a lot. Now, if I put a piece of sandpaper and taped it to the ground and did my foot to this, is it going to stop it more or less?

S [several]: No, you're going to rip it.

T: Why would I rip it?

S: Because that's not enough force.

S: Because you're pushing your weight on that side.

T: Okay, so, but I'm not ripping the ground up when I do this.

[00:02:10.05]

[chatter with several ideas about why he won't rip the floor up - couldn't make out all of them]

S: It's a concrete surface. LEVEL 0 - observation

S: It's because that's the ground.

T: So what's the difference between the sandpaper and the ground?

S: That one's loose and that one's not. LEVEL 0- observation

T: Okay, let's go into a hypothetical. Let's say I actually made the whole ground out of sandpaper.

S: It would hurt 'cause then you might fall. LEVEL 1

T: Why would it hurt?

[lots of chatter again]

S: Sandpaper's rougher. LEVEL 0 – observation

S: Sandpaper's rough. LEVEL 0- observation

S: It would scrape and it would hurt. LEVEL 1

T: But what I'm trying to ask is what's the difference between the sandpaper and this floor right here? Mark?

Mark: The floor has more friction than the sandpaper. LEVEL 1

T: The floor has more friction than the sandpaper?

S: No it has less friction. LEVEL 3 – counterclaim within a series of student claims

T: Okay, you say sandpaper has more friction than the floor?

S: No, this has less friction right here. [rubbing his arm] LEVEL 3- series of claims/counterclaims without evidence.

T: This has less friction? [rubbing his arm in the same place] Okay, let's really put this in my mind. Which has more friction? Sandpaper or, like, ice?

S [several]: Sandpaper. LEVEL 1

T: And what makes it - what do you think makes it have more friction?

S: Those little bumps. LEVEL 1- little bumps cause the friction

T: Oh it's got some little bumps.

S: Sand.

S: It's rough. LEVEL 0

T: So, let's do a test. So, Mr. [teacher name redacted] will take his hands. I rub them like this - you've got to listen for it. No, just me. Just me. Shhhh. Okay, here's my hands. Just, hand on hand. [rubs hands together] Now I take sandpaper - do you think it's going to make more or less noise?

S: It's going to hurt you. LEVEL 1

S: More noise. LEVEL 0

T: [rubs hand against sandpaper]

S: I see your skin fall down.

T: Yeah [laughs]. Okay, so then we can say that it - what does it do to my hands? What does friction do?

O: It makes it bleed. LEVEL 1

T: No...

S: It scratches them. LEVEL 1

T: It makes them...

S: Slow down. LEVEL 3 – series of claims -friction slows objects down.

T: Slow down. And then causes them to stop. So, slow down. [writing "slow down"] Okay. Now, we have about one minute left to get cleaned up and to get out of here. Wait, hold on - there's two things you need to do for homework. Shhhh. I don't know why everybody's moving right now - you need to know what you're going to do. Alright, this is going to have to fast because we're wasting time. I need all the materials in the boxes, the Post-Its can be thrown away. I need a conclusion written for homework and you have to do the homework that's written up there.

[00:04:40.02]

**Appendix J – Lesson Three Transcript**

Black = transcript

Red font = coding from 5-point rubric
Green= commentary
**Actual student names replaced with pseudonyms.**
**R=researcher**

Prior to allowing students to begin the "explore" section-

T: Today, and for the rest of the next two weeks, I want you to pay attention to one thing. And this is the most important thing. We are now going to be extremely accurate with how long our arrows are. That means the biggest difference to us from now on.

Explore:

27:06- 29:04
Group: Alan, Daniel, Mark, Ian
Boys holding down toy motorized car to examine forces acting on it and to determine whether these forces are balanced or unbalanced.

Alan: Is there any way to turn it up? Look at the wheels! Look at the wheels! (points to wheels then walks over and touches them with his hand as partner Isaac continues to hold the car down on the table).

(all four boys writing)

Alan: Okay, this is a constant force because it keeps on happening. LEVEL 2

Mark: (looks back to reference entextualization on front white board). It's balanced force because the- LEVEL 1

Alan: (goes over to Mark's paper and students look over the drawings Mark has in his notebook). It's constant cuz it keeps on happening. LEVEL 2

Daniel: We have to answer if it's balanced or unbalanced. So, what's the first one?
(Mark turns around to look at Dave's entextualization on front white board).

Alan: Oh. It's balanced and it's- LEVEL 1

Mark: They are the same. Balanced. The friction (gestures right hand in toward center of body) and the force (gestures left hand in toward center of body, then re-checks front whiteboard) balance it. (All our students write again). LEVEL 2.

(series of claims in a row with evidence make this a level 4)

Daniel: The second one is unbalanced?

Mark: Yeh.

---

29:50- Explore
Group: Alan, Mark, Daniel, Ian

R: How do you know that the fan was pushing it more?

Mark: (gestures a sweeping movement across the table)

Alan: Because it was moving faster. A normal car won't move because a normal car would probably- if you pushed it (points to an empty space on the table) right here, it would probably stop right here, but this keeps on going (slide hand holding pencil across table), so it has less friction.

Mark: If you push (takes motorized car) See, it's hard to stop.

R: But I thought you were supposed to put your finger Right?

Daniel: It is still the same amount of friction. Remember, friction is what stops it.

R: But remember when he had the marker in his hand? That was balanced forces, right?
(Students nod affirmatively).

Ian: This is a balanced force, because the hand and the fan is still stopping it (gestures).

R: But I thought you guys say that it was unbalanced?

Ian: They said that (indicating his other group members).

R: So, what do you think now? If your hand is up against the car, and your hand is moving it this way, and the fan is moving it this way-

Ian: It would be balanced because they are not going the same speed, but they are both pushing the same way-no, not the same way, but the same. Even (gestures with two hands). And gravity is pushing it down, the table is pushing it up.

---

34:02- 36:13
Group: Alan, Ian, Mark, Daniel

Daniel: I don't know.
(silence for several seconds, boys draw in their notebooks, then set the parachute man in the center of their table)

Alan: Hey, I think weight has to do with - I think gravity's pulling down on it. LEVEL 1

Mark: Yeh.

Alan: No, I mean it's pulling down on it stronger than other forces. LEVEL 1

Ian: I think this one's balanced because-LEVEL 1 (LEVEL 3- series of claims without evidence)

Daniel: It's going up (gestures up with pencil), and the air resistance is going down (gestures down with pencil). Provides evidence for previous level 1 claim to bring this to a LEVEL 2.

Ian: The air is going through the parachute (gestures parachute with fingers and hands), making it slow down, which makes gravity and the- LEVEL 3 –series of claims without evidence.

Mark: Friction goes up (gestures up with hand) and gravity goes down (gestures hand down). LEVEL 1

Ian: Yeh, but they're both the same. LEVEL 1

Mark: Nods head no. nonverbal LEVEL 1

Alan: Hey, it's like this right here- (lifts up notebook to show his drawing, while Mark begins to lift the parachute up and down in front of the group. All talking at once.)

Ian: Gravity's pulling on it. That's what I'm saying. Look. It's just that this (grabs parachute) is slowing it down. So-LEVEL 3 –series of claims without evidence

Mark: So, yeh (nods head in agreement).

Ian: It's unbalanced. LEVEL 1

Alan: Wait, why's it unbalanced?

Ian: Alright (grabs parachute). If he didn't have the parachute, he would just (allows parachute to drop straight down), fall. But since he has the parachute, (lift parachute in hand and up at face height), making him go slower.

Mark: (adds a slow gesture with his hand moving down, and looks at Alan)

Ian: which makes the friction stop

Alan: air resistance-

Ian: yeh (points at Alan in affirmation),

Daniel: which makes him fall slower

Ian: yeh, the air resistance slows him and gravity, gravity always stays the same, but in this case, it's going like (moves the parachute man slowly side to side and down)

Alan: Okay, so the air resistance is up, and the gravity's kind of down.

Daniel: When it's going down, the air is going up (gestures an upward movement with his hand). Air resistance is going up, making it fall slower.

(all four students writing).

LEVEL 5 achieved- a series of co-constructed claims with evidence, but also with one "exception" articulated to the claim.

Explain Portion

[00:36:17.24]

T: "We're already smart, working on brilliant. You are armed and dangerous with knowledge of forces… you know friction, you know gravity, you know constant force, instantaneous force, tension, compression. You know all that stuff now. So, now you're going to say, "what is going on with parachute man, what are the force arrow diagrams?" Okay. Parachute man. What forces were acting on parachute man? Alan?

Alan: Resistance. LEVEL 1

T: Which one?

Alan: Resistance.

T: Oh, wind resistance. How do I draw that?

Alan: Uh, you draw.

S: Oh. [interrupting]

T: Okay. Hold on a second. Alright, Alan, what was it? Wind resistance? Which direction?

Alan: Huh?

T: Which direction?

Alan: Up (deictic pointing at easel).

T: Up. Okay. So I draw it like this? [drawing] Wind resistance [writing at the same time]. Okay, what was another force acting on parachute man? Daniel?

Daniel: Gravity. LEVEL 1

T: Okay, gravity. Which way should gravity go?

Daniel: Down (gestures hand down). LEVEL 1

T: Would that be longer or shorter or the same as wind resistance?

Daniel: Shorter? Because it's making it fall?

T: So you think it would be shorter like that?

Daniel: It's making it fall slower. LEVEL 1

T: Gibbs, do you agree with this picture?

Gibbs: [nods]

T: Everybody agrees with this picture?

Gus: I think there's only two! (claps hand together). LEVEL 1 That's all there is.

T: You guys agree with the length of the arrows - this being bigger than the gravity?

S: Yes.

T: So, so...

Gibbs: No, I think they'd be the same 'cause if, then it would be like that (moves hand slowly down), slow (moves hand very slowly down). LEVEL 1- Counterclaim without evidence

T: Okay, Gibbs thinks they should be the same. Gus?

Gus: On that one, I didn't put two arrows, I put three. One was the one because you threw it up, (gestures a hand thrown up in the air), the hand which is up, gravity pulling down, and the wind pulling kind of to the side 'cause when you throw it up it didn't, like, go straight down, it went like [makes wind noise and makes gesture with his hand showing wind down and to the side]. LEVEL 3 – series of claims

T: We're not concerned about the hand for right now because we're more concerned about the moment when he's falling down. My question, though, is, are the arrows okay?

S: Yes.

S: I think that gravity should be a little bit bigger. LEVEL 3

T: She thinks that gravity should be bigger. Right now we have it shorter. Gentlemen [to chatty students]. Gibbs - you said that they should be the same size. So we need to figure this out. We need to all agree on this. Gus - your attention needs to be up here please. Okay, Daniel and then Ian.

Daniel: I disagree with Gibbs because if we put them as the same length, it would be balanced, it would just- LEVEL 4- a series of claims/counterclaims is developing with accompanying evidence

T: It would just stay right there, right.

Daniel: It would just keep standing still. (still part of the LEVEL 4 documented above)

T: Okay. So anybody want to come back against that. Gus?

Gus I agree with whoever said that the gravity thing should be bigger because it went down. LEVEL 4 continued

T: Okay. Ian?

Ian: I was going to agree with Gus. If the wind resistance were heavier it would be going up instead of coming down. LEVEL 5- series of claims is maintained, now with the addition of at least one articulated "exception" to another student's claim.

T: Yeah, if the wind resistance were heavier, wouldn't it be pushing it actually going up? [points at somebody]

S: It does in the beginning when you bring the opening it goes up. [makes gesture of tossing parachute man up] LEVEL 0- observation

T: Well I'm thinking after the parachute opens and he's like trickling down to the ground.

S: Yes.

T: Okay, so then we can agree that gravity should be a longer arrow like this. Gravity should be stronger than wind resistance because he is falling down to the ground. Alright, so, you guys are saying that gravity's longer so he's going down. (Teacher sediments all input up until now in a clear statement). What about this sideways? - what does that make him do? Does he go like [draws a line straight down on the picture] What does he do?

S: It makes him travel like in a [makes a gesture to the side with her hand].

T: Okay, so he kind of goes like [draws another line on the picture]. Is that right?

S: It kind of [makes a spiral motion]

T: It actually makes him swirl a little bit? Okay, that one's harder to draw.

[general laughing]

T: Now, here, let's get to the questions. Was this balanced or unbalanced forces?

S [several]: Unbalanced. LEVEL 1

T: Okay, are there arrows equal in opposite directions?

S [several]: No.

T: No, so this is then...

S [several]: Unbalanced. LEVEL 1

T: Unbalanced. Okay, so this is an unbalanced situation.

[00:40:16.26]

T: And then, describe the motion of the parachute man.

S: He's going down real slow [making spiral motion with his hands]. LEVEL 0 - observation

T: Remember what were the three things when I say the word motion you think of...

S: Speeds up, slows down, or stays the same.

T: Okay, so what was the parachute man doing?

S: He was slowing down (makes spiral motion with hand). LEVEL 1

T: Slowing down?

S: Speeding up! LEVEL 1

T: Parachute man is falling. What do you think?

S: I think it stays the same. LEVEL 3- series of claims/counterclaims with no evidence

T: Okay.

S: No, 'cause he goes like this, he goes [makes hand motion of some sort]. Begins to provide evidence to bring to a level 4

S: I think he's speed up (gestures) because gravity's a constant force so gravity's pulling him down so that means he's speeding up. LEVEL 4

T: Okay, so we've got a bunch of different ideas. Okay, so we've got one person saying he's slowing down, one person says he stays the same speed and then he stops because he hits the ground, and another person says because of a constant force he's speeding up. What do you guys think?

Daniel: Speeds up because gravity's a constant force. LEVEL 4

T: Is it a constant force that causes things to speed up?

Daniel: Yes.

Ian: But the parachute slows him down. LEVEL 4

T: We know he's definitely not staying the same speed because-

S: (student who had previously claimed this, giggles and covers her face with her hands momentarily)

Ian: Slowing down. It's slowing down because of the parachute. That's what makes it slower as it goes down.

T: Okay, you guys drew this arrow much longer than this arrow. So this one's going to conquer every time right?

S: Yes.

T: So even though this one's pushing against it, it's still going to be speeding up, just not as much.

Gus: Yes. So I'm right, right?

T: Alright, so if you didn't get those answers, there we go. Alright, moving on to our next picture. We will do the, um, football.

[00:42:06.02]

T: Okay, give me one force that's acting on the football, Alan. One force that was acting on the football. [long pause] What do you think? What do you think? [long pause] What did you have Alan? What'd you have? [goes over to look at his paper] Alright, his hand. Okay, Alan has his hand coming across like this. Alright, what was another force acting on this football, Ian?

Ian: Air resistance. LEVEL 1

T: Air resistance. How would I draw that?

Ian: Opposite way.

T: Now do I draw it shorter, longer, or the same as this one?

Ian: Shorter.

T: What else was acting on this, Daniel?

Daniel: Gravity. LEVEL 1

T: Gravity. Okay, so this one is longer than this one. So which way do you think it's going to go? To the right or to the left?

S [several]: To the right.

T: To the right. Okay. Is that what it did? Did it go away from your hands?

S [several]: Um hm.

T: Okay, so that's right. Now, is there anything keeping, opposing gravity right now?

S [some]: Yes.

S [others]: No. LEVEL 3- claims with no evidence

S: Friction (pushes his two hands past one another and makes a swishing sound).

T: But friction is the opposite of motion, so it should be-

S [interrupting]: So put that.

T: So, not only is something pushing it to the right, but there is something also pulling it down. So what do you think it's path should be?

S: A curve (several students motioning a descending curve).

S: A rainbow.

T: Alright, so, let's check it out. Now, a lot of people I saw tossing it like this [makes a motion]. That would not be a straight across arrow, that would be more of an angled arrow [indicating an angle with his hands]. So I'm going to push it straight across. I'm going to go straight at Gibbs. If this is right and there's one force pushing directly sideways and another one pointed down, you guys are telling me it should go down like this, right? So let's see. I'm going to go straight across.

[pushes the football and it falls to the ground]

Is that what it does?

S: It went straight down.

T: It didn't go straight down - straight down would have been like that [points straight down at his feet]. [By now, Gibbs had picked up the ball again] So Gibbs, push it straight across there [He pushes it but not straight across]. Okay, you kind of threw it. You've got to go straight across - like straight across [pushes it straight across again to Gibbs - Gibbs pushes it back but still gets under it]. No, you're still pushing up. You've got to go straight [pushes it back to Gibbs - Gibbs pushes it back better this time]. Yeah, see, like that. So it goes, and then it goes down. So, this is pushing it to go this way - what's the thing pulling it down?

S: Gravity. LEVEL 1

T: Gravity. So, when you have one that's this way and another one this way, they're both going to affect how it moves.

S: So, the way it goes, the way it's going to be like a negative slope - it'll start and then it'll go down. LEVEL 1

T: Right. Alright, so is this balanced or unbalanced?

S [several]: Unbalanced. LEVEL 1

T: Okay, good, good. Unbalanced. And what was the motion of the football? [pause] Speed up, slow down, stay the same speed.

S: Slow down. LEVEL 1

S: Speeds up, then slows down. LEVEL 3 – series of claims with no evidence

T: Okay we've got speeds up, then slows down.

S: I think it's slow down because, like, when you threw it, you threw it at a certain height and when it got to, when it got to Gibbs, it was, like, (gestures) all the way down, it was slowing down, and it slowed down. LEVEL 4 – series of claims with evidence

S: It was an instantaneous force. LEVEL 1

T: It was definitely an instantaneous force, I can write that right here.

S: Instantaneous forces always speed up and then slow down.

T: Instantaneous forces you said speed up and then they slow down. So let's check it. We've got it slows down and we've got it speeds up and then slows down. Gibbs, I'll need you one more time. Alright, so, what is its speed right now?

S [several]: Zero.

T: Okay. So I'm going to put my instantaneous force on it [pushes the football]. Okay, what does it do?

S: Speeds up and then slows down. LEVEL 1

T: It speeds up and then slows down. Okay. Alright. So, uh, those were our two questions. Alright, cool. Next one. Our last one was our fan cart. And if you got the fan cart right, then you are a master of forces.

[00:47:21.00]

T: Alright, here is my little simple fan cart. Shhhh. Alfonzo, tell me one force acting on this cart.

Alfonzo: The fan. LEVEL 1

T: The fan. Is that going to be a long arrow, a short arrow, or a medium arrow?

Alfonzo: Medium.

T: Okay, you want to draw a medium one. Okay, John, give me another force acting on this cart.

John: The other force was your finger. LEVEL 1

T: Right, my finger was pushing back this way. Now, should my finger be longer than the fan?

S: No, the same because it kept it like, kind of still. LEVEL 2

T: Okay. Okay, what other forces were acting on this cart. Daniel?

Daniel: Gravity. LEVEL 1
T: Gravity's always there. Okay, gravity. Dana?

Dana: The table. LEVEL 1

T: Which one is the table? [she points up] And how should I draw that arrow? Should it be shorter, longer, or the same as this one?

Dana: The same.

T: The same? Okay, so I'm going to measure it. What else? There's one you're missing.

S [a few]: Friction. LEVEL 1

T: Friction. Which way is friction going?

S: That way. It's going this way right there. LEVEL 1

T: It's going against the way it moves, right? So friction would be like that. Now, here's an interesting idea. [pause] I've got two arrows, both pushing in the same direction and there's one arrow over here. Was this cart moving?

S: No.

T: Okay, so we can say the motion was stays the same.

S: It was trying to.

T: It was trying. So, obviously it didn't go up or down, so these arrows are the same. What do you think I should do with these two arrows versus this arrow?

S: Add another one to the fan.

T: If it wasn't moving, right, it didn't go either way - it didn't go to the left and it didn't go to the right. So what do you think these two arrows, how should they be related to this arrow?

S: They're the same. LEVEL 1

T: Like, they should all be the same length?

S: No. LEVEL 3- series of claims with no evidence.

[lots of people talking]

S: Make the fan a medium arrow and then make the finger and the friction two small arrows.

T: So, okay. Would you say that, looking at this picture, that the combined force of your finger and friction together were equal to the fan pushing on it?

S [several]: Yes. LEVEL 1

T: And is that why it didn't move?

S [several]: Yes.

[lots of people talking]

T [addressing one student's question]: You could keep yourself from moving and I could still push you down. [laughing] 'Cause I have more force. Okay, so if it stays the same, and these are equal on these ends and these are equal on these ends, is this balanced or unbalanced?

S [several]: Balanced. LEVEL 1

T: It's balanced. Alright, so let's write down a final statement about what we learned today. Unbalanced forces - and we're going back to our key question - what is the motion of an unbalanced force?

S: None. No motion. LEVEL 1

T: No, that's balanced. Unbalanced.

S: Speeds up and slows down. LEVEL 3 –series of claims

T: Unbalanced forces can speed up or slow down objects. [writing that down] What about balanced forces? Keep in mind our fan cart.

S: I think that balanced forces, uh, speeds up. LEVEL 3

T: You think speeds up? Think of our fan cart here. We said that this one here was balanced. Mark, what do you think?

Mark: Stay the same. LEVEL 3

T: Balanced forces cause cause objects to stay the same speed. [writing that down] Alright, in a minute, I'm going to send you guys back to work on your conclusions and I'm going to come around and pass out your homework. Your homework tonight - in fact I'll pass it out right now -

S: So, after this we have to go back to our tables?

T: Just a second, just a second. [handing out homework]

Alright, listen up please. Gentlemen. Ladies. Let me explain your homework. Alright, when you go back to your seats, I want a conclusion. Now, there are some people in this classroom, um, and I'm going to put them on the spot a little bit, like [name I'm not sure how to spell] and I think it was John and I think it was Mark and Thelma- they have just written fantastic conclusions. Awesome conclusions. Okay, so if you're not sure what your conclusion should look like, maybe you should look over and be like "hey man, help me out here, I'm not sure what mine should look like." What did we do today? Somebody raise your hand and tell me what did we do today?

S: We did a bunch of experiments to figure out if things are balanced or unbalanced forces.

T: Okay, what experiments did we do? Specifically - when I say, "what did we do" -

S: Fan cart.

T: Fan cart.

S: Football.

T: Football.

S: And parachute man.

T: Parachute man. Okay. What were your results? Parachute man was balanced or unbalanced?

S: Unbalanced.

T: Okay. What was the fan cart?

S: Balanced.

T: What was the football?

S: Unbalanced.

T: Okay, those are your results. And what is your final claim? Well, that looks pretty good right there. [pointing to the board] Then, your homework is to complete this sheet. Look at the paper right now as I explain it. It's a little difficult. There's an example with a soccer ball in the middle. You can always look at that but basically this is what you're going to do. Look at the jet. Look at the jet at the bottom corner of the page. It says, describe the motion of the plane. So, looking at the picture, what do you think the motion of the plane is?

S: Speeds up.

T: Okay, speeds up. Alright. It says, describe force arrow number 1. What do you think force arrow #1 represents?

S: The engines.

T: The engines. Is that constant or instantaneous?

S: Constant force.

T: Okay. Describe force arrow #2. What do you think that is?

S: The wind resistance.

T: Wind resistance. Is that constant or is that instantaneous?

S: Constant.

## Appendix K – Lesson Four Transcript

Black = transcript

Red font = coding from 5-point rubric
Green= commentary
**Actual student names replaced with pseudonyms.**
**R=researcher**

(Teacher seated at doc cam writing answers to prelude, which is projected on a screen in the front of the room. Students seated in "elliptical meeting area" formation).

T: So what is my distance for Car #1?

S: 457

T: What is my time?

S: 4 seconds.

T: What will I write in this next box? (Calls on a particular student).

S: Velocity equals distance divided by time.

T: With direction, right?

S: With direction.

T: ______, the next box.

S: I thought speed equals d over t.

T: It's the same thing, but velocity has a direction. It's the same thing, only with direction.

S: V equals 457 meters over 4 centimeters.

T: So, velocity is what?

S: 114 meters per second.

S2: No!

S: Yes!

S3: I got that.
T: (nods head affirmatively as she writes this answer on the doc cam). How about for car 2? My distance for car 2 is … (hands go up)

S: (shouts out an answer).
T: _______, next time you need to be in the meeting area, and you need to wait your turn.

S: Sorry.

T: What's the time for car 2. Alberto? What's the time for car 2?

Alberto: stretches, (inaudible answer).

T: My velocity equals 382 divided by 2 seconds, forward.

S: So, v equals 191 meters per second.

T: Forward. Which car is going faster? Car number one or car number 2? David? Why is car number 2 going faster?

David: Because the velocity number is bigger.

T: Yeh, this number is bigger. So, which car is going to hit first? Which car is going faster?

Ss: Car 2.

T: Car 2. What happens between car number one and car number 2. Raise your hand, don't blurt it out. I know you're excited. Raise your hand. What happens between car number 1 and car number 2? Alberto, what happens between car number one and car number two? (Another student sitting right next to him, claps her hands together and whispers. 'they crash' to him, cupping her hands).

Alberto: They crash?

T: Impact. What does impact mean? They crash. Alright? There is a collision. The energy comes from the collision.

S: What does that mean?

T: So, my receiver…

S: What's collusion?

T: Collision is a crash. My receiver is car #1 because it was going slower.

S: Can we write it right here? (points to a page in her notebook).

T: Now we're going to write the evidence on the side. Watch this you guys. Your teacher is such a cheapskate, she's going to write the answer on the side (turns paper under doc cam to write more on the edge of the paper). Evidence. The evidence- car number one is moving faster so it must crash into car 2.

S: That's all? Is that all?

T: That's it.

(Students writing)

T: This next part's going to involve watching a brief video on my computer, and I really mean a brief video. This is from the Ohio State Police. Each of their car's is equipped with a video camera. It and Indiana. They have video cameras in every single police car there. So, I got some really good chase video and some really good car crashes. They chase suspects, and when they crash, they get it on video. So, just a second here, you can see the newest picture of my kids, camping this summer. This is ____; she's three. That's _____, he'll be 5 in about a month. And _____, she's 5, she'll be six in January. So, those are my babies, that's camping up in Northern California (video of car chase comes up). So we got this car going, nice speed chase. So they go for like 2 minutes. So we've got this minivan who has decided to act the fool and run away from the Ohio State Troopers. Watch, this is when it goes terribly wrong. He's going to swerve over there. Oh no! It's a spike strip! Boom (car crashes into the middle divider).

S; I can't believe it!

T: And he stops. The black thing that you see going back in forth is the windshield wiper, so it was raining at the time. Flip over your paper. Tappers, you shouldn't be at a desk, so tapping shouldn't be an issue right now. So, what is the source if I'm looking at the car smashing into the center median? He hits the spike strip, he overcorrects and lands into the wall. So, the center median. What was the source?

S: The minivan.

T: The minivan.

S: Do we have to copy that?

T: You don't have to copy this (pointing to part of her writing on the doc cam). You have to copy this part (pointing to another section of her writing on the document camera). This is our minivan (draws it).

S: That looks like a trailer.

T: It could be a UPS delivery van for all I know. So, the source is the minivan. What is the energy, Louis? (student has his head down on desk, but is facing the doc cam). What is the energy in this car chase?

Louis: I don't know.

T: So, let's pay attention up here instead of having your head down. What is the receiver? If the minivan was the source, what was the receiver of the minivan? The center median.

S: What is that? (another student motions her hands back and forth along a long line in front of her to draw the center median for her peer).

T: The concrete wall in the middle of the freeway. They're the ones that divide the freeway.

S: What does that say?

T: It says "the center median." So, it is cement up here and up here. And whenever one begins they have a whole bunch of cylindrical cones and big plastic containers filled with water or sand, so that it cars crash into that, they don't die and slash their cars up like they would if they crash into concrete.

S: Oh, I know what that is. (Two girls gesture and speak Spanish, translating what the teacher has just said).

T: What was the energy if the minivan was the source and the center median was the receiver, what was the energy? How is energy transferred from the minivan to the center median?

S: The wheel?

T: Sandra, thank you for having your hand up.

Sandra: The crash.

T: The crash. The energy was the crash itself. That's how the energy got transferred. So, if I want to draw this. This is called an energy diagram. If I want to draw that into a force arrow diagram, there's a different type of way to put this.

So, the force arrow diagram is only concerned with the receiver. It could care less about the source. It wants the receiver. Who gets the energy and how much energy did I get? So, the center median had a really big force hit it. Right? When something gets hit like in a car accident, is that a push or a pull?

S: A push.

T: A push. A push from the van. The center median, does it still look the same after a person has hit it going 100 miles an hour? Does it move a little bit this way (indicates a move with an arrow)?

S: Yes.

T: It moves in a little bit, right? Even if it's a full concrete wall, it moves. This shows you where the energy came from and what energy was transferred. So, it was pushed and moved. Movement from crash. So, it moved backwards, sort of just buckled in. We can represent these with numbers. This can be like 100 Newtons, and this can be like 10 Newtons because it's not as big as the force that hits it. Force is in Newtons, but we're not concerned with the numbers yet. This is your first exposure to force arrow diagrams. By the end of the class period, you should be able to draw these.

S: What do we draw in the box?

T: Nothing. The box is empty. When I made these in college, it was just a circle with an arrow (draws an arrow to the left) and an arrow (draws an arrow to the right of the dot). We didn't use boxes, we used a circle, but I thought it would be easier for you guys to use a square.

S: Because we'll get confused.

T: This is how they will teach you in high school. So, we're going to use what you will need for high school. What do you think is the book definition of a force is? What is the book definition of a force, David? What's the definition of a force?

David: A push. It's like a powerful push.

T: A push or a what? Or a what? What's the opposite of a push?

S: A pull. A push or a pull is the book definition of a force. I also like to add in it's an interaction or event, between two objects. Stop it! How do you draw a force occurring?

Sandra: The arrow showing what's happening.

T: The arrow showing what's happening.

Sandra: And another arrow showing what changed?

T: You guys have some of the best definitions in my classes. Good job.

S: Thank you!

T: All my other classes I had to like pry it out of them. I kept giving them leading questions (students copy down the definitions and notes). Are any of you not going to be here on Friday? I have your Thanksgiving homework already typed and printed. I'll give it to you.

S: When is Thanksgiving?

T: It's next week. Thanksgiving vacation is next week. We have no school all next week, so starting Friday, you have nine days without seeing me. That includes the weekends. Today's lab involves you taking a paragraph description, a paragraph description (points to the paragraph on doc cam), turning it into an energy diagram, and then on into a force arrow diagram. Your homework for the vacation is going to be that. I lost ya'. You've got about a minute left if you cooperate, maybe two, and then you will be at your desks. (To two students): Please move apart from each other, because you can't seem to be able to sit next to each other. _____, come sit over here. Get your chair and move. So, I'm going to show you the first one, so that you can all answer this: "A toy car is placed on a table and a person pushes the car with a medium speed toward the white wall. Another person places a wood block on the table, and pushes it with medium speed towards the toy car. The two objects hit and bounce off each other, and then they stop." (Turns to face ____: Okay, ____you have lost your ability to sit in a chair for right now, so you need to stand up against that couch. If you flip over, you are going to crack open your skull, and I really don't like cleaning up blood off the floor. It's not so much fun.

S: The janitor does it.

T: No, they make us do it. I don't want to clean your blood. I don't want to have to deal with that. Don't lean back in your chair. Okay, back on this. My source, my receiver, and my energy. My source is my car. I am using a big tipped pen because it is easier to see, and I'm writing large.

S: Be quiet, please (Teacher waits with hand on chin for quiet).

T: Your receiver is what? The wood block. The wood block. My energy is what? The crash. You then need to write evidence from the story. What happens? I am writing big so you can see it. The evidence is the car crashes into the wood block causing it to move.  That's how you know it's the source because the wood block moves.

S: What?

T: The car crashes into the wood block and causes it to move. The force arrow diagram. So, what is this square representing, my car or my wood block?

S: The wood block.

T: The wood block?  So, I am going to draw the push from the car.  Remember your talking and goofing around whenever you have questions, because I'm going to skip you.  I already have a list of parents to call next period.  I am adding some names.

S: Am I one of them?

T: No. If the wood block bounces off, there is also an arrow pushing out the other side because it moved, right?

S: You should put the car instead of a box.

T: This is always a block, a square with arrows. It is not a shape, except for a square. This column is always squares (points to right column of paper). This column (points to left column of paper) has pictures.  This column has squares; this column has pictures. (Turns off doc cam). I will be giving you this worksheet plus another worksheet that has your questions to answer.  Your notebooks are sitting in a really good place, on the couch right beside the front door to my house.  I left this morning and just forgot to bring them.  Just thinking of a whole bunch of other things, and I just forgot them. That's why you have a copy of everything today because I felt guilty.

Ss: WHOO!

T: What should this room sound like and look like as I hear you work?

S: We should be absolutely silent?

T: No, not absolutely silent.

S: Quietly- whispering quietly?

T: Quietly, working with your partner.

S: Silently? Whispering?

T: Whisper voices working with your partner. If you get out of control, it's not going to be good. There are boxes up there if you need to demonstrate and see this (points back behind her to stacked boxes with supplies). A lot of you need to see it. You can't picture it in your mind. Go ahead and get a box if you want and go back to your seat. I'm passing out the lab.

(Video skips ahead to lab portion where students are working with the objects from the boxes. Every table opted to grab a box of supplies to demonstrate the movements of the objects in the scenarios provided on the lab).

Sandra and Alberto working together:
(They have set up two clamps with a rubber band stretching across it. As the teacher comes around, Sandra asks: "Isn't your hand the source?" T: Yep. Sandra: And the energy is when it pulls it" (pulls the rubber band back with her hand). T: Yep.

Sandra: (Reads a portion of the lab out loud, then points to a different paper). Okay, we have to do this first. So, the source is the hand (both write this). The hand (waves her hand in the air at her partner and both write again). LEVEL 1 (Sandra pulls back on the rubber band between the two clamps). It's when you pull it. You pull it (pull back the rubber band and both write again). Okay, evidence. So, the evidence is, the evidence is that by pulling (motions a pull with her hand), by pulling the rubber band with your hand, it makes the stretch (motions a horizontal stretch with her hands). I think that's what we put. (Smiles a big grin and shakes her pen against her flat palm to pool the ink). Energy's when you pull it (gestures as she speaks; gesture and speech occur simultaneously) LEVEL 1.

Sandra and Alberto negotiate the text to figure out what to do with the objects of the next activity. Alberto blows up a balloon with a pump.

Sandra: So, this is the object (sets car to far side of her and just push it like, gestures a smooth flat space in front of her). Slide it on the table and push it (pointing to the balloon in Alberto's hand).

Alberto: Like this?

Sandra: So it slides. So, the source is the thing (hits her pen on the pump), the air pump with the balloon (both write), and the energy is the push (slides her hand horizontally across the table), and the receiver is the car (taps car with her right hand; both write in silence). LEVEL 3 (series of claims w/o evidence)

Next scenario with wood block and balloon:

Sandra is attaching balloon to wood block, but discovers it doesn't work due to a hole. Asks for a new one from the teacher, but before they get a new one, she says: Sandra: We don't really need it because we know how it's going to be (moves the wood block into the car), makes a sound as they hit, then says, "that's it.") So, the evidence is that um, the air makes the air puck move (slides a finger horizontally across the table in front of her) and it hits the car. So- (both write again in silence). LEVEL 1

Scenario 5: A person places the wood block on the table and pushes it at medium speed across the table until it hits the sides of the cabinets. The block bounces off and comes to a stop.

Sandra points and gestures a pushing movement into the side of the classroom wall to ask the researcher if that would be okay to use for the cabinet asked for in scenario 5. Researcher reads the scenario 5 above out loud.

Sandra: I think this is the source (holds up wood block)? This is the source (more sure of herself, she taps it with her hand). LEVEL 1 The block is the source (both write in silence). And the energy is the push (she doesn't look up, both keep writing), and the receiver is the wall LEVEL 3- series of claims in succession (no gestures for the last two comments). It is the wall, right? (addressing researcher) because (gestures a hitting movement against the wall with her hands) it hits it, so, it's, the- (continues writing) receiver. LEVEL 2 (claim with evidence) Once you push it into the wall (gestures), it bounces back. (begins to write) Once you push it into the wall, it bounces back. (gestures) The wood block bounces.

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Two female students are working together. One pulls back on the rubber bands between the two clamps. Unfortunately, unchecked by a more capable peer, or teacher, they arrive at a faulty claim.

S1: When you pull the rubber band (reading from text). The rubber band? Okay…(turns to the set up of the two clamps with the rubber band). Your fingers pull the rubber band (pulls the rubber band as she says this), and give it the- (allows the rubber band to snap back into place), the- (looks up in thought) the elasticity-(looks at her partner, then looks away) to (looks at partner and smiles) hit the air. Yeh? (Waits for partner's response) I mean gives it the elasticity (pulls back on the rubber band again with her fingers as she says "elasticity") Yeh. Yeh. (slightly tugs at the rubber bands). So, (writing now) fingers pull the rubber band and gives it, and, gives it elasticity to put back in place. LEVEL 0- only observations of what is occurring are articulated. This is the fingers (drawing), fingers (hears her name called across the room). Que? (in Spanish) Que? The rubber band, elasticity, (looks at her partner's paper). Back in place?

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Sandra and Alberto:

Sandra is moving the wood block back across the table. She is also pulling back on the rubber bands and appears frustrated. She sighs, looks up at the researcher, then goes back to looking at the text.

Alberto: If it's pushed it moves forward, if it's pulled it moves backward (looks at Sandra, as if awaiting approval). LEVEL 0 – only observations are articulated.

Sandra: But it says interactions or event between two objects (looks at researcher). Do you know the difference? (They ask the researcher if she thinks it depends on the problem.

R: Sounds good to me. So, do you think you can tell just from the picture? If I just showed you a picture?

Sandra: No. You can tell when it's in a word problem because it tells you. It depends on the problem. Word problem. Oh no, isn't a word problem for math?

R: No, word problems can be in science as well. It is any problem that is written in words.

Sandra: Thank you. (Reads from paper). Does it matter if the arrow is coming out of or going into the diagram? (points left with a sweep of her finger). In this one? (Points at a specific problem) For a force diagram?

Alberto: I think it is for a force diagram.

Sandra: Does it matter if the arrow is coming out of…(trails off re-reading the text, looks up at researcher and states emphatically): YES! LEVEL 1- claim w/o evidence.

R: You think so?

S: No. LEVEL 1- claim w/o evidence So, if they're both going out (gestures with two hands pointing opposite directions). Out (gestures both hands with pointed fingers going to her right) Oh no, this one's going into it and this one's going out of it, Observations – LEVEL 0 so it doesn't matter. LEVEL 1. It doesn't matter because um (gestures with hands out in front of her) the source hits the um (sways her hands held upright to the right slightly) receiver (holds hands out in front at elbow height) which, it doesn't matter because the source (moves hands at elbow height to the left) goes, hits the receiver, which is going in (moves hands together to the right) and the reaction of the receiver goes out. LEVEL 2 –claim with evidence/warrant (Shrugs). It doesn't matter (begins to write as she says this).

R: What are you saying the arrows meant then?

Sandra: (puts pen down). That, um (holds index fingers extended on both hands and holds hands so that both index fingers point to her left) it doesn't matter, if it's going in, because it's going in when the source hits it, and it's going out (moves hands to her right) when it makes a movement or a change. LEVEL 2 – claim with evidence/warrant (both begin to write again).

R: Good work you guys. Good thinking.

Sandra: (while writing) and then it goes out when the receiver has a movement or a change. LEVEL 1

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Sandra and Alberto attempt to write their conclusion. They appear to be stuck. This must include:

- summary of what you did
- summary of your results
- final claim of what occurred in this experiment
- answer key question (How does energy transfer during a force event?)

R: So, what did you guys do?

Sandra: We did, I think we did…

Alberto: We um, found the source (picks up the air pump) and the receiver, and then um…

Sandra: How did the receiver change.

Alberto: Yeh.

Sandra: I think in this lab, we did events where we know how the source causes the receiver to change (both write this). The source…(writes this as she says it, then stops to read her paper again, twirls her pen). In this lab, we- did events about the source causes the receiver to change. Our results depended on how the word problem was, if either it was pushed or, if either the source was pushed or pulled. LEVEL 1 I think- what's the key question? (Turns her paper over to look for it, then finds it and reads it). What is the proper way to show a force visually? (thinks for a long while at the paper). I know the answer. To show a force properly you show if a source pulled or pushed (gestures up and down for emphasis of push and pull) the receiver, and then after, and after the event happened, you put what changed, how did the receiver changed. LEVEL 1

R: That's the answer to the key question?

Sandra: I think that's it. Now I'm barely- summary of the results (turns paper over to re-read). In my results, in *our* results, we had um, I don't know (shakes her shoulders and tilts her head from side to side, then smiles, and tries again). In our results-

R: What did you find out?

Sandra: We find out how-

Alberto: Each different problem had different, different types of forces. LEVEL 1

Sandra: How each energy diagram goes through a force (claps hand together) LEVEL 1 - how an energy diagram helps (gestures), wait. In our results, we found out how an energy diagram helps you find a force diagram, which in a force diagram (looks up toward ceiling and uses gesture) our results was that, um, either the (taps finger on the edge of the table) receiver was pushed or pulled (slides finger across table), and that caused the change in (taps finger on edge of table) in the receiver. LEVEL 3 – series of claims So, like the results was (pulls on rubber band attached to clamps) the change in the receivers (smiles with surprise on her face). LEVEL 1 Isn't it?

R: So, give me an example.

Sandra: An example is when we pushed the air puck (gestures a push) with the balloon attached and it moved towards the car (gestures a sweeping movement with both hands to her right)- LEVEL 0- observations only.

Alberto: And the air from the bottom made it (touches table and moves hand back toward himself) move towards the car- LEVEL 0- observations only.

Sandra: And it made the car move. LEVEL 1 So- if it would have been a different car, it would have bumped or like something pushed in (gestures a slow push with an abrupt stop) LEVEL 1, so that would be a change because the car would have looked different.

R: And, Alberto, you said something about different types of forces. What do you mean by that?

Alberto: Cause in these forces, not all the forces had the same pull of push LEVEL 1. So for these forces-

Sandra: We had different answers.

Alberto: Yeh, we had different answers.

Sandra: We need to make like a little sense of that (brings both hands together as if to clasp an imaginary ball in front of her to crystallize an idea).

R: Yeh. Good. So, in each example the forces were not all the same? Is that what you're saying?

Sandra: So, I think that (again tapping index fingers on edge of table as she thinks) the answer to that is that in our results, we got different answers.

R: From each other?

Sandra: From each word problem because it had a different source, and a different energy. LEVEL 2 (claim with evidence)

R: And so what did that do to the receiver?

Sandra: It [the energy] changed it? But, um- it changed the receiver. LEVEL 1 I think that's our results! (surprised voice).

R: Did all of your word problems have something in common about the receiver?

Sandra: (looks back at paper) They moved. LEVEL 1

R: Every single one of them?

Sandra: They changed. They had something different. They moved because the cars were moving, and the rubber bands (smacks/pushes a flat hand on edge of table) stretched out (performs a stretching motion with her hands), and then the rubber bands came together (brings her hands together) and we had two cars moving, and then in one of them we had a block bounce off, so- they all changed. LEVEL 3

R: What do you mean by they all changed? What does that mean?

Sandra: They changed their like, their distance (eyes dart from place to place). LEVEL 1

R: They changed their distance? (begins process of providing scaffolding of linguistic objectification)

Sandra: Distance.

R: What changed their distance? The receivers?

Sandra: Well, not their distance, but the um- they changed their- (searches for words, begins to rock back and forth as she contemplates, frowns), yes, no – they didn't change their distance. LEVEL 1 They changed their um- the way they were cuz, if the car wasn't moving (gestures both hands in parallel from side to side across the table), well, what changed was that the car moved. LEVEL 2

R: Okay.

Sandra: And if, um- the um- if the rubber bands were normal and you like stretched it (gestures a stretching motion back and forth in front of her), it goes wider. LEVEL 2

R: Okay.

Sandra: So, it changed their- (long pause) their form of being? LEVEL 1(Begins to twist the rubber bands in tight circles with her left hand as she thinks).

R: Oh?!

Sandra: Yeh! Now, I have to change my answer (Puts her hands to her chin in prayer like formation).

R: This is getting very interesting! So, the receivers changed their form of being?

Sandra: Yeh (expression of pride on her face) Yeh. (Leans back in chair thinking).

R: Well, let's take them one by one. The rubber band-

Sandra: It stretched out (gestures stretch motion) LEVEL 0 – observations

R: But changed it's? What could we call that?

Sandra: Okay, we have a rubber band, right? (removes the rubber band from the clamps and stretches it out). Their size! (Delighted) It changes their size! Because it was smaller (lays rubber band flat on table), but once you stretch it (picks it up and stretches it), it gets like LEVEL 2

Alberto: bigger

Sandra: Yeh, it gets like a little bit bigger. So, for the first one (hold up rubber band) it changed their size. LEVEL 1

R: Okay-

Alberto: The more you stretch it, the more bigger it gets. LEVEL 0 – observations.

R: Okay. And what about the next example? How did that receiver change?

Sandra: (Looks down at paper). It changed because the car was still, it wasn't moving, and all of the sudden when the rubber band hit it, it moved like forward (gestures a thrusting movement forward with her right arm). LEVEL 2

R: Okay, so how did that receiver change?

Sandra: Um-

R: Did it change its size like the rubber band did?

Sandra: No, it changed its distance, and so in the next one it did too, because the air puck moved the car backwards (gestures), so it also changed its distance. And in the fourth one, in the fifth one, (picks up the wood block) when the block bounces the wall, um- it changes the distance too. Because first it's moving, but it stops it, because it has to keep on moving, but then it bounces back, so it changes its distance too. LEVEL 3 (series of claims)

R: Good! So, how can you put all that together for your results, what you found out about the receivers?

Sandra: That receivers changed their size or distance. LEVEL 1 So, my results for – I think I have my sentence. My results for this lab-

R: Good, Sandra! Do you agree with that, Alberto?

Sandra: My results for this lab is that the receiver changes their size or distance depending on how the source with the energy hits it? (begins to write) LEVEL 1.

R: Very good. I'm proud of you guys. That's a very sophisticated answer.

Sandra: Thanks (both write in silence for awhile). My final claim is that the receiver changes depending on the energy from the source. LEVEL 1
R: And how does it change?

S: It changes by moving its position, size, or shape. It's just like the results.

[Afterward, Sandra and Alberto tell the researcher that if they don't know a word in English or can't pronounce a word in English, it is helpful to be able to say it in Spanish. Sandra says: "We help each other out with accountable talk." The researcher asks if it helps to talk in Spanish sometimes and she said yes "because you have more ideas and you can express yourself more."]

## Appendix L – Lesson Five Transcript

Black = transcript

Red font = coding from 5-point rubric
Green= commentary
**Actual student names replaced with pseudonyms.**
**R=researcher**

(students seated in the "elliptical style meeting area," teacher at front with pre-prepared chart paper with notes).

T: What is a force?

S: A push.

T: A push. Okay, what else? Alberto?

Alberto: A pull.

T: What else is a force, besides a push or a pull?

S: Energy.

T: Energy. Okay, I like that. A force is also, so page 88, so a push or a pull, or an interaction (teacher unfolds chart paper to reveal pre-prepared notes on forces and motion). I am trying to save chart paper. It is $1.50 a sheet, so I am re-using the sheet. It's an interaction between two objects. So, everyone should be writing this down under the prelude. Please don't do that in my room. An interaction between two objects.

Ss: (copying the notes from the chart paper).

T: Next class I will not be here. I will be at a conference. This is a science conference. I am coming back to the school with a module kit worth about a thousand bucks that we will be using in the classroom. (Addresses researcher). I need to get you in contact with the Department of Defense contractor that I have as a contact.

R: SPAWAR? Is that where you're going?

T: Nods affirmative.

Ss: When are you coming back?

T: Monday.

T: So, I will be getting stuff for you guys. So, I will not be here on Thursday. I will not be here on Thursday. You will have a sub. Motion- is push related to forces?

S: Do we copy that down?

T: Is motion related to forces? Tell me. Yes. How is motion related to forces? (a student raises his hand). John?

John: Like energy.

T: Energy. It moves. Motion is a push or a pull. (Teacher points to corresponding notes on the chart paper she stands next to). So motion is a movement in a direction. This should be review to you guys. This should be easy.

S: Do we need to copy this?

T: Yes (stands with hands on chart paper). Energy diagrams (unfolds more of the notes). Energy diagrams. You have the source, the energy and the receiver (teacher points at diagram with source and receiver). Beneath it you have your evidence. A lot of you are giving me evidence that is only one word. Your evidence needs to be at least two sentences. When you give me supporting evidence for a claim it should be two sentences. At least! Force arrow diagrams (points to chart paper). You have your cube, your block. You have arrows either coming into it or going out of it (gestures arrow towards her body and away from her body).

S: Do we copy the evidence too?

T: (Teacher nods).

S: Duh.

T: You have arrows going into it and going out of it for force arrow diagrams. Just to remind you of concepts we learned before we left.

Ss: (copy notes for a full minute in silence).

Video skips ahead.

T: (holds up a sheet of paper.) Situations. It tells you, it gives you an example of something that is happening. Like a jet engine on the bottom of an airplane pushes the airplane up. You are going to use that situation to create a little mini

poster. I'm sorry, all I've got is light pink paper. I'll put in another request for colored paper tomorrow. You're going to create a poster. That poster is going to include your situation, (points at instructions on easel chart paper). You're also going to include an energy diagram, with your source, the energy, the receiver, and evidence. The force arrow diagram with the square and the arrows coming in and out of it. A description of the force. Is it a push or is it a pull? Is it a constant force or is it an instantaneous force? So, Alberto, come here.
(Alberto comes to the front of the room). A constant force is this…(pushes student around the periphery of the room). Constant force. Instantaneous force (pushes student once).

S: Oh, constant force is like…

T: Always happening. Instantaneous is one instant. Instantaneous is for a split second (snaps fingers). Just for that moment (snaps fingers). Constant force occurs for a distance or for a period of time. Me nagging you about your notebooks being awful is a constant force. Instantaneous force is when your parents see your progress report and go, 'oh, you're failing. Why? You're failing, you're grounded – that's an instantaneous force.

S: It's like often?

T: Constant is all the time. Instantaneous is just for a moment. It's just for that moment.

S: You could start with like (gestures with her finger around the periphery of the room).

T: So, constant force is me pushing Alberto around the room, and instantaneous is me shoving Alberto (uses a gesture to show shoving).

S1: What? Say it again?

S2: Constant is like when she pushed Alberto a lot, asi…(gestures around the room).

T: keeps on going. Gravity is a constant force. It happens all the time-

S1: Gravity? (student writing quickly)

T: Gravity. We can't get away from it unless we go out into outer space.

S2: and instantaneous is like fast, like that moment, pushes hand out quickly in front of her).

S1: Do we copy that in page 11?

T: So, you don't need to copy this down. I'll be giving you the situation. I'll be giving you the poster paper. When people go to their seats, you're going to work in groups. Your quiz is going to have 14 different situations. You will get one of these 14 situations as your quiz. Question for you to answer. So, if you pay attention in class today, you will have no problem on this quiz. You don't pay attention, you're going to have a problem. On Thursday, that quiz will be the last 20 minutes of class time. You're going to do a lab and then you are going to have a quiz.

S: Only 20 minutes?

T: You are going to have 20 minutes to do it. You're going to get about a half an hour to make your posters in class today, and we're going to take a half an hour to present. Are there any questions?

T: (Slams a book in front of a student). YOU! Don't fall asleep in my classroom again! (students laughing) Put your head up (to the student previously sleeping). Go back to your desks. I'll be passing out your situations.

(video skips ahead after the students have worked on the explore portion ---jumps ahead to the evaluate portion)

T: When someone is presenting you are not talking, you are not doing anything else. You are giving them your undivided attention, your eye contact. These are the questions your quiz is going to come from. Go!

S: My situation is, Eddie Guerrero lived….and hold him there. It's fine. My source is Eddie Guerrero, my energy is the lifts, and the receiver is Eddie carrying- lifting the- My evidence is the source is lifting the receiver and is making it stay there. I don't know how this is called (points to force arrow).

T: Force arrow.

S: My force is the arrow going this way.

T: Why is it going that way? (Am I pushing this way or am I pushing this way? (Motions with hands and arms in air).

S: Up.

T: So why are your arrows that way?

S: I don't know. I am going to change them.

T: Well, see, that's an important thing. Your arrows go in the direction of the force. Up (motions up with pen in her hand). This is a learning process here my friends.

S: This situation is a constant, (looks back at paper), a constant, because he keeps on lifting (motions with right hand up) and he don't move him, so he keep on going.

T: Yeh, if he doesn't hold him constantly, he's going to have the poor guy topple in on him. Leave it on the doc cam.

(Students applaud)

T: We're going to get all these done in the next five minutes, so…

S: hurry up,

T: Go! C'mon Romero. Read it out loud. (reads off of paper, teacher tells him to put it on the doc cam- no discussion) Yep, thank you very much. Put it down. Next student. Go!

S: My situation was a boy who is pulling a wagon for thirty minutes straight. The source is the boy. The energy is pull. The receiver is the wagon. (Teacher directs student to show his poster to the class). It is a constant force because the boy is (looks back at poster) holding onto the wagon.

T: There is a lot of disrespect going on during these presentations. Your chairs should be down, you should not be whispering. You should not be rustling your own papers. It doesn't feel too good when you're trying to present, does it?

S: It is very disrespectful.

T: It's really hard when you're trying to present?

S: Yes.

T: So you should be done with your posters by now. You need to put the markers away, in the box. Meet in the circle, and we need to stop the whispering. When you present, you hold your poster in front of you, and you're not looking down at it (hides face in paper she is holding). You should know what you said on that paper. We need to see it (models turning paper around to face the front). Okay? Some tips. I'm going to have you all trained on how to present a project by the end of the semester. And it will be no big deal. (Asks a student to go next.) Go now. (The student says he is still working on his.) Alberto is going to go last because he is still working on his.  Oh, you're still working. You've got two more people.

Ss: Woo hoo.

S: The energy diagram, the source is the slingshot, the loss is the energy, the target is the receiver.  The evidence of this is the slingshot gives evidence to the motion to the target. And, the force arrow diagram, the arrows go here (points).  It is instantaneous because is not holding it there all the way. LEVEL 2

T: Yeh, it just hits it for a split second.  Thank you, _______.

Next student gets up to present.

S: My thing is water in the river is pushing against a rock in a river.  My source is the water, The energy is the waves (makes a metaphorical gesture with hands). The receiver is the rocks. My evidence is the source, or the water, is moving the rock in the center of the river. It's a push because the water pushed the rock into the middle.  It's a constant force because it keeps on going on, so. LEVEL 2

T: Good job.

S: My situation is a construction worker slides a piece of construction paper across a piece of wood, and my energy diagram is that the source is a construction worker, and the energy is muscular strength and the receiver is a piece of sandpaper. The evidence is that the construction worker pushes the sandpaper across the piece of wood. For my force arrow diagram, I drew it like this because the construction worker pushes the sandpaper, and yeh. I believe it looks like that because it goes back and forth (moves his paper back and forth), and so for the first question you wrote up there, description of force if it is a push or pull, I put both because he has to go back and forth to make the wood move. I think it's a constant force because, well, a constant force has a pull and has a push, because it switches off, and they go back and forth, so.  LEVEL 2

T: So they're going constantly back and forth and back and forth?

S: Yeh, you can't do it instant, like (motions with a push of a paper on a flat surface).  You have to go, (moves paper back and forth with his hands).

T: Yep.

S: (whispers). That's not a constant force.

T: Okay, next (calls a student by name).

S: My leg's broken.

T: No.

S: My diagram is how a car speeds up from 30 miles per hour to 50 miles per hour. The force arrow diagram shows how if you constantly keep your foot on the gas pedal, the car keeps going constantly with constant energy.

T: Very good. (Begins to call on individual students by name). I'm going to all the people who weren't done now.

S: My situation is a jet engine above an airplane pushes the engine forward. The source is the engine blowing fire. The receiver is the airplane. This is a push act because the engine blows the fire back but the airplane continues to move the forward. The force arrow diagram is going forward. The evidence is there are two engines, the one underneath the wing helps the plane stay in the sky. The one in the back blows invisible fire backward.

T: Very good. Next.

S: My situation is a lazy man sits on a couch and pushes a button on his remote control. The source is he is sitting on the couch, pushing the remote for the TV. His energy is his thumbs. My receiver is the remote control. It is a constant force because it is going forward (moves finger forward).

T: Yes, thank you. Next.

S: My situation is four boys pulling a rope attached to a donkey. My source is the four kids. The energy is the pulling from the four kids. The receiver is the donkey. My evidence is it is a pull because the boys are pulling on the rope, and it's a constant force.

T: Good. Thank you very much. I am very proud of you all.

(Class is interrupted by an announcement by Director of school).

S: YES! (realized there is no time for him to present).

(Teacher takes the poster from the last student presenter and walks around with it on the inside of the circle. It is not in front of any student for longer than about a second.)

T: Your homework. I'm going to pass out your homework. This is what it looks like (shows paper to class). In the first column, you need to state whether this is a constant force or instantaneous, second column you're going to need to say why.

This is going to go in your notebooks on page 89. While I pass these out, I need you to pick up every single little scrap of paper that's on the floor.

## Appendix M – Lesson Six Transcript

Black = transcript

Red font = coding from 5-point rubric
Green= commentary
**Actual student names replaced with pseudonyms.**

T: ____, what's friction? You had your hand up first.

S: A source of energy?

T: A source of energy. Okay.

S: Oh, it is?

T: No, you say what you think it is because he might not be right. What do you think it is?

Alberto: (Consults two papers in front of him). It's a force that pushes me in an opposite way?

T: Ooh! A force that pushes in the opposite way. Wow! You're smart and you're right.
So today's activity involves all sorts of balls (takes out a plastic bag of the lab materials), and it involves astroturf and all kinds of other fun stuff. We have big balls.

S: That looks like a croquet ball!

T: We have footballs (holds up different balls), a racquetball, soccer ball. I got a basketball around here somewhere too.

Ss: loud chatter.

T: I'm sorry. I'm teaching. You're not talking. So, if we take a ball, like this tennis ball, and we cut it in half, the inside of this tennis ball is hollow. Everybody see that? (sets tennis ball on doc cam). The inside of the tennis ball is hollow. Here I have a softball and a baseball (shows them, also cut in half, walks around the inside of the elliptical meeting area). So, are these two made of the same material?

Ss: Yeh!

T: Well, what about this one? Is that the same as this (holds up two more kinds of balls cut in half). This is a little league ball. It's got like a wooden core, with a bouncy ball around it. So, little league balls are different from major league baseballs. It's got more bounce to it, so you can hit them out. (Sorts through plastic bag of materials and pulls out another ball part, holds it up). What is that?

Ss: A basketball.

T: A basketball.

S: Oh, that's sick right there.

T: Soccer ball (holds up another one). Inside (holds up both) the basketballs and the soccerballs are the same.

S: Air is the reason they bounce. LEVEL 1 (ignored by teacher)

S: Is that cut up right there?

T: Yes, (walks over so the students can see the objects better). Here's the inside of the racquetball (holds up), squishy and hollow (puts under doc cam). You guys can see that. These are actually the materials that I got from the conference that I went to just the other day.

S: You went there for science?

T: I actually went there for science. Amazing. They were nice enough to give us the materials, so let's listen. Pull it together. I know it was a rough start before the class began, but I know you can be the perfect students. I'm going to do a shared read on friction with you (turns to doc cam), then we're going to do a lab activity. Please do not write on your reading, because I am trying to be a cheapskate and not make more copies of it. "Friction in sports." Everybody should have it open and be looking at it right now. "Friction in sports." (Waits for quiet). "You are seated in an ice arena, watching the sport of curling, a new Olympic event. A player steps across the ice and slides a smooth 42-pound, granite stone down the ice toward a target. So, there's two people. They have a big circular (points and circles with her finger around the picture of the granite stone) stone, and they are sweeping right in front of it with a broom. It's actually an Olympic sport. His teammates jump into action with brooms. They sweep the ice that lies in the path before the stone. Without touching the stone itself, they make the stone slide farther and farther and cause it to veer to one side until it finally comes to rest closer to the target than the opposing team's stones. Victory." Why are they sweeping the ice back and forth?

S: So, it will keep on going faster? LEVEL 1 – Claim= the team is sweeping the ice back and forth so the stone will keep on going faster.

T: So, the stone will go faster.  Why?

Sandra: (hand is up).
T: Sandra.

Sandra: So the ice is smoother (gestures a flat surface with her hands). LEVEL 2 Claim= the team is sweeping the ice back and forth so that the stone will go faster because the ice is being made smoother by their actions (co-constructed with use of student gesture and teacher prompting).

T: So the ice is smoother?  Is the ice sort of melted or is it just, or are they brushing off the dust?

Sandra: They're brushing off the dust because when they skate, there's like bumps and stuff. LEVEL 0

T: Are they brushing out all the bumps?

S: Yeh.

T: Are they melting some?

Sandra: (Shrugs).

T: You don't know.

S1: Yeh.

T: Yeh, you think so?

S1: Yeh, because the water like makes it slide (gestures a flat surface and sweeps his arm across in front of him). LEVEL 2- The water makes the ball slide, so therefore the ice must be melting (co-constructed with gesture).

T: Okay, let's keep reading and find out.  "As you know from experience, the force of friction slows down moving objects, such as gliding skaters." Exactly what Sandra was just saying. "… flying balls, and rolling wheels.  The amount of friction between two objects depends upon the surface of each object." So, the amount of friction between two objects depends upon that surface.  So, I don't have very much friction up here.  I can go like wheee (slides her own chair towards another student's chair). I can go on carpet (has to work harder to slide her chair). I can't go very far.  There's no whee factor. "There's more friction between your shoe and a concrete sidewalk than there is between your shoe and a patch of ice, and therefore your shoe slides more freely across the ice.” Hard for you guys to see that because we live in San Diego and it never freezes. But, how many of you have been to the ice rink (one student raises his hand).  It’s slippery, right?

S: Ah huh.

T: “In the sport of curling, players use their brooms to control the amount of friction between the stone and the ice. Curlers produce heat through friction by sweeping their brooms against the ice.” So, they’re sweeping their brooms back and forth (gestures sweeping/pushing movement), back and forth, back and forth, back and forth. Getting rid of all the bumps (gestures a level surface) and melting the ice some.  “This heat causes a thin layer of ice to melt. The resulting layer of water reduces the friction between the stone and the ice.  Therefore, the stone travels farther.  The friction of one body against another is called kinetic or sliding friction.”  So, if you’re sliding (gestures a flat sweeping hand) on water or ice or even on snow (continues to produce flat sweeping gestures) it’s kinetic. Just sliding friction.  There’s two types of friction. We’re only going to be studying kinetic because, do we have ice?

Ss: No.

T: No. We live on the beach. Rolling friction.  This is something we can actually study in this class because we have no access to ice. We have access to all types of things warm.  “Rolling friction is also important in sports.  Rolling friction is the force that resists the movement of any rotating body in contact with a solid surface. Take a golf ball cutting across the green.  The greater the friction, the shorter the distance the ball can roll before coming to a halt.” So, if I try to play gold in really long grass, is my ball going very far?

Ss: No. LEVEL 1 Claim- ball will not go far in long grass.

T: What if I have really, really short grass, like my carpet (points to meeting area carpet). Is my ball going to go very far?

Ss: Yes. LEVEL 1 Implicit Claim= The ball will go far on short grass, but then the teacher supplies all the rationale in her explanation below.

T: Yeh, it’s going to keep going. “On a golf green, on a golf green, the condition of the grass can have a major effect on how well the golfer plays because the type of grass, how densely it is packed, and how short it is, determine the amount of friction between the ball and the green. The golf course at Torrey Pines?  Their grass is like this (gestures a width with thumb and forefinger).  This short, and dense.  Really, really short grass, because normal grass is like that wide (gestures again). Their grass is like this long (gestures), and really, really densely packed. You cannot count how many pieces of grass there are if you pull it out. Whereas, at my house, my grass is really long, especially now because of the rain. At my house, you could count how many pieces of grass there are if you pulled it out from the ground. My grass is really long, especially since it rained, my grass is super long. “How densely it is packed together and how short it is cut determine the amount of friction between the ball and the green. This in turn affects how fall the ball can roll. On a firm green, a softly putted ball can roll a long way. The same ball put on a softer green might stop several feet short of the hole. For this reason, green’s keepers help golfers by measuring the speed of the green with a device called the stepmeter.” Did you know there is actually someone who gets paid to see how fast the green is?

S: How much they get? A million?

T: No, they get paid a salary. At Torrey Pines they have two. “To do this, the green’s keeper rolls a ball down to the green and measures how far the ball rolls across the green before it stops. In this activity, you will be using a similar procedure to test the rolling friction between a ball and a variety of surfaces.” I am going to set up four tracks in this room in just a minute. Four tracks with four different surfaces. There’s three of you which is you don’t stop talking you are going to get negative consequences from me immediately. STOP TALKING! You’ll be given 5 minutes to read the following pages. You need to read these two pages (holds up which ones). I’ll be calling you back up here in just a minute, and we’re going to be doing the lab together. Why are you moving and why are you talking? We’ll be using a test ramp (holds up) that is marked. It is going to be sitting on top of books, and then we’re going to be rolling across one of these surfaces. This is a nice piece of foam (places foam on top of the books and marker that make a ramp-surface for the foam to sit on). It’s going to be rolling across the foam. Or, rolling across a piece of astrotruf (takes out the astroturf). This is real astoturf from a real playing field- real astroturf.

S: Where’d you get that?

T: I was given it. Or, a piece of heavy duty styrofoam. Everybody listen up. It’s very durable, hard. Or, a piece of indoor-outdoor carpet. Very different from that astroturf, right? (A student reaches out to touch it). Because if I hold up this, and I hold up this. Anybody notice the difference? The astroturf is a lot thicker- big difference when you land on it. We’ll be doing this in a very controlled environment. Each group is going to get a different ball to test on our different surfaces. We’ll be combining at the end of class to get class data. You’ll have two data tables for this. I need to see your best behavior, okay? Go back to your desks. Please read the two pages.

(Video skips ahead to after students have read their directions. In the next section, they prepare a data table with their teacher. Students are seated in the group table formation, not in the “elliptical meeting area”).

T: I need you to fill in part of your data table- the data table for rolling friction. The first one you are writing the Styrofoam pink. Second, write foam. That’s the yellow stuff. Indoor-outdoor carpet. Astroturf. Astroturf.

S: What’s the third?

T: Indoor-outdoor carpet. I want you to write down your prediction on how far you think your ball is going to roll on each four of these surfaces in meters. This is one meter (holds up the meter stick). You’re going to write that down right here. Everybody needs to write their four right here right now (shows where to write on the doc cam). How far do you think it’s going to roll in meters? Write it down (teacher circulates around the room as students write). Write down how far you think it is going to go. Next part. I have made a line on each ramp 40 centimeters above and they’re all stacked up don top of three of our beautiful science books because you know that’s what we use the books for. We never look at them. So, you’re going to write right here (points on doc cam) 40 centimeters, 40 centimeters, 40, 40. It’s the same for all of them.

S: All of them?

T: Um hum. Next, it says for you to measure the length 5 times. You can’t do that. We don’t have enough time to do that and get done with this lab. So, we’re going to do it 3 times. You’re going to roll it down 3 times, and get 3 separate times with 3 separate distances. So, if you need a box, you can (drawing a box to put answers on doc cam). You don’t have to. I’m just doing it on here. So, you’re going to take your ball, get rid of the meter stick (picks it up and puts over shoulder) and roll it down your surface (models). I wish the styrofoam was larger. It’s not. Now, I’m going to measure how far my ball rolled. One meter. I am using my handy-dandy finger. 175 centimeters. Then I do that again, and again. And then I will tell you when we switch stations.

S: Are we going to put the centimeters?

T: Yes.

S: Centimeters or meters?

T: Centimeters to convert to meters. So, 175 that would be 1.75 meters.

S: Okay (nods head, not clear she understands. It is clear she doesn't understand when she is measuring during the lab and asks for help converting the centimeters to the meters).

T: This will be a timed activity. I am going to assign you where you are going to go, and I will tell you where you are going to go next. We have 4 stations and we have one, two, three, four, five, six, seven groups. Three little stations are going to have two groups at them. You'll get along (nods head up and down, proceeds to show each group where they will begin). Get started. So each group needs to use their own ball and record on their own data table. You should have one roller, one measurer, and one recorder.

(Video footage shows student measuring, calling out numbers; teacher tells when to rotate stations and handles disruptions, telling students to be patient, etc…)

After explore:

T: When you are done, you need to look at steps seven and eight. You have to take an average of your numbers. I want you to put your data table there, calculate your averages, and write your observations (to Alberto seated next to Sandra at their work table).

(Video shows some students seated at their tables working, some finishing up the lab).

Sandra: How do you do this? (to teacher)

T: So, you're going to take all these numbers, add them up, and divide by the number of trials.

Alberto: Do we put it in meters?

(Video skips ahead to all students seated at their tables, teacher seated at doc cam).

T: Your average distance per surface- you should have added these three (indicating with her pencil on the doc cam) numbers together and divide by three to get it. Your other observations are your physical observations of how the ball rolled across the different surfaces. Like Louis and Ahmad noticed that on the styrofoam their ball rolled super fast, it could roll forever if it was all styrofoam. But on the floor, their ball hardly rolled anywhere, because their ball was heavy. Their ball was heavy. Why are you talking? Look up here. Observations go here (indicates column on doc cam). How is your ball physically rolling across? In just a second we are moving onto the class data. We're going to take everybody's information on three surfaces and the type of ball, and how far they rolled, so we will be able to graph it. So, if you're done with this, just chill for just a second.

S: How do we find the other observations?

T: What three surfaces do you guys want to use? The pink styrofoam, the foam, the indoor-outdoor carpet, or the astrotruf?

S: The pink, the foam, and the astroturf.

T: Pink, foam, and astroturf? Who all agrees with that? Who wants me to use the pink for the class data?

S: She only said that cause she likes pink.

S: Oh, my gosh. Pink-

S: Hey, what's wrong with pink? Hey, what is wrong with pink?

S: Shut up.

T: Stop saying that. So, you should all be filling in your second data table like mine is. Group one, what ball did you use? Tennis?

S: We're using pink, foam, and astroturf.

T: So, everybody should be starting to fill in their second data table if they're done. Table two? The softball?

S: We used the two-pound ball, whatever that is. Is there something funny (to another student).

S: No, I coughed, fool, I'm sick.

T: Sandra, what ball did you guys use?

Sandra: Um, I don't know.

Alberto: The one that if you throw it hard, it doesn't go-

T: Oh, the whiffle ball?

Eduardo: Yeh.

T: With the holes? It's called whiffle- W-I-F-F-L-E.

S: Wiffle, wiffle.

T: And you used the bocce ball, Louis.

S: Bocce?

T: Yeh, they're lawn bowling balls.

S: Bocce.

T: I use them on the beach. Eddie, what ball?

Eddie: Golf.

T: And you guys used soccer.

S: What was number 5?

T: So, I figure all of you can write in the surface texture of the ball. Does everybody know what all these balls look like? Does everybody know what everybody's else's balls look like from just doing the lab?

Ss: Yes.

T: Yeh, I think so. The bocce ball, by the way, is 2.75 lbs. It's heavy.

S: It's the yellow one.

T: Yeh (nods head affirmatively).

S: The one I had.

T: So, I'm going to go through every group and I'm going to ask you what was your average distance for your three different surfaces, and I'll fill in the appropriate spot for each one, and if you pay attention- B- o –c-c-e.

S: Do we write 40 centimeters?

T: Yeh.

S: 40?

T: 40. All the way down. So, what was your average surface on the pink surface, Omar?

Omar: 1.04.

T: 1.04. On the foam?

S: 1.7

T: On the Astroturf.

S: 0.25.

S2: Um, 1.19

T: 1.19

S2: 66.6

T: So, was it .66 or did it go 66 meters?

S: 66.666

T: So, it’s .66 meters.

S: Oh, so, no it says 66.666

T: If it went 66 meters, that’s about (points across to back of room) to Ms. [teacher name redacted] room.

S: I don’t know. That’s what it says.

T: Centimeters. So, that’s .66 meters.

S: Oh, so it’s .66?

T: Astroturf?

S: 73. Oh, no. .86 (student comes up to the doc cam to give the teacher, who is using a golf pencil, an eraser).

T: Thank you for the eraser. I have no eraser. Sandra or Alberto, are you ready? On your pink, what was your number?

Alberto: 1.54

T 1.54. Wow, it went really far because yours was very light. On the foam?
Alberto: 1.75?

T: And their numbers are right, because I was chasing the ball for them.

Alberto 1.02

T: What was it?

Sandra: 1.02

T: 1.02? On the pink, boys in the back.

Louis: Who me?

T: On the pink, how far did it go?

S: 197 meters?

T: 1.90? On the foam?

S: 50.62 centimeters? Wait, is this the average?

T: Yeh.

S: Oh, um

S: Oh man!

T: So, we'll come back to you in a minute when you've got it.

Louis: No, I got it, I got it. Which one?

T: We'll come back to you. Get all your averages and we'll come back to you.

Louis: No, I got it.

T: Oh you got it? Okay, what was your average?

Louis: 190

S: No, it wasn't.

Louis: 190!

S: Cause we got – how could it be 190.

Louis: It's 190, man.

T: Okay, the foam?

Louis: 55

T: What was it?

Louis: 55.

T: .55? On the astroturf?

Louis: 158.

T: 158? So, the golf ball. On the pink foam, how far did it go?

S: 57.

T: .57?

S: Yeh.

T: On the foam?

S: (inaudible)

T: 1.84?

S: no, 84.3

T: It went 84.3?! It went to my car?! (students laughing)

S: 184!

T: Astroturf?

S: .40

T: And how about my soccer ball friends?

S: Okay, for the pink Styrofoam, 1.79.

T: Foam.

S: 1.67

T: And, astroturf?

S: 1.25

T: So, which surface seems to have the least amount of friction? Which surface would you say has the least amount of friction? (Jovan's hand goes up) John?

John: Pink Styrofoam. LEVEL 1 Claim = The pink styrofoam surface has the least amount of friction.

T: Pink Styrofoam. Why is that?

John: Because everybody's average is the highest of all of them. LEVEL 2 – claim with evidence.

T: Yeh, but why physically is this the fastest surface to roll across (finds the pink Styrofoam and brings it to the front for all to see).

John: Because it's hard (touches it) More evidence

T: It's hard (pounds her hand on it, pounds it against the front of her face). So, what was the next in our little choice, the next easiest to roll across?

Ss: The foam. LEVEL 1- Claim made, but this claim is not true for all groups.

T: You guys said the foam, but Louis, was foam the easiest for your ball to roll across?

Louis: (nods head no).
T: Because notice what happens (takes the foam back out and lays it out in front of the group). Here's my foam. (Takes out bocce ball). Here's Louis's ball (drops it on the foam surface).

S: Ooh, that thing went straight through. LEVEL 0 – observation.

T: Yeh, it's heavy. So, is foam- if the object is heavy is foam good for friction? Does it provide a lot of friction? Is this why we wrap up all our collectibles in foam?

S: Roll it! I want to see it!

T: I'll roll it. It doesn't go very far. (Tells students the answer without allowing them first to observe the re-enactment themselves)

S: It doesn't go! LEVEL 0

T: (rolls yellow bocce ball across the foam surface for the class to see). See, it stops. (does the perceptual objectification for the students) Now, the lightest ball (takes out the wiffle ball and rolls it across the foam). There. The wiffle ball keeps going. (again, states what is occurring for the students, rather than allowing them to use their own language to talk about what they are observing). You can use this data. Excuse me- you're going to use this data to answer the questions on the last page of the lab. I'm going to give you a copy. You may read the last page and start copying them.

S: Do we do it right here or do we do it in our notebooks?

T: In your notebook. Your work will need to be glued in. I have them copied (holds up copies of the questions from the lab for students to write on and glue into their notebooks).

Sheet the students are given reads:

*Interpretation of the Data*

1. Which surface allowed the ball you used to roll the farthest? Which surface most impeded your ball's motion?
2. How do your data compare with those of your classmates? For all the different kinds of balls, was there one surface that allowed the ball to roll the farthest? Was there one that most impeded the ball's motion?

Did some balls roll farther along some surfaces than other balls did? Which ones? Which types of balls stopped rolling soonest? Summarize the class's data in a few sentences.

T: This goes on page 101. I'm going over the questions on the board (teacher sits in chair next to the doc cam). I'm going over the questions- everybody, listen up!

S: Do we have to write the questions down?

T: No, I just gave you the questions. You knew it. You were just saying it "Do we have to write the questions down?" (mimics a silly voice) Okay, listen up. We're going to go over it. I'll wait. I'm patient. Sort of.

S: Be quiet!

T: (reading from doc cam) "Which surface allowed the ball you used to roll the farthest?" So, you're going to describe why that is. "Which surface most impeded your ball's motion?" What does impeded mean?

S: Like- provided!

T: Nope. (Stands up and walks over to a student and pushes him in the back). I impede Alberto by telling him, ‘stay in my class, you’re not allowed to go.’ (Puts hands on Alberto’s shoulders and holds him down in his seat). When you impede something you slow it down, you stop it, you tell it no. It does not move, it stays put.

S: On what page do we write this?

S: It’s the opposite of move.

T: Your data-

S: I can’t wait ‘til this class ends.

(Lots of student chatter).

T: Which surface slowed it down? Stop boys. I’m sorry. Come up to the meeting area.

S: Oh my G-d!

T: Meeting area, c’mon. Boys, stop. (students begin to form the “elliptical meeting area”). 19, 18-

S: Hey, you’re not in the meeting area!

T: Which surface slowed your balls? (Points to question on the doc cam. Students now seated in the meeting area). Number two, “How do your data compare with those of your classmates?” So, that’s where you’re going to use that class data table. “For all the different kinds of balls, was there one surface that allowed the ball to roll the farthest? Was there one that impeded the ball’s motion? Number three, did some balls roll farther across all surfaces than other balls did?” Did some balls roll farther regardless of the surface? You have to look back at that class data. Which ones? “Which types of balls stopped rolling soonest?”

S1: The big ones. LEVEL1 Claim- the big balls stopped rolling the soonest.

T: So, “the big ones” won’t be a complete enough answer.

S1: The heavy ones! LEVEL 1 Claim- the heavy balls stopped rolling the soonest.

S2: The bocce!

T: Guys- the heavier, larger, more dense balls. Teacher tells them the answer.

S1: Where do we write this?

(Students chattering)

T: Wait just one second!  This is ridiculous!

(Teacher goes over all the questions aloud.  No student discussion. Labs and calculators to be left in center of desks).

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