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Free to Explore a Museum

Embodied Inquiry and Multimodal Expression of Meaning

A dissertation submitted in partial satisfaction of the requirement for the degree of
Doctor of Philosophy in

Cognitive Science

by

Nancy Owens Renner

Committee in charge:

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2013

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The Dissertation of Nancy Owens Renner is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Co-Chair

Chair

University of California, San Diego

DEDICATION

For my mom Rita, one who inspires perseverance, adventure, service and loving kindness.

EPIGRAPH

“...the native and unspoiled attitude of childhood, marked by ardent curiosity, fertile imagination, and love of experimental inquiry, is near, very near, to the attitude of the scientific mind...”

John Dewey, 1910

How We Think

TABLE OF CONTENTS

Signature Page	iii
Dedication.....	iv
Epigraph.....	v
List of Figures.....	xi
Acknowledgments	xviii
Vita.....	xx
Abstract of the Dissertation.....	xxiii
1 Free to Explore a Museum.....	1
2 Relevant Literature	19
Defining cognition: Distributed and integrated.....	21
Active perception: embodied, situated, enculturated	23
Cognition in interaction.....	27
Language as tool.....	30
Gesture, thinking with the hands	33
Relationships between perceptual and conceptual	36
Museums, engagement, and learning	41
Models of learning and educational theory	44
3 Research Methods	56
Seeing cognition in action	56
Making sense and making meaning in a multisensory museum	57
Methodology provides structure and discipline for observation	58

Primary data — Video data collection.....	61
Video perspectives: First and third person	63
Lessons learned about recording video	65
Mixed methods applied to an exhibition case study.....	67
Quantitative Analyses	68
Qualitative Analyses.....	68
Secondary data — Coding the video	69
The foundational multimodal coding scheme: Look, Touch, Talk, Gesture	70
The coding scheme and iterative development.....	75
Lessons learned about coding video	76
Organizing and interpreting the coded video	78
Observational research, division of labor, and professional vision	82
Appendix 3A: Exploratory Phase: Coding Scheme #1.....	88
Appendix 3B: Descriptive & Explanatory Phase: Coding Scheme #2, Multimodal Engagement.....	89
4 Free to explore the nature of objects	95
Multimodal engagements with concrete exhibit-related speech	98
Object-oriented engagements and cognitive functions	101
Children ask <i>What is it?</i>	101
Children ask <i>Is it a _____?</i>	106
<i>Sabertooth?</i>	107
Children name and describe objects.....	111
Fossil shells, teeny, tiny shells.....	112

A very big whale	119
Children classify objects	123
A fake sea cow	125
California Condor, dead and real	126
A horse fossil: male or female?	130
Enculturation in museum practices	132
A lesson on how to read the museum: real or fake	132
Real dinosaur eggs?!	133
A clash of classification schemes	134
Children evaluate museum objects	139
Positive affect in the museum	141
Evaluation, enjoyment, imagination	142
Consequences of observation	143
Appendix 4A: Coding Talk.....	146
5 Taking action in the museum.....	149
Using hands for exploration: Forms and functions of touch and manipulate	152
Forms of hand actions.....	153
Functions of touch and manipulate	162
Using hands for expression and exploration: Forms and functions of gesture	175
Using the voice for action: forms and functions	180
Forms of action-oriented speech	180
Functions of action-oriented speech	180
Exploiting resources, coordinating modalities, emergent functions.....	183

Emergence of function	187
Children demonstrate	188
Children show and interpret	190
Children test cause and effect	194
6 Processes of representation and making meanings with things.....	203
Functions of concrete/abstract speech	206
Children name objects as representations.....	207
Are museum objects real or fake?	213
Children describe relations.....	214
Children link the present with memories, projecting back in time	220
Children use museum objects as springboards for imagination	221
Children imagine possible futures.....	223
Children create alternate realities	226
Children make meaning by making sounds	229
Using the hands and voice in acts of representation	233
Emergent properties of multimodal multiparty meaning-making	236
Layering of narratives.....	236
Giving form to imagination and filling a gap	242
Potential confounds, or criteria to satisfy?	253
7 Conclusion: Implications for Practice, Education, and Design	260
Exploring the museum driven by questions	261
Children explore and express the nature of objects: <i>What is it?</i>	262
Busy hands: <i>What can I do?</i>	262

Multimodal sequence, coordination, and function	263
Consequences of interactivity and <i>What does it mean?</i>	267
Consequences of multimodal exploration	268
Distribution of cognitive labor and cognitive complexity	269
Using observation to inform design	271

LIST OF FIGURES

Figure 1.1. A child watches other children looking at fossils	1
Figure 1.2. Sequences of modal engagement	8
Figure 1.3. How and where children pay attention in a natural history museum.....	9
Figure 1.4. Multimodal engagement, strong patterns emerged among the children.....	10
Figure 1.5. Children’s speech in the museum.....	12
Figure 1.6. Behavioral profiles for six fourth-grade children in a natural history museum.....	15
Figure 1.7. Interactive mechanical skulls attract and compel multimodal attention.....	17
Figure 3.1. Video data collection schedule with fourth-graders in a museum.....	62
Figure 3.2. Two synchronized streams of video provide a rich record of children’s activity.....	64
Figure 3.3. Coding scheme for speech.....	74
Figure 3.4. Applying the coding scheme highlights aspects of activity recorded on video.....	83
Figures 4 a–c. Children move through the museum, exploring numerous kinds of objects.....	95
Figure 4.2. Functions of object-oriented concrete speech events.....	99
Figure 4.3 a, b. Functions of object-oriented speech events, two different children.....	100
Figure 4.4. Graphic panel with an introduction to the exhibition themes.....	101
Figure 4.5. A child first looked at the mastodon tusk, touched it, and asked “What is this?”....	102
Figure 4.6. Another child looked at the mastodon tusk, asked “What is this?” then touched...	102
Figure 4.7. When Fossil Mysteries opened, the title wall included text only.....	103
Figure 4.8. Touchable fossils feature prominently in preliminary sketches for the title wall.....	104
Figures 4.9 a, b. Each title wall now includes a touchable fossil.....	105
Figure 4.10. A fourth-grade child read the title wall text out loud, with classmates nearby.....	105

Figure 4.11. A fourth-grader looked at and touched the fossil tusk fragment on the panel.....	106
Figure 4.12 a, b. A child looked at, talked about, and manipulated a sabertooth cat jaw.....	107
Figure 4.13. Video still of sabertooth cat skeleton from head-mounted camera.....	108
Figure 4.14 a–e. A child looks at a mounted fossil walrus skeleton from multiple angles.....	110
Figure 4.15. The same child looked at, manipulated, and talked about a sabertooth cat skull..	110
Figure 4.16 a,b. Children respond to objects in the museum in unique and similar ways.....	111
Figure 4.17. Children look at marine invertebrate fossils.....	114
Figure 4.21. A child points at tiny shells in a display case.....	114
Figure 4.22. A child points at tiny fossil shells a second time.....	114
Figure 4.20. One child points to a map, while two other children touch fossils.....	115
Figure 4.21. A child speaks and points at a big shell, redirecting her friend’s attention.....	116
Figure 4.24. A child points to fossil sea star in a display case.....	116
Figure 4.23. R points at sea urchin illustration on a graphic panel.....	117
Figure 4.24. Video still from child’s point of view. “Nos vamos aquí.”	117
Figure 4.25. Coding discourse themes provides one way of seeing conversational structure....	118
Figure 4.26. Coding the conversation by turns shows discourse themes.....	118
Figure 4.27. A child offers a card with labeled pictures of fossil shells to M and R.....	120
Figure 4.28. M and R walk toward a fossil whale skeleton.....	121
Figure 4.29. M gestures toward whale fossils, “...that’s why they are fossils.”	121
Figure 4.30. M reads and points to the whale fossil label.....	122
Figures 4.31 a, b. A touchable sea cow sculpture attracts several children.....	125
Figure 4.32. Patting the sea cow model reinforced her statement, “This is just fake, see?”	125
Figure 4.33. R talks about a taxidermied condor.....	126
Figure 4.34. M reads exhibit text.....	127

Figure 4.35. M leans on the panel and looks closely at the condor mount.....	127
Figure 4.36. R looks at M while talking about the condor.....	128
Figure 4.37. While walking away, a friend spins M around to look at the condor.....	129
Figure 4.38. R gestures toward horse fossils mounted on a horse-shaped armature.....	129
Figure 4.39. R points to the horse display while the children talk.....	130
Figure 4.40. An educator explained the concept of taxidermy to a group of fourth-graders....	132
Figures 4.41 a–c. A child approached a modeled dinosaur nest with eggs.....	133
Figure 4.42. A child approaches a touchable rock.....	135
Figure 4.43. The teacher and child look at, touch, and talk about the rock.....	136
Figure 4.44. The teacher asks a question and the child reluctantly offers an answer.....	137
Figure 4.45. The teacher explains to the child, his gaze on her, his arms and legs crossed.....	138
Figure 4.46. A video still shows the dinosaur gallery opening up before the child.....	139
Figure 4.47 a–d. Children engage with a touchable dinosaur model.....	141
Figure 4.48. A child spotted the giant Carchodon megalodon shark from across the gallery.....	142
Figure 4.49. Looking into the face of the giant shark model, the child said “Hello, Sharky.”	143
Figure 4.50. Entering the gallery, one child’s point of view appears similar to another’s.....	145
Figures 5.1 a, b. One child used his hand to move the jaw of a sabertooth cat.....	150
Figure 5.2. Some museum objects afford looking only.....	154
Figure 5.3. Some museum objects afford touching.....	154
Figure 5.4. Some museum objects afford manipulating.....	154
Figure 5.5 a, b. Comparing what exhibits offer and what children do.....	158
Figure 5.6. Children crowded around an interactive touchable map.....	159
Figure 5.7. Space opened up and the focal participant had access to see and touch the map...	159

Figure 5.8. <i>Fossil Mysteries</i> floorplan, indicating opportunities to touch and manipulate	160
Figure 5.9. Occurrence of touch and manipulate.....	161
Figure 5.10. Functions of touch.....	162
Figure 5.11. Form: touch exhibit; function: physical anchoring.....	163
Figure 5.12. Form: touch exhibit; function: occupy physical and social space.....	164
Figure 5.13. A child looked at, read, and manipulated an exhibit that represents a fault.....	165
Figure 5.14. When does movement have meaning? What kind of meaning?.....	167
Figure 5.15. A series of video frames shows a child's sequence of action.....	167
Figure 5.16. A child listened to a museum educator speak about the mounted condor.....	168
Figure 5.17. Turning a knob causes the gibbon skeleton's forearm to rotate.....	169
Figure 5.18. This child touched a chunk of igneous rock and said "Is this a real one?"	170
Figure 5.19. This child touched the text panel, moving her index finger while reading aloud....	171
Figure 5.20. Two fourth-grade friends point to exhibit text and read aloud side-by-side.....	172
Figure 5.21. In the absence of others, one child pointed to a video and said, "Oh look."	172
Figure 5.22 a–e. A focal participant used her index finger to "hold a place" in an illustration...	173
Figures 5.23 a, b. A child placed the tip of his finger at the "mouth of the volcano."	174
Figure 5.24. Manual gestures, proportions of indexical and iconic.....	176
Figure 5.25 a–c. Children touch, manipulate, talk and gesture with a plate tectonics exhibit....	178
Figure 5.26. Children use their hands to index objects and link semiotic resources.....	179
Figure 5.27. Functions of action-oriented speech.....	182
Figure 5.28. Two children spun a wheel that drives the movement of a skeletal deer leg.....	187
Figure 5.29. An exhibit, designed to represent biomechanics emphasizing form and function..	188
Figure 5.30. A child slid the plate tectonic model and read text through a small window.....	190

Figure 5.31. One child moved the exhibit showing tectonic plates, while another touched.....	191
Figure 5.32. While pointing to the exhibit, the child said “The past is better.”	191
Figure 5.33. A focal participant showed and interpreted a plate tectonics exhibit.....	193
Figure 5.34. Adult user’s view of San Andreas Fault plate tectonics interactive exhibit.....	193
Figure 5.35. A child grabbed and turned the knob attached to the gibbon skeleton’s hand.....	194
Figure 5.36. A mounted gibbon skeleton with a mechanical rotating arm.....	195
Figure 5.37. At his height, the child cannot see the critical elements in the skeleton arm.....	196
Figure 5.38. A child moved a model of a deer foot on the graphic panel.....	197
Figure 5.39. A classmate reached for the model of the deer foot on the graphic panel.....	198
Figure 5.40. The child looked at the deer skeleton while moving the deer foot model.....	198
Figures 5.41 a, b. Children moved a sliding lens and looked at microfossils.....	201
Figure 6.1 a, b. At an interactive model, children enact representational gestures.....	203
Figure 6.2. Exhibit-related speech forms.....	204
Figure 6.3 a, b. Children work with an exhibit that represents subduction.....	205
Figure 6.4. Frequency of functions of concrete/abstract speech form.....	206
Figure 6.5. A child’s fingertips dance atop the volcanoes, “tssss, tssss.”	208
Figure 6.6. A child manipulated the arm of a gibbon skeleton cast and asked, “Is it real?”	213
Figure 6.7. Hands and speech identify the exhibit elements in a child’s act of representation..	215
Figure 6.8. A child traced the volcanic vent with his finger, “It goes up, it goes out to this.”	216
Figure 6.9. The child manipulated a moveable map, “The present, oh right now.”	217
Figure 6.10. Children coordinated speech with action to express relationships.....	218
Figure 6.11. Children talked with a museum educator about their experiences with animals...	220
Figure 6.12. Children gather around a display about volcanic processes and products.....	221

Figure 6.13. Two friends looked closely at tiny clam shell fossils.....	223
Figure 6.14 a–d. A child walked toward a model of a giant shark, gasping, shuddering.....	225
Figure 6.15. Children leaned on, caressed, talked about, and talked to a giant boulder.....	226
Figure 6.16. A child spoke to a model of an extinct sea cow baby.....	227
Figure 6.17. A child manipulated the plate tectonics seafloor model, “boodyumpbaa...”	229
Figure 6.18. While demonstrating subduction, the child sonified the action, “brrrrrchh.”	230
Figures 6.19 a, b. The child’s gesture began with two fingers, then shot up into the air.....	232
Figure 6.20. Concrete/Abstract Utterances Co-Occur with Hand Actions.....	233
Figure 6.21. Interactional profiles of four children who used concrete/abstract speech.....	234
Figure 6.22. Plate tectonics digital interactive exhibit.....	237
Figure 6.23. One child points to a red dot on the screen, “there we are, over there.”	237
Figure 6.24. The child controlling the exhibit changes the display by pressing a button.....	238
Figure 6.25. A child points to the red dot a second time, “Look, that’s where we are...”	239
Figure 6.26. Manipulating the digital interactive changes the plate tectonic visualization.....	239
Figure 6.27. “I control you.”	240
Figure 6.28. Through manipulation, continents move to a recognizable configuration.....	240
Figure 6.29. With an explosive upward gesture, a child enacted a volcanic eruption	242
Figure 6.30. Representational features of a manipulable interactive exhibit	243
Figure 6.31. A rapid upward gesture represents an explosive volcanic eruption	244
Figure 6.32. A radial spreading gesture on the surface represents a volcanic eruption	244
Figure 6.33. A generic model for conceptual blending shows two input spaces	245
Figure 6.34. Perceivable features and abstractions provide inputs to a blended space	246
Figure 6.35. The input space of the physical exhibit lacks a feature in the conceptual space	247

Figure 6.36. Bodily gestures provide an additional input space in conceptual blending	247
Figure 6.37. The body provides meaning-making resources to create a conceptual blend	248
Figure 6.38. The child forced a tectonic plate down and touched the lava	249
Figure 6.39. The subduction exhibit can support representation of continental uplift.....	250
Figure 6.40. A child and teacher gestured “uplift” at the subduction exhibit.....	251
Figure 6.41. An uplift gesture corresponds with the physical and conceptual space.....	252
Figure 6.42. Children use gesture to represent objects and relations in the museum.....	257
Figure 7.1 Active bodies, minds and imaginations are evident in a child’s enactment.....	278

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- Garcia-Luis, V., Garibay, C., Huerta-Migus, L., Plaza, C., Renner, N., Yalowitz, S. (2012). *Bilingual Exhibits Research Initiative: Current Practices and Visitor Engagement*. Association of Science-Technology Centers Annual Meeting. Columbus, OH.
- Adams, M., Renner, N., Simpson, P. (2012). *Is the Art Museum Experience Different from Science and History Museums? Results from a Study of 12 Museums in Balboa Park*. New York, NY: National Art Education Association Annual Meeting.
- Renner, N. (2011). *Multisensory sensemaking: Children's exploratory behavior has organizing structure at micro- and macro-scales*. 33rd Annual Conference of the Cognitive Science Society. Boston, MA.
- Renner, N. (2011). *Moments of Discovery: Active Perception for Scientific Thinking*. San Diego, CA.: International Mind, Brain, and Education Society Annual Meeting.
- Adams, M., Renner, N. (2011). *Family Learning in Interactive Galleries*, Longitudinal Case Studies. Institute for Museum and Library Services.
- Renner, N. (2010). *Multisensory Sensemaking: How Children Engage with Objects and Ideas in a Museum*. Unpublished master's thesis, University of California, San Diego.
- Renner, N.O., Chiba, A., Núñez, R., Spock, D., Gabriel, P. (2009). *Learning Brains, Learning Bodies: Cognitive Science Informs Museum Practice*. San Diego, CA: Western Museums Association Annual Meeting.
- Renner, N.O., Jennings, P. and Cutts, B. (2007). *Exhibit Planners: Collaborate, Communicate, Create*. Oakland, CA: Western Museums Association Annual Meeting.
- Renner, N.O. (2006). *What's Really Important? Curiosity, Creativity, and Skepticism at a Natural History Museum*. WestMuse. Oakland, CA: Western Museums Association.
- Renner, N.O. and Adams, M. (2003). *Learning by Doing: Visitor Studies at the San Diego Natural History Museum*. Visitor Studies Today. Arvada, CO: Visitor Studies Association.
- Renner, N.O. (2003). *The Bilingual Dilemma. The Exhibitionist*. Washington DC: National Association of Museum Exhibitors.
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San Diego Natural History Museum, 2003–2005

Science Night at the San Diego Cooperative Charter School, interactive workshops, 2003–2005

San Diego Cooperative Charter School, Parent/Staff Association Co-President and Founding Board Member,
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ABSTRACT OF THE DISSERTATION

Free to Explore a Museum

Embodied Inquiry and Multimodal Expression of Meaning

by

Nancy Owens Renner

Doctor of Philosophy in Cognitive Science

University of California, San Diego, 2013

Professor Edwin Hutchins, Chair

Professor James Hollan, Co-Chair

In the complexity and idiosyncrasies of everyday human activity, social scientists seek patterns—first to describe, then to explain the organization of thought and action. In a natural history museum, a setting of complex activity, video-based research addresses fundamental questions:

How do children use museum exhibits? How do they make sense of experience when confronted with a rich array of resources, including natural objects, environments, models, digital and mechanical interactives, static and moving images, text and sound? How does design constrain and afford different forms of engagement and meaning-making?

Theories of cognition—as embodied, situated, and distributed—informed methods of analysis focused on multimodal interaction. A detailed behavioral coding scheme, applied to video of six multilingual fourth-grade children, highlights when they look, touch, talk, and gesture with exhibits. Quantitative analyses focus on behavioral frequencies and sequences. Qualitative analyses describe the forms and cognitive functions of the children’s multimodal engagements. In this cognitive ecosystem, the diversity, abundance, and distribution of modes of interaction permit inferences about the role of the environment, consequences of design and the potential for learning.

Children’s self-directed explorations of the museum clustered around themes: objects, action, and representation. The children’s activity embodied inquiry. They asked, explicitly and implicitly, *What is it? What can I do? What does it mean?*

Children used multiple sensorimotor and expressive modalities for different functions, and they distributed and integrated cognitive labor across modalities and individuals. When children manipulated objects in the museum—opportunities for interaction that they actively sought—they achieved feats of cognitive complexity. They tested cause-and-effect relations in the physical world, created layers of narrative interpretation, and filled conceptual gaps in exhibits with their own expressions of meaning. Guided by children’s behavioral and cognitive inclinations, museums and schools can, and should, create environments for meaningful exploration, imagination and expression.



Figure 1.1. A child watches other children while they look at fossils that spin on a disk under a video camera for magnification (video still, recorded from a child's perspective).

1 Free to Explore a Museum

When speaking of children in museums, adults sometimes express this gist: “Those kids can’t possibly be learning anything. They bounce around randomly like ping pong balls. They push and pull things and don’t even wait to see what happens.”

During my museum tenure, I heard a museum director express this skepticism about interactive learning environments, including some science centers, despite his commitment to interactivity. At a meeting of museum professionals (AAM, 2006), one practitioner expressed

her belief in the power of multisensory, interactive experiences for museum visitors. She also expressed frustration with her executive director and board who needed to be convinced of the value of multisensory exploration and learning with and through the body. She put out a plea for empirical evidence and a rationale to convince them of what she felt to be true. I've conducted numerous interviews and focus groups with parents, teachers, and museum educators; they often talk about the value of hands-on experiences for increasing engagement and learning among children—based on their first-hand experience with children in their lives.

What if those who needed convincing simply watched children in spaces well suited to their exploratory inclinations? How can we see what really matters? What can we learn from watching children use their whole bodies, with a suite of cultural practices (language, interaction patterns), when they come into contact with objects, ideas, and settings? Can we move beyond a superficial evaluation of multisensory interactive learning environments as either good or bad? Can we inquire deeply into how children use museum resources and explore the consequences of their interactions?

This research has a dual focus—observing human interaction in a museum and inferring the cognitive consequences of design. The researcher played a central role in creating the exhibition under study, entitled *Fossil Mysteries / Misterios fósiles*. As exhibit developer, I worked with a team of scientists and artists to translate ideas into experiences. Embedded in the exhibition are innumerable decisions, decisions guided by the natural history content and collections, learning research, exhibit evaluation, ergonomics, biases, and intuition. Important decisions required negotiation among various team members with different perspectives. Colleagues sometimes called me the “visitor advocate.” Indeed, I did advocate, for accessible multisensory experiences and opportunities for social and physical interaction. Traditionalists on

the team sometimes resisted design ideas rooted in the accessible, multisensory, interactive agenda, perceiving them as a threat to the rigor of the content and the gravitas of the museum.

To honestly explore the consequences of design, this research does not aim to make a blanket statement that accessible, multisensory, interactive, and hands-on exhibits are good. Setting value judgments aside temporarily, this research documents the forms and functions of children's engagement with exhibits, inquiring into the nature and consequences of embodied and distributed cognition among children, objects, and ideas in a museum. Documenting the consequences of children's engagements with accessible, multisensory, interactive, and hands-on exhibits may lead to advocacy—based on empirical observation.

When confronting skepticism about interactivity, “hands-on” opportunities, and “discovery learning,” one might ask: Have we spent sufficient time watching children explore their world? Can sustained observation move us beyond anecdotes and confirmation of biases, especially in matters of education and design?

For those who say children just bounce around randomly, we might begin by challenging the notion of randomness in human behavior. Although it may appear chaotic, social scientists discover and describe the organization present in activity. Systematic observation supports discovery of patterns in human behavior. Guided by that commitment, this research looks closely at what children do in a natural history museum and how they use physical and conceptual resources found in museum exhibits.

When fourth-grade children enter this museum exhibition about fossils, rocks, and the processes that created them, their interactions with exhibits involve many variables. Each child brings different life experiences, prior knowledge, and habits of interaction. They choose

different pathways through the exhibition. They spend different amounts of time with each exhibit where they stop, and the configurations of their social groups vary. The observable particulars of their engagements—what they do with their eyes, hands, bodies, and speech—comprise unique interactions. And yet, despite individual differences and the variability inherent in real-world activity, we see patterns in how children engage with objects and ideas. Using a mix of methods, this research yields results relevant to understanding children’s cognition in action. In addition, close study of children’s activity can guide the design of learning environments that work with, rather than fight against, children’s cognitive and behavioral inclinations.

Activity in the world is not without constraints. Close observation and the patterns we discover reveal the presence and nature of the relevant constraints. The physical body and physical space enforce constraints. Social interactions abide by constraints in their forms, sequences, and dynamics. Social interaction gives form to the continuous negotiation of social relations and their multiple meanings, in the museum as elsewhere. Cultural practices, expressed as improvisations on learned scripts for social interaction, provide a matrix within which children explore objects and express ideas. Concepts, created and vivified via cultural practices, provide structure made useable and/or visible via *processes* of representation.

Children inhabit the museum with their whole bodies, a simple fact sometimes lamented by adults. When free to explore a museum, children move around. They probe the world with their senses, moving eyes, hands, and their whole bodies. Bodies enable perception, action, making sense of experience, and creating meaning. Interweaving multiple processes, children explore their world, and they express their perceptions and understandings, always situated in a social and physical context. When in the museum, what do children pay attention

to? How do they talk about what they see, and how do they engage their bodies and integrate the actions of multiple modalities in exploration, expression, and meaning-making?

Detailed and rigorous observation of children in a natural history museum supports description of a range of possible engagements in this particular social-cultural-material ecosystem. We see the diversity, abundance, and distribution of different forms and functions of multimodal engagement, and how the physical designed environment constrains and affords engagement across multiple dimensions. Children's engagements and interactions depend directly on what the museum makes available, based on institutional decisions about content, design, fabrication, and context. Institutional decisions have downstream consequences for the people who inhabit museum spaces. This research investigates those consequences, aiming for relevance to cognitive science, museum practice, education, and design.

This research targets a unique intersection of so-called formal and informal education. (See Lave for a critique of this terminology, 2011.) A special elementary school museum immersion program brought third-, fourth-, and fifth-grade students to multiple museums for week-long residencies. The children spent one in four weeks of the school year on the multi-museum campus. Museum educators led lessons in the morning; the regular classroom teachers took over in the afternoon, presenting another layer of interesting social dynamics, but not the focus of this research.

The exploratory work of collecting video-based *specimens of activity* in a museum serves both descriptive and explanatory purposes. Drawing on a subset of a larger video corpus (recording six exhibition visits with twelve focal participants), this research focuses on six children and their classmates during a unique time in the children's school life—when adults allowed the children freedom to explore an exhibition in a natural history museum. However,

the freedom to explore is only relative to other more prescribed activities in their school day. Their museum explorations are bounded by constraints: everyone abides by normal classroom rules; the teachers contain the children within a gallery, so they must negotiate for available resources; the teachers permit the children to move gallery by gallery en masse under supervision; the adults direct the children to look for rocks, as expressed by the lead museum educator, “Ok, we’re looking for rocks.” In some cases, classroom teachers turned the children away from exhibits, strictly enforcing the museum educators’ imperative to look for rocks. One said, as he shooed the children away from an interactive sabertooth skull, “These aren’t rocks. Go look for rocks.”

The teachers and educators also expressed their beliefs about how children should behave and the nature of learning in this special museum immersion program, as in this statement, “Ah, excuse me. I need to say something. You guys have a job to do here. You're supposed to be looking for rocks. I see very very few people actually looking for rocks and then sitting and reading. I see a lot of people running from picture to picture and learning absolutely nothing. Now, give me a reason to bring you back into this museum, because right now I don't have one. You're acting like this is a field trip instead of a place where you're supposed to learn.”

In the museum—a knowledge-rich, object-based, socially interactive space—what do the children actually DO? To what do they pay attention? How do they engage with the exhibits? How do they use the museum resources in combination with their own personal endowments of knowledge, curiosity, and abilities to move, sense, and act? What are the cognitive consequences of different forms of engagement? Do the children’s actions show any regularities across individuals? How do patterns of interaction correspond with aspects of the designed museum environment? Are they *learning* anything? With a deeper understanding of

children's predispositions and the consequences of design on cognitive activity, how might we change our approach to design for engagement and learning?

The first year of exploratory research (Renner, 2010, 2011) uncovered interesting patterns in the children's engagements with museum exhibits that brought focus to the present inquiry. Among six children, roughly three-quarters of engagements with exhibits involve touch, and a full two-thirds instantiate the sequence Look-Touch, with variations (figure 1.2). The most common multimodal sequences are: Look-Touch, Look-Touch-Talk, Look-Touch-Talk-Gesture, and Look-Talk-Touch. Children talked about the exhibits after touching exhibits with twice the frequency than talking in any other condition. However, there are multiple forms of touch and talk, and a wide variety of exhibit types. Do particular forms of touch and talk occur together? If so, can we infer any causal relationship, perhaps related to exhibit design? What are the consequences of different forms of touch and talk? And by extension, what are the cognitive consequences of design?



Figure 1.3. How and where do the children pay attention in a natural history museum? A child sustains visual attention on an exhibit—this “exhibit engagement event” provides one unit of analysis for this research focused on the cognitive consequences of design.

Each of the following chapters has a particular focus: *objects*, *action*, and *representation*, based on analyses of speech events that relate to objects, action, and representation. However, the analyses address more than speech. Examination of perceptual-motor modalities that co-occur with speech (eye gaze, touch, manipulate, gesture), interaction with others, and the situational context enables interpretation of the cognitive functions of the various speech forms, as well as actions of the hands, i.e. when children gesture, touch and

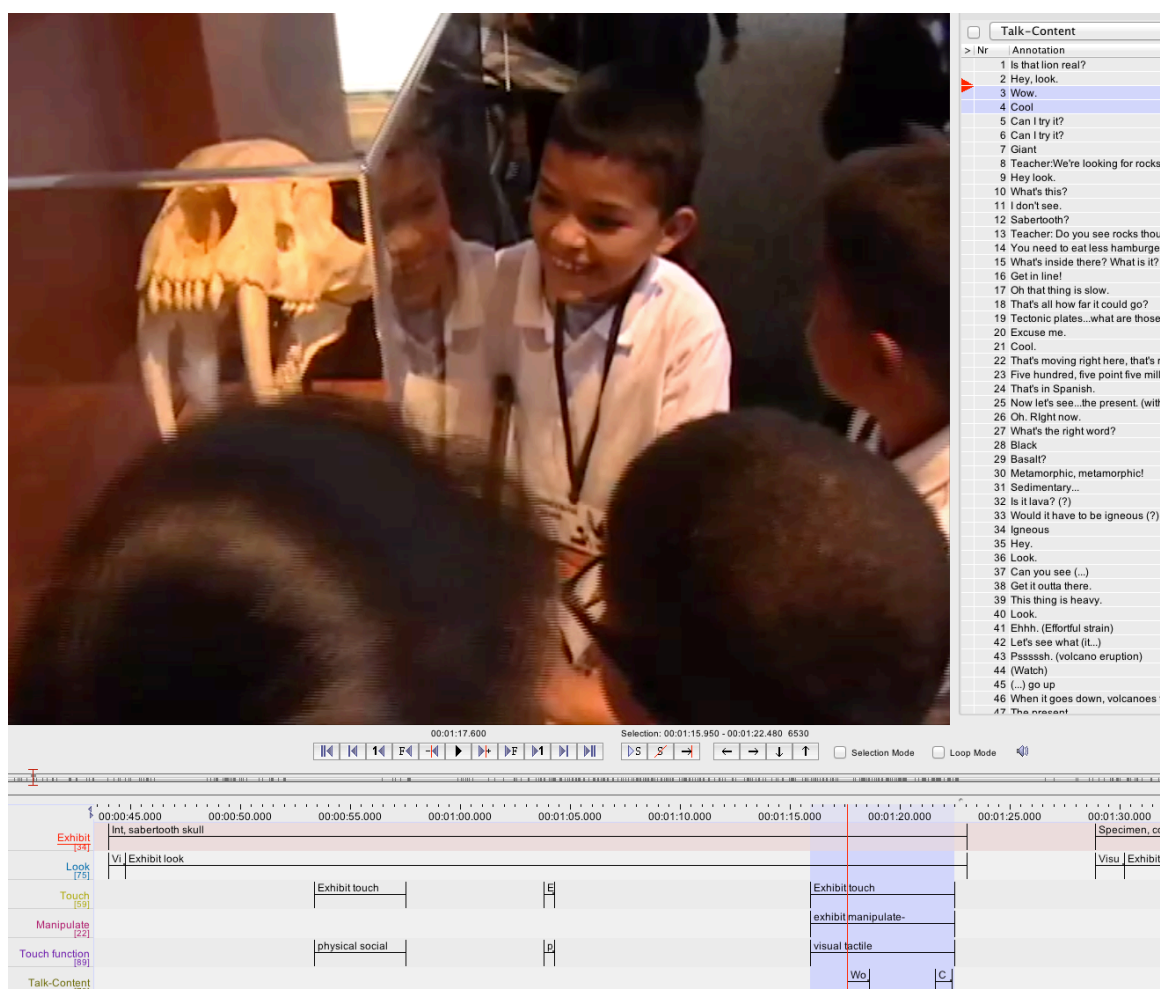


Figure 1.4. Despite individual variation, strong patterns emerged across the six case study children. Among the children's exhibit engagements, 30% involve the modal sequence Look-Touch-Talk, as shown in the example with annotated video data above (generated in ELAN). The Methods chapter tells more about the video-based analysis that enabled the discoveries reported in the chapters that follow.

manipulate exhibits. Multimodal analysis of interaction provides the basis for all results and conclusions presented here.

In the chapter focused on *objects*, analysis includes interactions that involve exhibit-related concrete speech to address the question—What cognitive work do children accomplish when they talk about objects in museum exhibits, (e.g. specimens and models)? In the chapter focused on *action*, analysis of concrete action-oriented speech and actions of the hands sheds

light on the next question—How do children’s action words and hand actions serve different functions as they engage with exhibits? Museum exhibits use concrete objects to represent abstract ideas. Children make concrete and abstract references in their multimodal expressions using speech, gesture, and actions with exhibits and other people. In the chapter focused on *representation*, analysis of blended concrete/abstract speech and gesture events addresses the question—How do children express representational meanings of museum exhibits?

Speech plays a particular role in the children’s explorations, and thus provides important data for analysis. Although the words are sparse, the children’s speech accomplishes significant work, often unique to the language modality. Words can provide a particular specificity that other expressive modalities lack—a name, a category, a question, an evaluative judgment. Within their social and physical contexts, words entwine with other actions—eye gaze, body orientation, posture, gesture, touch, manipulation. In order to describe *cognition in the wild*, we track these dynamic multimodal configurations of talk, action, and meaning. Through multimodal interaction analysis, we see the coordination of modalities that assemble into meanings, allowing interpretation of not just the forms but also the functions of speech and action. We can also disentangle the modalities (speech, gesture, eye gaze, etc.) and propose what each contributes in the distribution of cognitive labor. Looking at activity at a macro-level, we see organization of activity clustering around tacit questions: *What is it? What can I do? What does it mean?* Looking at more micro-level activity, we see how engaging multiple modalities complexifies the activity. Often, speech, gesture, touch, and manipulation each make a unique contribution of cognitive function. Children achieve cognitive accomplishments through the distribution of cognitive labor across modalities and the integration of function

across modalities. The potential for cognitive complexity increases with the incorporation of additional modalities in the activity.

Children's speech does not focus equally on objects, action, and representation, due in part, to the resources the museum makes available. Concrete object-oriented speech events are most abundant, concrete action-oriented speech events are less abundant, and concrete-abstract representational speech events are least abundant (figure 1.5).

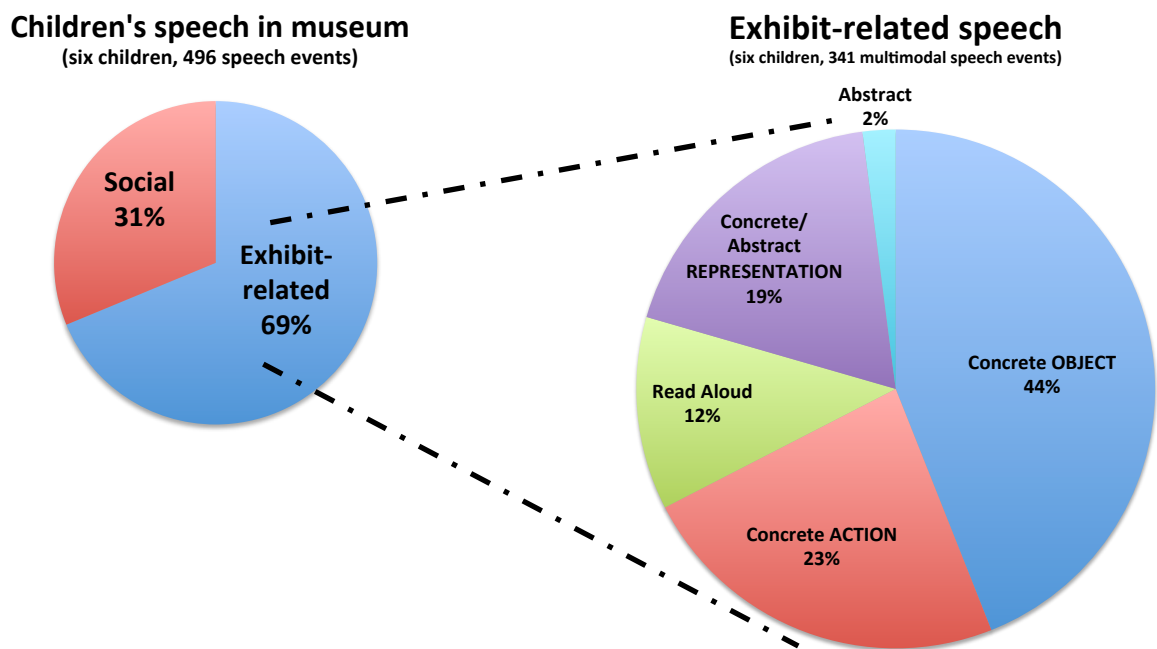


Figure 1.5. Children's speech in the museum.

Most of the children's speech relates to exhibits. Object-oriented concrete speech is more abundant than concrete action-oriented speech and concrete/abstract representational speech. Analysis of all speech involved observation of multimodal engagements in physical, social, and temporal contexts.

The children's engagements with museum exhibits have a multi-layered tangled complexity. Their activity often serves multiple cognitive functions simultaneously. The strategy for parsing the results with the themes of *objects*, *action*, and *representation* exposes the complexity of how children use the museum—how they probe the material aspects of objects, exploit objects' affordances, navigate physical and social spaces, and discover and express conceptual structure at many levels.

Inspiration for the focus on objects, action, and representation comes from the structure and organization of the children's activity. With words and actions, the children ask and answer a set of questions: *What is it? What can I do? What does it mean?* As they simultaneously navigate physical, social, and conceptual spaces, they integrate multiple modalities for exploratory and expressive purposes in the museum ecosystem. The following chapters describe diverse "species" of these differently embodied interactions, their forms and functions, abundance and scarcity, and distribution relative to resources in the museum. Vignettes from the video data, focused on multimodal speech events, illustrate "specimens" of these species of activity.

Quantitative results based on video data of six fourth-grade children provide a sense of the range and frequency of phenomena. These statistics are descriptive, not inferential. Coding and quantification of behaviors provides a rationale and context for the qualitative descriptions of the forms and functions of engagement, with measures of diversity, abundance, scarcity, and distribution of behaviors and cognitive activity relative to resources made available by the museum. These results may provoke additional research questions and hypotheses for testing. For example, design experiments could test the hypothesis that compelling children to gesture with exhibits invites engagement and increases depth of understanding. Another hypothesis

worthy of testing: exhibit designs that create a conspicuous conceptual gap elicit action by users to fill that gap. Observational and analytic work would be necessary to describe the exhibit's conceptual structure, define the nature of the conceptual gap, and identify behaviors deemed as meaningful in filling that gap.

The data for six children reflects a range of possibilities for engagement with exhibits. Individuals show differences in their manner of engagement. For each participant, the quantification of different behaviors provides one representation of a "behavioral profile" on the occasion of their museum visit (figure 1.6)¹.

Some children touch, talk, read, and/or gesture more than others. Despite these differences, similarities across individuals reveal patterns that transcend individual variability. Children touch exhibits and graphic panels (the most abundant resource) more than they touch objects (specimens, models), and more than they manipulate interactives (the scarcest resource). Concrete speech is more abundant than concrete/abstract speech. Indexical gestures outnumber iconic representational gestures.

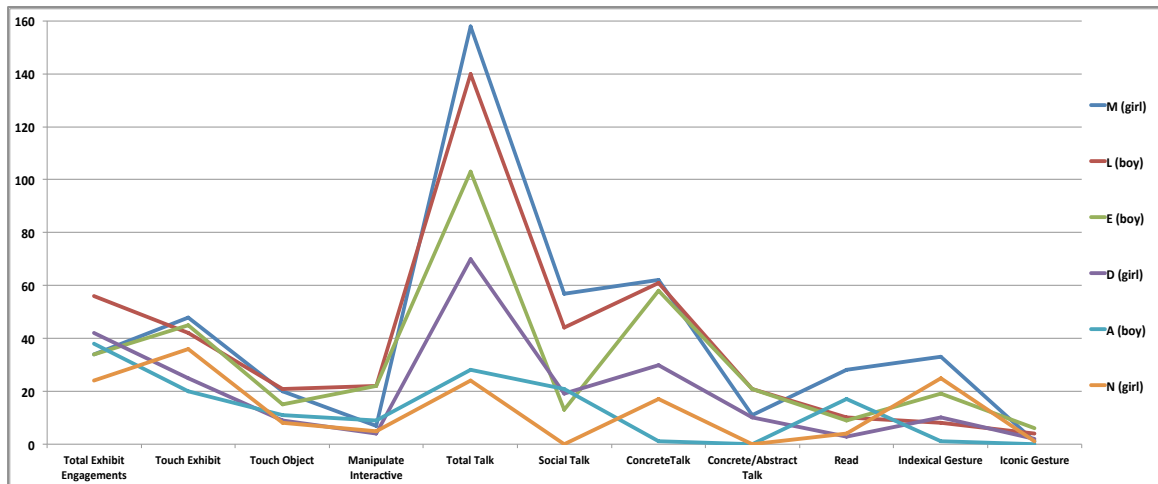


Figure 1.6. Behavioral profiles for six fourth-grade children in a natural history museum. Although some children are more active in the museum—simply touching, talking, and gesturing more—some behavioral trends transcend individual variability. To address questions about gender differences requires more specifically focused research.

In a complex activity system, a researcher might identify and quantify behaviors of interest in multiple ways. In this research, the children’s activity drives the sampling technique. We followed the children to the exhibits that they chose, then categorized and counted observable behaviors to document the diversity, abundance, and distribution of certain kinds of multimodal cognitive events when the children engage with exhibits. This research is a cognitive ethnography of a cognitive ecosystem comprised school children in a museum exhibition—an environment expressly designed for learning. A targeted sample—exhibit interactions among six fourth-grade students—results from aggregating the data from the six children during their museum visits.

How do these results generalize to other exhibit interactions, with other children in other museums? Generalization carries the power to make predictions and apply results in new, as yet unstudied, contexts. However, results earn the rights of generalization when a body of relevant knowledge grows to an impossible-to-quantify critical mass. This work—that

documents the cognitive organization of children's behavior and the cognitive consequences of design in museums—has only just begun.

As the body of knowledge grows through collective effort, we will make judgments about what factors exert critical influence on behavior, activity, and cognition. We will demonstrate how institutional practices result in consequences for engagement and opportunities for learning. We can apply the methods pioneered in this study to expand our research on how people use designed objects, media, and environments. These methods might inspire different approaches to embedded ethnography and modes of evaluation, supporting museum practitioners to reflect on the consequences of design decisions.

This work provides a model for seeing parts of a cognitive ecosystem—with the museum, children, and adults all bringing suites of resources to each interaction. The central target of this research drives at the cognitive consequences of design—how children use museum resources, what they do, and how they think with and through their bodies in the museum.

The children's uses of exhibits embody cognition through sequences of perception, action, and interaction. With results from this research, we can describe and explain what happens in one exhibition, and formulate and test hypotheses about children's cognition in action in other knowledge-rich settings, hypotheses that we might never have considered if we didn't start by looking at these six kids in one natural history museum.



Figure 1.7. Interactive mechanical skulls attract and compel multimodal attention. Children push and pull levers to move the mountain lion and deer jaws. They watch the moving forms and co-time their speech, using the skulls like puppets to enact a conversation between predator and prey. See figure 6.10, Ecological relations, for details.

¹ For one focal participant 'N,' some of the video data was unusable as it did not focus on 'N,' but on her classmates instead. This explains the low number of total exhibit engagements for 'N.'

References

American Association of Museums Annual Meeting, The Museum Group informal discussion. (2006). Boston, MA.

Lave, J. (2011). *Apprenticeship in Critical Ethnographic Practice*. Chicago, IL: The University of Chicago Press.

Renner, N. (2010). *Multisensory Sensemaking: How Children Explore Objects and Ideas in a Museum*. University of California, San Diego. Unpublished master's thesis.

Renner, N. (2011). *Multisensory sensemaking: Children's exploratory behavior has organizing structure at micro- and macro-scales*. Paper presented at the 33rd Annual Conference of the Cognitive Science Society. Boston, MA.

2 Relevant Literature

Focused on the cognitive consequences of interaction in a museum—an environment designed for learning—this research draws on the fields of cognitive science, education, and museum studies. In these disciplines, significant parallels exist. They stem from a shared cultural matrix, so similarities in theory and philosophical orientation should not surprise. The traditional focus in cognitive science, education, and museum practice centers on information transmission and symbolic logical knowledge. Over the past one hundred years, various researchers, theorists, and educators have challenged the persistent hegemony of the traditional perspective for two reasons, one theoretical and one practical. From a theoretical perspective, models of learning and cognition limited to information transmission and symbolic forms of knowledge provide neither an adequate nor an accurate description of human thought and activity. From a practical perspective, modes of education based solely on information transmission fail for many learners in many disciplines. This failure results not in a benign absence of learning. Rather, many educational practices have detrimental effects by discouraging curiosity, creativity, and active engagement of learners' bodies, with all the resources they bring to bear in embodied exploration.

Alternative approaches to understanding cognition and learning shift the focus from the *entities* of information and knowledge to *processes* of action, perception, representation, and meaning-making (cf. Ingold, 2011). Information and knowledge certainly matter, but the shift from entity to process allows us to see how and why they matter. Relevant literature provides theoretical justification for the current inquiry into how children use natural history museum

exhibits, and what cognitive consequences result. Each section that follows serves as rationale for looking at distributed cognitive systems centered on interacting humans and particular forms of modal engagement, namely visual attention, speech, gesture, and other actions of the hands.

Advances in cognitive science, based on integration of findings from multiple disciplines, support an understanding of cognition as embodied, situated, and as a consequence, distributed. Theories of embodied cognition contend that the forms and functions of bodies shape and constrain the content and processes of thought. For intelligent human activity, the human body, with its capacities for perception, movement, and internal mental processes, provide organizing structures in cognition.

Theories of situated cognition contend that the context of interaction constitutes part of the cognitive system (Robbins & Aydede, 2009). Engagement with objects, environments, and other people defines the nature of the cognitive task and determines what external resources are available. Observing individuals and groups engaged with social and physical environments, we see how sequences of action enact and embody trains of thought (Alac & Hutchins, 2004). The environmental context and culturally determined patterns of action structure activity and cognition.

Distributed Cognition Theory elucidates how cognitive systems distribute cognitive labor over space and time (Hutchins, 1995a). Applying the distributed cognition lens to embodiment, we see how, at a behavioral level of analysis, various perceptual-motor modalities participate in cognitive processes. With regards to situated cognition, the distributed perspective reveals how multiple agents may contribute to cognitive processes, how cultural practices that develop over time support and constrain cognition, and how cultural artifacts embody the cognitive effort of the many people who shaped their form and content. History at multiple time scales—

evolutionary, cultural, developmental, and situational—exerts powerful inescapable influences on cognition. (For foundational work on distributed cognition in education, see Salomon, 1993; Pea, 1993.) In museum studies, the Contextual Model of Learning aligns with Distributed Cognition Theory with a focus on interaction among personal, socio-cultural, and physical elements over time (Falk & Dierking, 2000).

Human activity—in laboratories, schools, museums, workplaces, playspaces, essentially everywhere—is shaped and constrained by physiological, physical, social, cultural, and historical factors. Observing children in a museum should reveal regular patterns of activity. These patterns should suggest processes that organize and structure behavior and cognition. The cognitive labor involved in accomplishing any task is distributed at every level of the relevant cognitive system (from areas of single neurons and networks of neurons to individuals within organizations and organizations within societies) (Hutchins, 2010a). To investigate the processes and consequences of embodied engagement and interaction, we examine the coordination and contributions of observable parts of the cognitive system, in particular, the perceptual-motor modalities of participants in the social-cultural-material context of activity. This activity-based systems-oriented approach to educational research aligns with a systems-oriented paradigm in the learning sciences. Additionally, a focus on activity and audience characterizes a progressive movement in museums as a revitalized technology for exploration and imagination.

Defining cognition: Distributed and integrated

Cognition is often defined as a mental process, assumed to take place in a brain. First generation cognitive science emphasized information transmission and symbolic mental

representations, ignoring context, culture, history, and emotion, with the intent to add them back in after solving the difficult problems of cognition (Gardner, 1985). Individual cognizing agents were construed as information processors, which set the boundary for the unit of analysis at the individual level. Curiously, in great contrast to humans, scientific models of these information-processing agents lacked sensors and effectors. Models of cognition (and by extension, learning) focused on amodal symbol manipulation, treating perception as separate input to cognition, and action as separate output. These models neatly expressed the “mind as computer” metaphor. Carving intelligent behavior into categories that separate cognition from perception and action reflects how first generation cognitive science reacted against behaviorism in psychology (Miller, 2003). Behaviorism focused exclusively on observable stimuli (and perception) and response (resulting action), claiming that invisible activity of the mind (cognition) could not be studied scientifically. Cognitive science focused on what behaviorism rejected—the stuff in between perception and action. With cognition as independent of the processes (if not the content) of perception and action, and perception and action as separate non-cognitive functions, the study of cognition excluded interaction with the environment.

Models of learning that focus on informational content and transmission too often ignore perception and action, sometimes treating them as intruders on the learning process. The resulting implicit cultural models that put all cognition inside the head, separate from perception and action, treat the learner as an “empty vessel” to be filled or a “tabula rasa” on which knowledge can be inscribed (Hein, 1998).

Second generation cognitive science integrates theoretical and methodological advances that reveal how perception and action participate in processes once considered as separate and “cognitive.” Embodied cognition theory derives from understanding the

integration and interaction of action, perception, and other forms of cognition. Organisms' bodies—the biological form, perceptual and motor abilities, and other nervous system functions, conscious and unconscious—form the content and processes of cognition.

Opportunities for and constraints on cognition emerge from processes at multiple time scales: phylogenetic, cultural, ontogenetic, microgenetic (in-the-moment) (Cole & Engeström, 1993). Furthermore, an integrated understanding of cognition at multiple levels guards against misattributing the properties of cognitive systems to parts within the system, maintaining the appropriate focus on the phenomena we seek to describe and explain (Hutchins, 1995a). The work of cognition is, by necessity, distributed across multiple systems that include brains inside bodies embedded in social-cultural-material worlds (Ibid).

Active perception: embodied, situated, enculturated

Because we have limited conscious awareness of our perceptual processes, people often think of perception as passive, i.e. something that happens to them or inside them. For example, the camera serves as a common metaphor for vision in which the eyes take in an image of the world and the brain records a veridical image from which to extract information. However, multiple lines of research assert that each person's vision is unique to the beholder. In the seminal paper "A Critique of Pure Vision," researchers and theorists outlined a framework for understanding the interactive nature of vision (Churchland, Ramachandran, & Sejnowski, 1994). Entire fields of research explore aspects of "interactive vision" (Ibid), arguing, for example, that vision integrates time-dependent information from multiple motor and sensory modalities (Jacobs & Shams, 2010); vision involves prediction and expectation (Shams, 2011; Gray & Tan,

2002); vision depends on memory and prior knowledge (Palmeri & Tarr, 2008); and what we see at any moment is a partial representation of what is present in the visual world (Simons & Ambinder, 2005). We often fail to see what is right before our eyes, a phenomenon called inattention blindness (Simons & Chabris, 1999). Multimodal integration, prediction and expectation influenced by prior experience, and constraints of attention likely govern other perceptual modalities, although the most research has focused on vision.

Attention is a limited resource that we selectively allocate. At a fundamental level, conscious and unconscious allocation of attention makes perception an active embodied process shaped by interaction with the environment (Gibson, 1979; Nöe, 2004). People probe the world for sensory information with movements of eyes, head, and body (O'Regan & Nöe, 2001; Gibson, 1979) and manipulation of objects (Kirsh & Maglio, 1994). Allocation of attention (e.g. activity of the eyes and hands) informs the researcher about the nature of active perception (Johnson, 2010).

The union of perception, action, and cognition can be found in an explanatory framework of “active sensing” (O'Regan & Nöe, 2001). In this model, the nervous system learns associations between sensations and the body's movements. These sensorimotor contingencies encode *invariants*, or law-like relations, in the interaction of each sensory system with the outside world (Ibid). Exploratory behavior links perception and action, in sensorimotor feedback loops and in associative learning grounded in sensorimotor experience. Sensory systems do not apprehend the physical world all at once to create an internal representation. Rather, the body probes the world with its senses, and in the process, updates and refines neural dependencies (Nöe, 2004, pp.1–15). Sensorimotor contingencies result from cross-modal associations strengthened by repeated activation.

Ecological psychology, with a complimentary view, focuses on the intersection of the whole organism and the physical world (Gibson, 1986, pp. 7–15). Every object has a range of possible uses, or *affordances*, that may or may not be perceived or intended; this does not change the nature of the object (Ibid, pp. 130–143). The affordances of a wrench are different for an adult, a child, and a dog, and all are simultaneously present and defined by relationships between bodies and objects. The proportions and configuration of a body shapes the organism's perception of objects and determines the object's possible uses (or affordances) for that organism. Gibson states that bodies also have affordances for other bodies (Ibid, p.135), offering another way of thinking about the complex interplay of people in physical, social, and cultural contexts.

Vision, like all forms of perception, is an active process in many senses of the word. Vision results from sensorimotor coupling. Vision happens through interaction between a moving organism and its environment (Gibson, 1986). Perception seeks to find information. Information, according to Bateson, is “a difference that makes a difference” (1979). In perception, changes (or variants) may have systematic correspondences across modalities. For example, the body moves forward and objects in the central field of vision loom larger. In addition, constants (or invariants) may also maintain some form of cross-modal consistency, for example, the body moves forward, and same-sized equidistant objects occupy the same amount of space in the peripheral visual field. The perceptual patterns mean something—they correlate with patterns of bodily motion and movement of objects in the environment. Brains integrate information from multiple modalities synchronously, comparing present experience to the past and anticipating the future. This cross-modal integration enables the organism to differentiate objects in the environment from itself, determine what is in motion, direction and speed. While

the organism determines where objects are located in space, relative to itself and other objects, it simultaneously compares objects' visual features with memories of objects previously experienced, in multimodal fashion, associating visual experience with linguistic labels, that may have aural, motor, visual associations. For example, a child sees an object then says (feels and hears) a word..."sabertooth."

Much of human activity incorporates cultural practices that involve seeing, naming and interpreting objects, cultural practices of particular relevance in the museum setting. For example, both students and professionals—in diverse disciplines such as archeology, geology, and museum exhibit design—record information in physical representations through systems of coding, and they make some information more salient through practices of highlighting (Goodwin, 1994). From a perspective focused on museums, authors have explored themes of museum semiotics, i.e. interpreting museums as engaged in communication with semantic and pragmatic consequences (Horta, 1992) and object literacy, i.e. learning the practice of reading objects for information (Jones, 2002). At a basic functional level, experimental researchers using visual search reaction time paradigms suggest that linguistic labels and semantic categories exert an early influence on visual processing and don't merely bias output of perceptual systems (Lupyan & Spivey, 2008; Lupyan et al, 2010). Their results put forward the idea that the application of labels and conceptual categories profoundly shape what and how we see, from the earliest phases of visual perception.

Information from all sensory modalities, in addition to vision, integrates into time-correlated multimodal information (Jacobs & Shams, 2009; Spence, 2007). Of particular concern to this research is the role of touching and manipulating objects, in combination with looking and speaking. Research on learning in object-based and interactive museums tends to focus

analysis on conversation (Paris, 2002; Leinhardt, Crowley, Knutson, 2002). Research on “hands-on learning” often results in broad-level descriptions of outcomes, such as increases in positive attitude and engagement, and expressions of preference for hands-on activities (Haury & Rillero 1994; Garrity, 1998). The educational research and museum studies literatures have a distinct gap in articulating the consequences of touching and manipulating objects at a fine-grained level, and how those consequences contribute to a greater whole. The following research results contribute to filling that gap.

Cognition in interaction

The embodiment thesis contends that sensorimotor processes are constitutive of cognition, and sensorimotor activity takes place in the world. So embodied cognition necessitates interactive cognition embedded in situational contexts (Robbins & Aydede, 2009). Understanding cognition as situated, we might discover how people think with things depending on the problems they face. A series of examples illustrates thinking made possible by interaction with the environment.

People use action to solve problems. They don’t just solve problems “in their heads.” The things they act upon become tools. In the time-pressured context of playing the digital game Tetris, expert players spin shapes to assess whether they fit. *Epistemic action*, taken to gain knowledge for the achievement of a goal, is distinguished from a *pragmatic action* aimed directly at accomplishing a goal (Kirsh & Maglio, 1994). For shoppers situated in a grocery store, the computational challenge of finding food for the best unit price inspires a variety of problem-solving techniques, drawing on resources available in that environment (Lave, Murtaugh & de la

Rocha, 1984). Shoppers frame their activity and perceive problem-solving resources differently, and each shopper experiences a unique setting within the shared arena of the grocery store (Ibid). Objects in the environment can provide structure for thought by serving as material anchors for conceptualization (Hutchins, 2005). For example, when projecting the idea of a trajectory onto a group of people standing in a linear configuration, the people stably hold the representation of directional movement in sequence, and the group becomes a queue that gives structure to the activity of waiting (Ibid). Situational context shapes meaning. People make and use tools, and they opportunistically turn objects into tools for gaining knowledge, solving problems, and making meaning.

Introducing a tool illustrates other aspects of situated cognition: restructuring of the cognitive system, redefining the cognitive task, and redistributing the cognitive load. Imagine multiplying two very large numbers without moving your body or using any tools. Compare mental multiplication to computing the product with pencil and paper, or with a calculator. In each case, the introduction of physical tools changes the composition of the functional system and the nature of the task (Cole & Griffin, 1980; Hutchins, 1995b). Museum exhibits can serve as tools for various cognitive tasks. Traditionally, museums have used exhibits as media to transmit information. Innovative museum practices have resulted in exhibits as tools for exploration of physical phenomena, perceptual discernment of different types of objects, and creative collaboration.

Of particular interest in educational settings such as museums, external representations support and enable cognitive processes that differ from exclusively internal mental processes. When people interact with external representations and other objects, their material nature lends stability to mental and social processes (Hutchins, 2005). External representations can

anchor thought; perceivable concrete objects can stand for intangible abstract concepts in a persistent way (Ibid).

In a laboratory study, Alac (2011) documented interactions among expert and novice cognitive neuroscientists using various tools, imagery, speech, and gesture. The sequence and timing of actions reveals how participants create meaning by using their bodies to establish conceptual relationships among representations in different media. Combinations of media and action may serve representational (iconic) functions and linking (indexical) functions. Fields of interaction refer to the physical space shared by participants in their joint project of making meaning with the available resources. Through their activity, participants create an infrastructure for seeing. The participants' bodies play a critical role in making and reading iconic and indexical signs, not alone by their actions, but by their interactions tied to context in sequences of activity. To accomplish the task of making meaning, both Goodwin and Alac emphasize the role of *juxtaposition*—in time and space, bringing together ideas, objects, and signs that signify what is relevant in the field of interaction.

Design involves deliberate shaping of objects for functional and representational purposes. Design exploits analogical mappings between experiences of physical properties (e.g. growth, gravity, bodily motion) and abstract concepts (e.g. good, bad, time) yielding cultural conventions based on image-schemas such as “up is good,” “down is bad,” and “space is time” (Tversky, 2011). These cultural conventions implicitly train people to decode visual-spatial displays. Design conventions also provide a vast reservoir of flexible yet constrained resources for conveying and interpreting information (Ibid; Hegarty, 2011).

External representations permit inference-making by sharing the cognitive load with sensory systems (Kirsh & Maglio, 1994). They provide a substrate for the overlay of imaginary

structure in a process called projection (Kirsh, 2009). External representations provide persistent referents and shareable objects of thought (Kirsh, 2010a); they contribute explicit content for conversational common ground (Clark, 1996). When people talk, they often anchor their gestures to the objects, layering ephemeral dynamic representations over static or predictable representations (Alac & Hutchins, 2004; Goodwin, 2007). When people can manipulate objects, their representational potential expands by changing what is available for perception. Concrete objects in motion can represent conceptual objects *and* their spatial and/or temporal dynamics, exploiting perceptual processes to make those relations more explicit. This alignment of structure between aspects of perceptual experience and mental content may provide the basis for analogical reasoning (Gentner, 2010) and the amazing human capacity for representation (Gentner, 2003).

These varied examples of cognition in interaction highlight issues relevant to this dissertation research in a museum—common activities are often over-looked and not well understood. Humans routinely exploit bodily interaction with the world to solve problems and make meaning. We often take these ubiquitous—and fascinating—cognitive acts for granted. If we can better understand how people use their bodies as they interact with the world to explore and make sense of experience, then we can use that knowledge to design environments for living and learning that work with, not against, human patterns of interaction.

Language as tool

People use language to coordinate their activity, and language provides a powerful means of linkage within and between systems of semiotic resources. Language (speech and

gesture) serves as a tool to mediate experience shared between people. Language requires mutual participation and coordination in a form of joint action (Clark, 1996). Conversation is improvisation, yet regularities—such as turn-taking, adjacency pairs, and a tendency to repair errors in communication or understanding—lend organizing structure to discourse (Schegloff, Jefferson, & Sacks, 1974). In cooperative (non-deceptive) conversation, speakers use an economy of language to achieve mutual understanding, acting on their assumptions about what is common ground or shared knowledge (Clark, 1996). As a result, speakers often tacitly express meaning, using words that listeners (and researchers) can disambiguate using contextual clues including eye gaze, gesture, prosody, and interaction with objects. Multiple individuals deploying multiple modalities (sequentially or simultaneously) may collaboratively construct a meaningful phrase (Hutchins & Nomura, 2011; Goodwin, 2000a; Goodwin, 2000b).

Language also mediates between external experience (perceptual, social, etc.) and internal experience (e.g. imagination) (Vygotsky, 1934). Language can coordinate and connect shared social meanings with individual remembering, associating, and creative thinking. As Lemke observed in great depth in science classes, students and teachers continuously and simultaneously negotiate and navigate social dynamics and science content, often a complex task (Lemke, 1990).

Children use self-directed “egocentric” speech to organize their own activity, and later internalize aspects of self-directed speech to structure speechless thought and action (Vygotsky, 1934). Indeed, speech is a form of thought in action. Everyday models of language often entail internal preformulation of meaning inside the brain/mind that comes out in words, oblivious to development over time and the bodies’ interactions in time. Vygotsky offers an alternative

model. Rather than language acting as a structure that works from the inside out, Vygotsky brings awareness to how language can structure thought from the outside in.

Language shapes and constrains thinking, while revealing both content and processes of thought. Human experience entwines language and perception in myriad ways. Hearing words can direct attention and heighten perceptual saliency of named objects (Lupyan & Spivey, 2010; Levinson, 1997). Embedded in language, like perception, are “dimensions of imagery,” which express part-whole relationships, levels of specificity, scale and scope, and salience of elements, features, and relations (Langacker, 1986). Perceptual experience of space structures language use, and language use structures perceptions of space (Talmy, 2000; 2011). Language can reveal the perceptual and conceptual distinctions that matter. The relationships between language structures and perceptual experience support the perspective that language use allows the researcher access to some cognitive processes of perceptual disambiguation and perceptual relationships (Langacker, 1990).

Experimental research suggests that perceptual and motor simulation play important roles in language production and comprehension (Barsalou, 2008; Yaxley & Zwaan, 2007; Taylor & Zwaan, 2008; Glenberg & Kaschak, 2002; Bergen & Feldman, 2008), suggesting the value and necessity of embodied experience in becoming a competent language user. Perceptual-motor engagement with the world, in coordination with linguistic labels, together provide complementary tools or resources, as humans learn to parse their experience into meaningful chunks. Perception and language patterns affect word learning: perceptual-cognitive functions may dominate when one learns nouns and adjectives, whereas language-based functions exert greater influence when learning relational words such as verbs (including path and manner) and prepositions (Gentner & Boroditsky, 2001). Use of different parts of speech reveals what is

perceptually salient regarding objects marked by nouns and adjectives and their relations specified by verbs and prepositions. This system for describing reality sets the stage for analogical reasoning between concrete experience and abstract concepts—a pervasive function that sets humans apart from other animals (Gentner, 2010).

Language use—as messy, complicated, and confusing as it can be—exhibits some reliable patterns that enable inferences by researchers. Research in pragmatics and cognitive linguistics provides guidance in interpreting language data. Meaningful conversation is an accomplishment constrained by perceptual/ motor/cognitive functions and social/cultural conventions. These patterns help the researcher determine what participants deem as meaningful (Alac, 2011). Speech permits careful inference about relationships of meaning with other forms of thought and action, performed by other modalities and other people in the conversational context.

Gesture, thinking with the hands

Many researchers consider gesture to be a part of language, capable of functions complementary to speech, e.g. expressing spatial and temporal dynamics more effectively (McNeill, 2005). McNeill asserts that imagery comprises an essential aspect of language. In this characterization, speech conveys linear hierarchical meanings in thought, and gesture expresses non-linear imagistic, spatio-temporal aspects of thought (Ibid). Gesture provides information about attentional focus and ideational content (Núñez & Sweetser, 2006; Parrill & Sweetser, 2004). Speakers often create gestures coupled with physical objects. Pointing, perhaps the most common human gesture, makes indexical reference to objects near and far. Indexical gestures

can effectively manage the attention of self and others. Iconic gestures can physically represent objects (both concrete and metaphorical) using correspondences described as *shape-for-shape*, *motion-for-motion*, and *path-for-shape* (Taub, 2001). Gestures can also be independent of any concrete reference. These may be metaphoric in nature, in which the speaker selectively represents some aspect of or association with a concept, such as waving the hand forward to represent the future, conventionalized in most cultures (Núñez & Sweetser, 2006), or symmetrically circling two hands to represent the diversity of life on Earth (Renner, unpublished data). The human body serves as a ready-to-hand representational resource.

Gesture can carry content that is absent in speech (Goldin-Meadow, 2003; Hutchins & Nomura, 2011). In language development, children will combine gesture and speech to express more complex ideas than they can in words alone (Iverson & Goldin-Meadow, 2005). These gesture-speech combinations reliably precede the development of greater sentence complexity in speech (Ibid), a phenomenon that may also relate to learning and practicing a second language, relevant to the bilingual children in our study.

Researchers have described multiple non-exclusive dimensions of gesture relating to presence or absence of concurrent speech, linguistic properties, morphology, conventionality, and semiosis (Kendon, 1980; McNeill, 2005, pp. 6–12; Hutchins & Nomura, 2011). Kendon's classification scheme differentiates sign languages (with formal linguistic structure) from emblematic gestures (with specific morphologies and conventionalized meaning) and gesticulation (which occurs naturally and perhaps unconsciously with speech) (for a review, see Kendon, 2004, pp. 98–105). Kendon subdivides gesticulation into further categories: deictic gestures (or indexicals that point to the referent), beat gestures (that occur with speech, follow a rhythm, and provide emphasis), representational gestures that are metaphoric (carrying

abstract symbolic semantic content) or iconic (enacting, modeling, or depicting features of an object or event) (Ibid).

Many assume the primary function of gesture is exclusively communicative, but research suggests otherwise. Gesture accompanies speech in non-communicative circumstances, e.g. when speakers talk on the phone and interlocutors are not present (Cosnier, 1982; Rimé, 1982), and when congenitally blind people converse with other blind people (Iverson & Goldin-Meadow, 1998).

Various hypotheses seek to explain possible roles of gesture that go beyond communication. Gesture may perform multiple cognitive functions, such as to support spatial problem-solving (Goldin-Meadow, 2003), facilitate lexical access (Alibali, Kita, & Young, 2000), enhance speech comprehension (Goldin-Meadow, 2006; Yu & Coulson, 2007), redistribute cognitive load between verbal, visuo-spatial, and motor processes (Goldin-Meadow, 2006; Wilson, 2001), package information into units to distribute cognitive load (Hostetter & Alibali, 2007), mark conceptual boundaries or categories (Cook, Mitchell, Goldin-Meadow, 2008), abstract key features from perceptual experience (Goldin-Meadow & Beilock, 2010; Kirsh, 2010b), provide visual and somatosensory feedback (Hutchins, 2010b), express and explore spatial configurations (Myers, 2006; Kirsh, 2010b). Gesture may sometimes result from mental simulation of motor activity (Hostetter & Alibali, 2008). These findings suggest that gesture is an act of cognition, not just cognitive effluent, and thus provides information to researchers about how people construe various meanings (Núñez & Sweetser, 2006).

Temporal relations in speech and gesture help the researcher to discern what is the relevant content and how participants weave together meaning from experience (Alac, 2011).

Therefore, the discourse analysis in this proposed research includes multiple modalities, including speech and gesture, and how they are coupled with the environment.

Relationships between perceptual and conceptual

The assertion that abstract conceptual knowledge derives from concrete perceptual experience goes back at least to Aristotle. But recent work in cognitive psychology corroborated by cognitive neuroscience suggests mechanisms that drive these processes, and that challenges uni-directionality and distinct separation between percepts and concepts. *Perceptual Symbol Systems* theory proposes that information derived from the sensory-motor modalities, proprioception, and introspection provide the raw material for schematized abstractions that can be productively and infinitely combined—here lies the key to imagination, conceptualization, and communication (Barsalou, 1999; Goldstone & Barsalou, 1998).

As the theory goes, patterns of neural activation instantiate the physiological mechanism of mental representations originating with embodied experience. A network of active networks could describe brain states that co-occur with the experience of “that dog running.” Subsets of these networks might code for aspects of that experience, i.e. a particular pattern of biological motion, variant and invariant spatial relationships among forms, various colors, etc. Perceptual symbols may be hierarchically composable and decomposable, as they represent abstractions from experience at different levels of detail and specificity. From multiple experiences of seeing, hearing, and feeling how dogs run, the recurrent patterns of activation provide a sorting mechanism for what features might generalize to dogs and running, as well as furry mammal, pointy ears, wet nose, etc. These biologically instantiated symbols can be used in

novel combinations in the absence of perceptual-motor inputs to simulate concrete or abstract objects and relations. Other authors suggest that perceptual symbols should integrate with other descriptions of cognition including conceptual blending, analogical mapping, and metaphor (Fauconnier & Turner, 2002; Gibbs & Berg, 1999). Although researchers will continue to probe the details for years, Barsalou's theory proposes a general solution to the symbol binding problem, suggesting a way to flexibly construct knowledge from experience.

Other research outlines mechanisms of perceptual learning that fit well with Perceptual Symbol Systems. These include *attentional weighting* (task-dependent selective attention and perception of category structures), *stimulus imprinting* (development of functional detectors for recognizing entire stimuli, features, or spatial relations), *differentiation* (the ability to make distinctions among features, categories, and dimensions), and *unitization* (integration of parts into wholes) (Goldstone, 1998). In recent work, researchers discuss the "education of perception" by which experience trains perceptual systems to more efficiently gather information by selecting relevant features and inhibiting irrelevant features (Goldstone, Landy & Son, 2010). They suggest that selective attention in "rigged up perceptual systems" represents processes parallel to or overlapping with so-called higher cognition such as rule-use, and that we adapt our perceptual systems to accommodate conceptual tasks in the world. The training of perception might be construed as processes of abstraction from experience to form concepts that then guide and filter perception. Alternatively, these processes may substantiate claims that perception and conception share cognitive continuity, expressed in their shared root "ception" and described in Talmy's "overlapping systems model" in cognitive organization (2000). A century-old philosophical tradition, grounded in psychological research, suggests that perceptual and conceptual experience merge and interpenetrate, and from the flux of

perceptual and conceptual experience emerges meaning (James, pp. 1007–1020, 1910). Concepts shape perception and enable us to carve objects from perceptual fields, and perceptual experience feeds the formation, elaboration, and abstraction of concepts (Ibid). Strategies for seeing—what Goodwin terms *professional vision*—evolve in communities of practice, depend on social roles and tasks, and include learned conceptual systems of representation, coding, and highlighting (Goodwin, 1994).

In the museum, children make sense of their multisensory engagements, an expression of the varied relationships between perceptual and conceptual experience. This dissertation research discusses perceptual and conceptual processes, without drawing a hard line between them. With regards to observable behavior, the research differentiates between objects of speech that are physically present and presently perceivable, and objects that are absent and brought into conversation through acts of imagination.

Sensemaking entails finding cognitive coherence or resonance, such that objects of attention, both concrete and abstract, can be reconciled into a structure without dissonance. Sensemaking, a fundamental though complex cognitive activity, provides the impetus for research in many disciplines. The term appeared in the applied psychology literature in the 1970s, specifically with organizational studies and information science (Weick, 1979; Dervin, 1983). Some researchers in the domain of Human-Computer Interaction describe sensemaking as a two-way process in which data derived from perceptual experience interacts with conceptual frames, or conceptual models (Klein, Moon, Hoffman, 2006). Conceptual frames enable the sensemaker to focus on and select data (perceptual information) from the complicated environment. Perceptual information drives selection of relevant frames; information might fit into a frame and shape modification of frames (Ibid). This formulation

recapitulates Piaget's notions of assimilation (fitting experience with existing mental models) and accommodation (changing mental models to fit with experience) (Piaget, 1969, pp. 4–6). This description of data and frames in sensemaking emphasizes the dialectic between perception and conception, and elaborates on prior work related to scripts, schemas, frames, and mental models (Schank, 1980; Minsky, 1975; Collins & Gentner, 1987). The act of *making sense* highlights participation by the senses, and points to how concrete experience dynamically interacts with and alters abstract concepts and the networks that link concepts.

Cognitive linguistics offers other theoretical frameworks that link bodily experience with concept formation and elaboration. Conceptual metaphor theory suggests that a limited set of physical relations understood within a cultural context, called image schemas, provides the scaffolding on which humans construct meaning (Lakoff, 1993; Lakoff & Johnson, 1980, pp. 56–60). These image schemas serve as source domains with generalizable cognitive content that maps to target domains with specific cognitive content. In other words, the structure of the source domain (or image schema) shares inherent structural attributes with the target domain (Lakoff, 1993). Examples of image schemas include SOURCE-PATH-GOAL, CONTAINMENT, EQUILIBRIUM, and FORCE DYNAMICS (Johnson, 1987, p. 126; Talmy, 1988). Conceptual metaphor provides a concrete perceptual basis for reasoning about abstract concepts (Johnson, 1987). The foundations of image schemas and conceptual thought may originate in infancy, as children unconsciously extract and analyze features from perceptual experience and organize them into groups based on similarity (Mandler, 2004, p.14). The image schema account sits squarely with the Perceptual Symbol Systems framework, which describes a similar process of filtering and storing in memory commonly shared features that cut across multiple instantiations (Barsalou, 1999). Meaning arises from the selective reactivation of relevant

abstracted features; in this way perceptual symbols have compositional capability (Ibid). These condensed descriptions of how humans make meaning assert that what we call “higher-order cognition,” e.g. abstract reasoning and conceptual metaphor, is grounded in accumulated, filtered, and sorted perceptual experience.

Research in cognitive linguistics and neuroscience aligns with an embodied account of how people generate meaning from experience. In cognitive linguistics, experimental evidence from numerous studies suggests that language comprehension involves visual and motor simulation and implicates the use of primary perceptual and motor brain areas tuned for simulation by experience in the physical world (for a review, see Bergen & Feldman, 2008). A few examples illustrate the point. Participants seem to engage in mental simulation of rotating visual imagery to make a similarity judgment between two images, a conclusion based on reaction times that were directly proportional to the angle of displacement between the two images, suggesting that larger angles take more time to mentally rotate (Shephard & Metzler, 1971). Participants seem to use motor simulation when they judge the sensibility of a sentence involving motion, based on quicker response times when they move their bodies in a manner compatible with the verbal description (Glenberg & Kaschak, 2002). Using neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), researchers have shown differential activation of motor cortical areas when participants process language with motor action content (Greze & Decety, 2001). For example, when engaged in a lexical decision task involving effector-specific verbs (hand, foot, or mouth), motor cortex showed corresponding activity in areas dedicated to movement of the hand, foot, or mouth (Pulvermüller, Haerle, & Hummel, 2001). Brains may learn associations between language and mappings to body parts and, through Hebbian learning rules, create flexible neural assemblies that involve distributed

region-specific activations implicated in language production and comprehension (Pulvermüller, 1999). The robustness of conceptual knowledge derives from its distribution over many brain regions, including primary sensory and motor areas that participate in networks of perception, action, memory, and consequently, learning (Fuster, 1997). The body actively seeks sensory information and the body recruits perceptual-motor functionality to cohere concepts.

Museums, engagement, and learning

Museums serve a dual cultural purpose—they acquire, create, and maintain collections of objects and representations, and they exhibit these collections to the public. Material culture and museum studies explore the multi-faceted nature of objects as representations (Dudley, 2010), but often in a non-scientific way. Cognitive science offers theory and methodological tools to examine museums' representational technology and their cognitive consequences. Although the cultural historical roots of cognitive science created a preoccupation with internal mental representations, a vanguard in the field has demonstrated how action constitutes a visible form of cognition (Noë, 2004; Spivey, 2007; Clark, 2008), and interaction with external representations serves a critical function in human cognitive accomplishments (Nersessian, 2012; Kirsh; Gooding, 2010; Bechtel, 2013; Becvar, Hollan, & Hutchins, 2005; Hutchins & Palen, 1998; Alac & Hutchins, 2004; Hutchins, 2005). At the intersection of museum studies and cognitive science, we see how material structure in the designed environment generates social, cognitive, behavioral patterns.

The community of informal learning professionals have issued various research agendas. The Museum Learning Collaborative established at the University of Pittsburg in 1999, asserted

a philosophical commitment to sociocultural theory and outlined an agenda centered on three themes 1) learning and learning environments; 2) interpretation, meaning, and explanation; 3) identity, motivation, and interest (Schauble, Leinhardt & Martin, 1997). Informal science education researchers have emphasized the need to examine learning processes, not just learning products (Rennie, Feher, Dierking & Falk, 2002). The National Research Council's extensive literature review *Learning Science in Informal Environments* advocates for developing theory that integrates "cognitive, affective, and sociocultural accounts of learning" (Bell, Lewenstein, Shouse & Feder, 2009).

In museums and informal science education communities, professionals advocate for multisensory and interactive learning environments. Various informal science education researchers have examined aspects of multisensory engagement and multimedia presentation, and articulated some critical concerns: apprehendability, physical interactivity, conceptual coherence, and reaching diverse learners (Allen, 2004); social interaction, co-participation, and collaboration (Heath & vom Lehn, 2008; Borun & Dritsas, 1997); activity frameworks (Humphrey & Gutwill, 2005); prior knowledge (Roschelle, 1995); and pitfalls in design (Allen & Gutwill, 2004). Others describe how learners use dialogue and action to engage in inquiry (Ash, 2003; Randol 2005). Educational psychologists have explored the nature of multisensory interaction, suggesting that consistency and coherence in visual and verbal modes of presentation enhances learning (Mayer, 1997). Learners actively select, organize, and integrate visual and verbal information (Ibid), and use a variety of strategies to interact with multimedia/multimodal presentations: for example, they dialogue with, control, manipulate, search, and navigate content (Moreno & Mayer, 2007). Also in mathematics education, researchers are delving into how embodied activity (movement through operational actions and representational gestures)

may constitute or reflect abstract conceptualization and conceptual change (Abrahamson, Gutiérrez, Lee, Reinholz & Trninic, 2011; Goldin-Meadow & Singer, 2003).

In the context of educational research, “multimodal” often refers to multiple modes of presentation or delivery of content (e.g. audio and visual) and describes an aspect of educational technology. In cognitive science research, “modality” refers to a channel for the flow of information in a bodily sense. “Multimodal” refers to use and integration of multiple sensory and motor modalities; “multimodal” simultaneously describes the nature of embodied experience and neural information processing. This research sits at the intersection of education and cognitive science and explicitly seeks to bridge these different construals of “multimodal” by looking at how learners’ multiple sensory, motor, and expressive modalities come into coordinated action with informational content and design in various media (or modes of presentation) in a natural history museum.

Models of learning and educational theory

Within the extended community of learning research focused on formal education (schools) and informal education (museums and other non-school settings), two epistemological paradigms predominate: objectivism and constructivism. Each paradigm carries multiple entailments, including the construal of objectivism and constructivism as dichotomous. Researchers in museum learning articulate how views on epistemology find expression in pedagogy (Hein, 1996; Rowe, 2002).

The objectivist view suggests that phenomena are objectively knowable and, in its extreme form, contends that one can discover Absolute Truth. Objectivist approaches to education implicitly or explicitly entail a relatively stable body of knowledge that should be imparted to learners through direct instruction (Engelmann & Carnine, 1971). As the name suggests, the Direct Instruction model emphasizes the instruction side of learning with a focus on content and delivery. Employing a behaviorist model, the Direct Instruction model contends that structured instructional stimuli should result in particular responses that equate with learning.

In contrast, Constructivist approaches to education grew out of Piaget's developmental research, emphasizing that children uniquely construct knowledge for themselves through sensory-motor experience in the world (Piaget & Inhelder, 1969). Vygotsky and succeeding activity theorists assert the critical role of cultural practices, social mediation, and tool use in the process of knowledge construction (Vygotsky, 1978; Cole & Engeström, 1993; Lemke, 1997). The Constructivist perspective takes pedagogical form in Discovery Learning models in which children engage in collaborative processes of inquiry and problem solving (Dewey, 1938; Bruner,

1961). Many approaches to discovery learning exist. Some include variations of hands-on, project-based, and service learning. Discovery Learning puts greater emphasis on the learner and learning process skills, with content knowledge as both means and ends, rather than the singular goal.

These two epistemological paradigms take form in museum cultural practices, exhibitions, and programs, often in non-dichotomous ways. Direct Instruction has an analog in informal settings with an emphasis on information transmission. Discovery learning, a term often used in informal settings, emphasizes opportunities for embodied exploration and social interaction. Traditionally, content experts and curators have advocated, implicitly or explicitly, for information transmission models focused on content. Educators, exhibit designers and developers often advocate for embodied exploration and social interaction focused on learners and interaction. Many current efforts seek to reconcile these perspectives, within and across institutions (21st Century Learning in Natural History Settings Conference, 2012).

In education, as in cognitive science, researchers and practitioners may focus more on the entities of information and knowledge or on the processes of exploration, interaction, and learning. Deep understanding demands an integration of these perspectives. When observing people in real-world settings, we find that “all socially organized activities provide opportunities for learning to occur, including learning that is different from what a teacher or designer might wish” (Greeno, 2006). Information and knowledge acquired by others provide resources for learning, but how can those resources be used for greatest impact?

“Additional research is needed to explore what physical, social, and symbolic tools best support science learning in informal environments. Researchers should build on the current research findings from studies of science learning in informal settings and draw more on

approaches from across related fields (educational research, cognition, anthropology) to identify and adapt methods of discourse and conversational analysis, as well as observation techniques, that have been effective in describing settings in such a way that they can be compared, measured, and analyzed for change over time.” An interdisciplinary cognitive science approach serves this direction for necessary research as articulated by the National Research Council (Bell, Lewenstein, Shouse & Feder, 2009).

With an understanding of cognition as embodied, situated, and distributed, we discover how action gives form to thought. Through observation, we see how activity has regular structure, constrained by physical properties of bodies and objects, cultural practices, and the historical accumulation and distillation of cognitive effort in artifacts. By examining cognitive ecosystems, the functions and distribution of cognitive labor (in space and time, across people, modalities, and artifacts) become clear. In this systems-oriented approach, we discover the cognitive consequences of interaction in environments designed for learning. From these discoveries, we can make inferences about how design can facilitate or inhibit learning processes, to build theory and articulate implications for design and educational practice.

References

21st Century Learning in Natural History Settings Conference. (2012). Smithsonian Institution, National Museum of Natural History, organized by B. Watson. Funded by the National Science Foundation.

Abrahamson, D., Gutiérrez, J. F., Lee, R. G., Reinholz, D., Trninic, D. (2011). From tacit sensorimotor coupling to articulated mathematical reasoning in an embodied design for proportional reasoning. In R. Goldman (Chair), H. Kwah & D. Abrahamson (Organizers), & R. P. Hall (Discussant), *Diverse perspectives on embodied learning: What's so hard to grasp?* Symposium presented at the annual meeting of the American Educational Research Association, New Orleans.

Alac, M. (2011). *Handling Digital Brains: A Laboratory Study of Semiotic Multimodal Interaction in the Age of Computers*. Cambridge, MA: The MIT Press.

- Alac, M., Hutchins, E. (2004). I see what you are saying: Action as cognition in fMRI brain mapping practice. *Journal of Cognition and Culture*, 4.3.
- Alibali, M., Kita, S., Young, A. (2000). Gesture and the process of speech production: We think, therefore we gesture. *Language and Cognitive Processes*, 15 (6): 593–613.
- Allen, S. (2004). Designs for Learning: Studying Science Museum Exhibits That Do More Than Entertain. Published online in *Wiley InterScience* (www.interscience.wiley.com).
- Allen, S., Gutwill, J. (2004). Designing with multiple interactives: Five common pitfalls. *Curator* 47(2): 199–212.
- Ash D. (2003). Dialogic inquiry and biological themes and principles: Implications for exhibit design. *Journal of Museum Education* 28(1), 8-13.
- Barsalou, L. (1999). Perceptual symbol systems. *Brain and Behavioral Sciences*, 22: 577–660.
- Barsalou, L. 2008. Grounded cognition. *The Annual Review of Psychology*, 59:617–45.
- Bateson, G. (1972). *Steps to an Ecology of Mind*. Chicago, IL: University of Chicago Press.
- Bechtel, W. (2013). Understanding biological mechanisms: Using illustrations from circadian rhythm research. In Kampourakis, K. (Ed.) *Philosophical issues in biology education*. New York, NY: Springer.
- Becvar, L.A., Hollan, J., Hutchins, E. (2005). Hands as molecules: Representational gestures as cognitive artifacts for developing theory in a scientific laboratory. *Semiotica*, 156-1/4: 89–112.
- Beilock, S. L., Goldin-Meadow, S. (2010). Gesture changes thought by grounding it in action. *Psychological Science*, 21, 1605-1610.
- Bell, P., Lewenstein, B., Shouse, A., Feder, M. (2009). *Learning Science in Informal Environments: People, Places, and Pursuits*. Committee on Learning Science in Informal Environments, National Research Council. Washington, DC: The National Academies Press.
- Bergen, B., Feldman, J. (2008). Embodied concept learning. In Paco Calvo and Toni Gomila (Eds.) *Handbook of Cognitive Science*. Philadelphia, PA: Elsevier.
- Borun, M., Dritsas, J. (1997). Developing family-friendly exhibits. *Curator*, 40(3), 178–196.
- Bruner, J.S. (1961). The act of discovery. *Harvard Educational Review*, Vol 31, 21-32.
- Churchland, P., Ramachandran, V., Sejnowski, T. (1994). A critique of pure vision. In C. Koch & J.L. Davis (Eds.) *Large-Scale Neuronal Theories of the Brain*. Cambridge, MA: The MIT Press.
- Clark, A. (2008). *Supersizing the Mind: Embodiment, Action, and Cognitive Extension*. New York: Oxford University Press.

- Clark, H. (1996). *Using Language*. Cambridge, UK: Cambridge University Press.
- Cole, M. & Engeström, Y. (1993). A cultural-historical approach to distributed cognition, in *Distributed cognitions: Psychological and educational considerations* (1–46). Cambridge: Cambridge University Press.
- Cole, M., Griffin, P. (1980). Cultural amplifiers reconsidered. In D. Olson (Ed.), *Social Foundations of Language and Thought*. New York: W. W. Norton.
- Collins, A., Gentner, D. (1987). How people construct mental models. In N. Quinn & D. Holland (Eds.), *Cultural Models in Language and Thought*. Cambridge, MA: Cambridge University Press, 243–265.
- Cook, S.W., Mitchell, Z., Goldin-Meadow, S. (2008). Gesturing makes learning last. *Cognition*, 106:1047–1058.
- Cosnier, J. (1982). Communications et langages gestuels. In Cosnier, Coulon, Berrendonner, Orecchioni (Eds.), *Les voies du langage, communications verbales, gestuelles et animales*, Dunod, Paris, 255-304.
- Dervin, B. (1983). An overview of sense-making research: Concepts, methods and results. Paper presented at the annual meeting of the *International Communication Association*, Dallas.
- Dewey, J. (1938). *Experience and Education*. New York, NY: Kappa Delta Pi.
- Dudley, S. (Ed.) (2010). *Museum Materialities: Objects, Engagements, Interpretations*. New York, NY: Routledge.
- Engelmann, S., Carnine, D. (1971). *Theory of Instruction: Principles and Applications*. New York: Irvington Publishers, Inc.
- Falk, J. and Dierking, L. (2000). *Learning from Museums: Visitor Experiences and the Making of Meaning*. Walnut Creek, CA: AltaMira Press.
- Fauconnier, G. Turner, M. 2002. *The Way We Think: Conceptual Blending and the Mind's Hidden Complexities*. New York, NY: Basic Books.
- Fuster, J. (1997). Network memory. *Trends in Neuroscience*, Vol. 10, No. 10. (451–459).
- Gardner, H. (1985). *The Mind's New Science: A History of the Cognitive Revolution*. New York, NY: Basic Books.
- Garritty, C. (1998). *Does the use of hands-on learning, with manipulatives, improve the test scores of secondary education geometry students?* Master's Program Action Research Project, St. Xavier University.

- Gentner, D. (2003). Why we're so smart. In D. Gentner and S. Goldin-Meadow (Eds.), *Language in Mind: Advances in the Study of Language and thought* (pp.195-235). Cambridge, MA: MIT Press.
- Gentner, D. (2010). Bootstrapping the mind: Analogical processes and symbol systems. *Cognitive Science*, 34: 752–775.
- Gentner, D., Boroditsky, L. (2001). Individuation, relational relativity and early word learning. In M. Bowerman & S. Levinson (Eds.), *Language Acquisition and Conceptual Development*. Cambridge, UK: Cambridge University Press.
- Gibbs, R.W., Berg, E.A. (1999). Embodied metaphor in perceptual symbols, *Behavioral and Brain Sciences* 22 (4):617-618.
- Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*. Boston, MA: Houghton Mifflin.
- Glenberg, A. M., Kaschak, M. P. 2002. Grounding language in action. *Psychonomic Bulletin & Review*.
- Goldin-Meadow, S. (2006). Talking and thinking with our hands. *Current Directions in Psychological Science*, 15(1): 34–39.
- Goldin-Meadow, S. (2003). *Hearing Gesture: How Our Hands Help Us Think*. Cambridge, MA: Harvard University Press.
- Goldin-Meadow, S. (2006). Talking and thinking with our hands. *Current Directions in Psychological Science*, 15, 34–39.
- Goldin-Meadow, S., Singer, M. A. From children's hands to adults' ears: Gesture's role in the learning process. *Developmental Psychology*, 39 (3), 509–520.
- Goldstone, R. L. (1998). Perceptual Learning. *Annual Review of Psychology*, 49, 585-612.
- Goldstone, R.L. (2003). Learning to perceive while perceiving to learn. In R. Kimchi, M. Behrmann, & C. Olson (Eds.) *Perceptual Organization in Vision: Behavioral and Neural Perspectives*. Mahwah, NJ: Lawrence Erlbaum Associates Publishers.
- Goldstone, R.L., Barsalou, L. (1998). Reuniting perception and cognition. *Cognition*, 65, 231–262.
- Goldstone, R. L., Landy, D. H., & Son, J. Y. (2010). The education of perception. *Topics in Cognitive Science*, 2, 265-284.
- Gooding, D.C. (2010). Visualizing scientific inference. *Topics in Cognitive Science*, 2 15–35.
- Goodwin, C. (1994). Professional vision. *American Anthropologist*, 96(3): 606–633.
- Goodwin, C. (2000a). Action and embodiment within situated human interaction. *Journal of Pragmatics* 32: 1489-522.

- Goodwin, C. (2000b). Gesture, Aphasia and Interaction. In *Language and Gesture: Window into Thought and Action*, edited by David McNeill. Cambridge, MA: Cambridge University Press, pp. 84-98.
- Goodwin, C. (2007). Environmentally Coupled Gestures. In *Gesture and the Dynamic Dimensions of Language*, edited by Susan Duncan, Justine Cassell, and Elena Levy. Amsterdam/Philadelphia: John Benjamins. pp. 195-212.
- Gray, R., Tan, H.Z. (2002). Dynamic and predictive links between touch and vision. *Experimental Brain Research*, 145:50–55.
- Greeno, J. (2006). Learning in activity. In K. Sawyer (Ed.) *The Cambridge Handbook of the Learning Sciences* (79–96). New York, NY: Cambridge University Press.
- Grezes, J., Decety, J. (2001). Functional Anatomy of Execution, Mental Simulation, Observation, and Verb Generation of Actions: A Meta-Analysis. *Human Brain Mapping* 12:1–19.
- Haury, D., Rillero, P. (1994). *Perspectives on Hands-On Science Teaching*. ERIC Clearinghouse for Science, Mathematics and Environmental Education.
- Heath, C., vom Lehn, D. (2004). Museums configuring ‘interactivity’: Enhancing engagement in science centres. *Social Studies of Science*.
- Hegarty, M. (2011). The Cognitive Science of Visual-Spatial Displays: Implications for Design. *Topics in Cognitive Science*, Volume 3, Issue 3, 446–474.
- Hein, G. (1996). Constructivist learning theory. In G. Durbin (Ed.) *Developing Museum Exhibitions for Lifelong Learning*. London, UK: The Stationery Office.
- Hein, G. (1998). *Learning in the Museum*. New York, NY: Routledge.
- Horta, M.L. (1992). *Museum Semiotics: A New Approach to Museum Communication*. University of Leicester.
- Hostetter, A., Alibali, M. (2008). Visible embodiment: Gestures as simulated action. *Psychonomic Bulletin & Review*, 15 (3), 495-514.
- Humphrey, T., Gutwill, J. (2005). *Fostering Active Prolonged Engagement: The Art of Creating APE Exhibits*. San Francisco, CA: Exploratorium.
- Hutchins, E. (1995a). *Cognition in the Wild*. Cambridge, MA: The MIT Press.
- Hutchins E. (1995b). How a cockpit remembers its speeds. *Cognitive Science*, 19, 265-288.
- Hutchins, E. (2005). Material anchors for conceptual blends. *Journal of Pragmatics*, 37: 1555–1577.
- Hutchins, E. (2010a). Cognitive ecology. *Topics in Cognitive Science*, 2(3): 1–11.

Hutchins, E. (2010b). Enaction, imagination, and insight. In J. Stewart, O. Gapenne, E. Di Paolo (Eds.) *Enaction*. Cambridge, MA: The MIT Press.

Hutchins, E., Nomura, S. (2011). Collaborative construction of multimodal utterances. In J. Streek, C. Goodwin & C. LeBaron (Eds.), *Embodied Interaction: Language and Body in the Material World* (29-43). New York, NY: Cambridge University Press.

Hutchins, E., Palen, L. (1998). Constructing meaning from space, gesture and speech. In L. B. Resnick, R. Saljo, C. Pontecorvo, and B. Burge (Eds.) *Discourse, Tools, and Reasoning: Situated Cognition and Technologically Supported Environments*. Verlag, Germany: Springer.

Ingold, T. (2011). Bringing anthropology to life. In *Being Alive: Essays on Movement, Knowledge, and Description*. Abington, UK: Routledge.

Iverson, J. M., Goldin-Meadow, S. (1998). Why people gesture when they speak. *Nature*, 396, 228.

Iverson, J., Goldin-Meadow, S. (2005). Gesture paves the way for language development. *Psychological science*, 16(5): 367–371.

Jacobs, R.A., Shams, L. (2010). Visual learning in multisensory environments. *Topics in Cognitive Science*, 2: 217–225.

James, W. (1910). *Percept and Concept and their Practical Uses*. Cambridge, MA: Harvard University.

Johnson, C. (2010). Observing cognitive complexity in primates and cetaceans. *International Journal of Comparative Psychology*, 23: 587-624.

Johnson, M. (1987). *The Body in the Mind: The Bodily Basis of Meaning, Imagination and Reason*. Chicago, IL: University of Chicago Press.

Jones, J. (2002). The art and science of seeing: Applying visual literacy interpretation in natural history museums. *Curator*, 45/4, 257-261.

Kendon, A. (1980). Gesticulation and speech: Two aspects of the process of utterance. In M.R. Key (Ed.), *Relationships of Verbal and Nonverbal Communication*, 207–228. The Hague: Mouton.

Kendon, A. (2004). *Gesture: visible action as utterance*. Cambridge, UK: Cambridge University Press.

Kirsh, D. (2009). Interaction, external representations and sense making. In N. A. Taatgen & H. van Rijn (Eds.), *Proceedings of the 31st Annual Conference of the Cognitive Science Society* (1103-1108). Amsterdam: Cognitive Science Society.

Kirsh, D. (2010a) Thinking with external representations. *Artificial Intelligence & Society*; 25:441–454.

- Kirsh, D. (2010b). *Thinking with the Body*. In S. Ohlsson & R. Catrambone (Eds.), *Proceedings of the 32nd Annual Conference of the Cognitive Science Society*, Austin, TX: Cognitive Science Society (2864-2869).
- Kirsh, D. and Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science*, 18: 513–549.
- Kirsh, D., Muntanyola, D., Jao, R.J., Lew, A., Sugihara, M. (2009). Choreographic Methods for Creating Novel, High Quality Dance. *5th International workshop on Design and Semantics of Form and Movement*.
- Klein, G., Moon, B., Hoffman, R.R. (2006). Making sense of sensemaking 2: A macrocognitive model, *Intelligent Systems, IEEE*, vol.21, no.5, 88–92.
- Lakoff, G. (1993). *The Contemporary Theory of Metaphor*. In Andrew Ortony (Ed.), *Metaphor and Thought* (second edition), Cambridge, MA: Cambridge University Press.
- Lakoff, G., Johnson, M. (1980). *Metaphors We Live By*. Chicago, IL: The University of Chicago Press.
- Langacker, R. (1986). An introduction to cognitive grammar. *Cognitive Science* 10.1-40. 1986.
- Langacker, R. (1990). *Concept, Image, Symbol: The Cognitive Basis of Grammar* (1–32). Berlin, Germany: Mouton de Gruyter.
- Lave, J., Murtaugh, M., de la Rocha, O. (1984). The dialectic of arithmetic in grocery shopping. In *Everyday Cognition*, 67–94. Cambridge, MA: Harvard University Press.
- Leinhardt, G., Crowley, K., Knutson, K. (2002). *Learning Conversations in Museums*. Mahwah, NJ: Lawrence Erlbaum Associates Publishers.
- Lemke, J.L. (1997). Cognition, context, and learning: A Social Semiotic Perspective. In D. Kirshner and Whitson, J. (Eds.) *Situated Cognition Theory: Social, Neurological, and Semiotic Perspectives* Mahwah, NJ: Lawrence Erlbaum Associates.
- Lemke, J. (1990). *Talking Science: Language, Learning, and Values*. Westport, CT: Ablex Publishing.
- Levinson, S.C. (1997). Language and cognition: The cognitive consequences of spatial description in Guugu Yimithirr. *Journal of Linguistic Anthropology*, 7(1): 98–131.
- Lupyan, G., Spivey, M.J. (2010). Redundant spoken labels facilitate perception of multiple items. *Attention, Perception, & Psychophysics*; 72(8): 2236-53.
- Lupyan, G., Spivey, M.J. 2008. Perceptual processing is facilitated by ascribing meaning to novel stimuli. *Current Biology*, Vol. 18, No. 10.

- Mandler, J.M. (2004). *The Foundations of Mind: The Origins of Conceptual Thought*. New York, NY: Oxford University Press.
- Mayer, R. (1997). Multimedia Learning: Are we asking the right questions? *Educational Psychologist*, 32(1), 1–19.
- McNeill, D. (2005). *Gesture & Thought*. Chicago, IL: University of Chicago Press.
- Miller, G. (2003). The cognitive revolution: A historical perspective. *Trends in Cognitive Science*, Vol.7 No.3.
- Minsky, M. (1974). *A Framework for Representing Knowledge*. MIT-AI Laboratory Memo 306.
- Moreno, R., Mayer, R. (2007). Interactive multimodal learning environments. Special Issue on Interactive Learning Environments: *Contemporary Issues and Trends, Educational Psychological Review*, 19:309–326.
- Myers, N. (2006). Molecular embodiments and the body-work of modeling in protein crystallography. *Social Studies of Science*.
- Nersessian, N. J. (2012): Modeling practices in conceptual innovation: An ethnographic study of a neural engineering research laboratory. In U. Feest & F. Steinle (Eds.) *Scientific Concepts and Investigative Practice*, 245–269. Berlin, Germany: DeGruyter.
- Nöe, A. (2004). *Action in Perception*. Cambridge, MA: The MIT Press.
- Núñez, R. & Sweetser, E. (2006). With the future behind them: Convergent evidence from Aymara language and gesture in the crosslinguistic comparison of spatial construals of time, *Cognitive Science*, 30: 401–450.
- O'Regan, J.K., Nöe, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, 24: 939–1031.
- Palmeri, T.J., Tarr, M. (2008). Object recognition and long-term visual memory for objects. In S. Luck & A. Hollingsworth (Eds.), *Visual Memory*. Oxford, UK: Oxford University Press.
- Paris, S. (2002). *Perspectives on Object-Centered Learning in Museums*. Mahwah, NJ: Lawrence Erlbaum Associates Publishers.
- Parrill, F., Sweetser, E. (2004). What we mean by meaning: Conceptual integration in gesture analysis and transcription. *Gesture*, 4:2, 197–219.
- Pea, R. (1993). Practices of distributed intelligence and designs for education. In *Distributed Cognitions: Psychological and Educational Considerations*, 47–88. Cambridge, MA: Cambridge University Press.
- Piaget J., Inhelder, B. (1969). *The Psychology of the Child*. New York, NY: Basic Books.

Pulvermüller, F. (1999). Words in the brain's language. *Behavioral and Brain Sciences*, 22, 253–279.

Pulvermüller, F., Haerle, M., Hummel, F. (2001). Walking or talking?: Behavioral and neurophysiological correlates of action verb processing. *Brain and Language*, 78, 143–168.

Randol, S. (2005). *The Nature of Inquiry in Science Centers: Describing and Assessing Inquiry at Exhibits*. Unpublished dissertation.

Rennie, L., Feher, E., Dierking, L., Falk, J. (2002). Toward an agenda for advancing research on science learning in out-of-school settings. *Journal of Research in Science Teaching*, 40(2): 112–120.

Renner, N. (2010). Unpublished data, video interviews at Crestridge Ecological Reserve.

Rimé, B. (1982). The elimination of visible behavior from social interactions: Effects on verbal, nonverbal and interpersonal variables. *European Journal of Social Psychology*, 12, 113–129.

Robbins, P., Aydede, M. (2009). A short primer on situated cognition. In P. Robbins & M. Aydede (Eds.), *The Cambridge Handbook of Situated Cognition*. Cambridge MA: Cambridge University Press.

Roschelle, J. (1995). Learning in interactive environments: Prior knowledge and new experience. In J.H. Falk & L.D. Dierking, *Public Institutions for Personal Learning: Establishing a Research Agenda*, 37-51. Washington, DC: American Association of Museums.

Rowe, S. (2002). The role of objects in active, distributed meaning-making. In S.G. Paris (Ed.) *Perspectives on Object-Centered Learning in Museums*. Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Salomon, G. (1993). *Distributed Cognitions: Psychological and educational Considerations*. Cambridge, UK: Cambridge University Press.

Schank, R.C. (1980). Language and memory. *Cognitive Science* 4: 243-284.

Schauble, L., Leinhardt, G., & Martin, L. (1997). A Framework for organizing a cumulative research agenda in informal learning contexts. *Journal of Museum Education*, 22, (2&3), 3-8.

Schegloff, E. A., Jefferson, G., Sacks, H. (1977). The preference for self-correction in the organisation of repair in conversation. *Language*, 53, 361-382.

Shams, L. (2011). Early integration and Bayesian causal inference in multisensory perception. In M. Murray & M. Wallace (Eds.), *Frontiers in the Neural Bases of Multisensory Processes*, 217–231. CRC Press, Taylor & Francis Group.

Shepard, R.N., Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*.

- Simons, D. J., Ambinder, M.S. (2005). Change blindness: Theory and consequences. *Current Directions in Psychological Science*, 14: 44-48.
- Simons, D. J., Chabris, C. F. (1999). Gorillas in our midst: Sustained inattention blindness for dynamic events. *Perception*, 28: 1059-1074.
- Spence, C. (2007). Making sense of touch: A multisensory approach to the perception of objects. In E. Pye (Ed.) *The Power of Touch: Handling Objects in Museum and Heritage Contexts*. Walnut Creek, CA: Left Coast Press, Inc.
- Spivey, M. (2007). *The Continuity of Mind*. Oxford, UK: Oxford University Press.
- Talmy, L. (1988). Force Dynamics in language and cognition. *Cognitive Science*, 12, 1, 49–100.
- Talmy, L. (2000). How Language Structures Space, chapter 3 in *Toward a Cognitive Semantics*. Cambridge, MA: MIT Press.
- Talmy, L. (2011). Address to the Cognitive Science Society annual meeting, Boston.
- Taub, S. (2001). *Language from the Body: Iconicity and Metaphor in American Sign Language*. Cambridge, MA: Cambridge University Press.
- Taylor, L.J., Zwaan, R.A. (2008). Motor resonance and linguistic focus. *Quarterly Journal of Experimental Psychology*, 61, 896-904.
- Tversky, B. (2011). Visualizing thought. *Topics in Cognitive Science*, Volume 3, Issue 3, 499–535.
- Tversky, B., Lee, P. (1998). How space structures language. In C. Freksa, C. Habel, and K.F. Wender (Eds.), *Spatial Cognition: An Interdisciplinary Approach to Representation and Processing of Spatial Language* (157–175). Berlin: Springer-Verlag. Volume 3, Issue 3, 446–474.
- Vygotsky, L.S. (1934/1986). *Thought and Language*. Kozulin (Ed.), Hanfmann & Vakar (Trans.). Cambridge, MA: The MIT Press.
- Vygotsky, L.S. (1978). *Mind and Society: The Development of Higher Psychological Processes*. M. Cole, V. John-Steiner, S. Scribner, E. Souberman (Eds.). Cambridge, MA: Harvard University Press.
- Weick, K. (1979). *The Social Psychology of Organizing*. New York: McGraw-Hill.
- Wu, Y.C. & Coulson, S. (2007). How iconic gestures enhance communication: An ERP study. *Brain & Language* 101:234–245.
- Yaxley, R.H., Zwaan, R.A. (2007). Simulating visibility during language comprehension. *Cognition*, 150, 229-236.

3 Research Methods

Seeing cognition in action

Cognitive ethnography, the overarching methodology for this research, reveals to the researcher cognition in action. Cognitive ethnography, comprised of an evolving set of methods, documents the “natural history of a cognitive system” (Hutchins, 1995) by describing diverse cognitive forms and their functions, their occurrence and distribution, and their relationships within social-cultural-material environments. This research involved a collection of methods—video recording from multiple perspectives, systematic coding of video, and variations of multimodal discourse analysis to reveal the details of children’s cognition in action in a natural history museum.

Looking closely and repeatedly at human behavior using video recordings as the primary data source, we see the complexity of interaction and discourse structure that is impossible to perceive in real time. Video provides a persistent record, which enables researchers to view and re-view behavioral sequences, multiple times and at various speeds. Digital tools support video annotation with forms of coding and highlighting that permit pattern detection at multiple scales in space and time. Video coding generates data for quantitative analyses, supporting inquiry about the frequency, co-occurrence, sequences, and distribution of cognitive events of interest. Video data also provide the primary source for qualitative descriptions of coordinated perception, action, representation, and meaning-making. Employing methods of cognitive ethnography focuses both on *what* meanings emerge through interaction and *how* people construct meaning through coordination of body-based resources, social interaction, cultural practices, and use of artifacts (Williams, 2006).

Making sense and making meaning in a multisensory museum

This naturalistic study tackles the complexity of human interaction head-on. The research questions—*How do children use exhibits in a natural history museum? How do they make sense of their multisensory experiences? What are the cognitive consequences of design?*—required methods for documentation and detailed analysis of children’s behavior in the museum context. The research methods involved video analysis of exhibit interactions among six children in three fourth-grade classes from a museum immersion program. Research methods included four major activities: collection of primary data in the form of video (with first-person and third-person perspectives), generation of secondary and tertiary data through systematic coding of the video, quantitative analyses of secondary and tertiary data (coded video), and qualitative analyses of primary data (video). Like a naturalist in the wild, I collected, classified, and described “specimens” of the children’s activity in the museum setting. This mix of methods supports documentation and description of the uniqueness, distribution, abundance and scarcity, and patterns of similarity and difference among activity “specimens” recorded on video. The analysis reveals how features of the museum ecosystem afford, influence, and constrain various forms of activity. Consequently, the analysis supports inferences about the cognitive consequences of design.

A methodology translates theory into active inquiry. The theories that serve as a foundation for this research—embodied, situated, and distributed cognition—identify important elements and their functions in a human cognitive system. Methodology defines what we look at and how we look. To examine how children use the museum and to understand the organization of their complex behavior, this research focuses on critical observable aspects of interaction—how children integrate perception and action as they engage with exhibits and

each other. Children **look** at things; they **touch** and **manipulate** objects; they **talk**, **gesture**, and **read**. How, when, where, and with whom do these behaviors occur? How do these actions combine into multimodal configurations? How do they occur in sequence? How do children *use* the museum exhibits, and what are the cognitive consequences? Applying multiple perspectives and a mixed methods approach, this research documents the existence of patterns of activity, the magnitude of those patterns, and relationships between behavioral patterns and features of the designed environment. New coding schemes and new approaches to analysis have resulted in methodological development; the results contribute new knowledge and implications for design and education.

An elaboration of the cognitive ethnography methodology follows, accompanied by more detailed descriptions of the methods used. Exploration of a natural history museum, a unique cognitive ecosystem, involved development of specific coding schemes that made visible cognitive phenomena of interest. Accompanying the description of methods are notes on iterative developments and lessons learned.

Methodology provides structure and discipline for observation

Cognitive ethnography provided the methodological framework for creating a case study of a natural history museum exhibition, based on observations of six children's exhibit interactions. Observational methods, drawing on multimodal discourse analysis and micro-ethology, involve a combination of coding, transcription, and narrative description to reveal, and then communicate, the organizational structures and processes of cognition in activity.

Cognitive ethnography focuses on the details of human interaction, with the goal of describing and explaining how participants organize their activity and make meaning in their “cognitive task world” (Hutchins, 1995). This methodology derives from the theory of Distributed Cognition and the theoretical assertion that everyday human cognition and activity, shaped and constrained by culture and history, abides by various forms of organizing structure (Ibid). Cognitive ethnography focuses on the *processes* of meaning-making, and stands in contrast to traditional approaches to ethnography in anthropology, which tend to focus on the *objects* of meaning in a community, their artifacts and practices (Williams, 2006).

Cognitive ethnography focuses attention on when and how participants create representations and propagate those representations, using various media, across space and time (Hutchins, 1995). According to Hutchins, the researcher should inquire *what information goes where, when, in what form?* Cognitive ethnography offers a means to understand cognitive ecosystems, the entities, processes, and relationships that comprise and organize intelligent human activity—including, but not limited to, individuals (Hutchins, 2010). From this perspective, cognitive tasks define the changing boundaries of cognitive systems. Indeed, in any moment of human activity, we can observe cognition at multiple time scales. At a micro-scale, we see how an individual or group comes into perceptual-motor coordination with the environment. At a meso-scale, current activity is both a product and a reflection of developmental trajectories, also of variable time scales. At a macro-scale, cultural practices and artifacts make the activity possible, and in turn, may be changed by the activity (Hutchins, 1995; Lemke, 2000). This research focuses at micro- and meso-scales, examining moments of multimodal engagement and sequences of action that combine into coherent meaningful activities in the museum. Professional practices in Cognitive Science and Museum Studies

provide conceptual structure that supports the interpretation of activity in the museum at different time scales. Concepts from these communities guide the categorization and coding of activity, bringing order to the process of seeing and describing organization in activity (Hutchins, 2012).

Multimodal discourse analysis explores the interconnections among social actors, cultural tools, actions, and practices (Norris, 2011). Emanating from theories of language and meaning as context-bound, multimodal discourse analysis identifies relevant resources and actions in discourse events (including speech, gesture, eye-gaze, use of artifacts), bringing attention to sequences and juxtapositions that build webs of meaning (Goodwin, 1996). Multimodal discourse analysis draws from and aligns with other similar approaches that attend to the micro-details of interaction: Conversation Analysis (Sacks, 1992; Schegloff, 1992) and Interaction Analysis (Jordan & Henderson, 1996; Sawyer, 2006).

Micro-ethology, pioneered in animal behavior studies, involves documenting organism's interactions with the environment in fine-grained detail based on frame-by-frame analysis of video to generate data for qualitative and quantitative analysis (Johnson, 2011). Micro-ethology, when combined with Distributed Cognition theory (Hutchins, 1995), makes three methodological commitments, presented here in the form of "rules":

1) Interaction is the unit of analysis. Coding schemes articulate relational actions (e.g. animal A turns *toward* B or A turns *away from* B, rather than A turns).

2) Coding schemes focus on changes in the configuration of bodies relative to the social and physical environment. Sensorimotor activities bring organisms into adaptive coordination with the environment, constituting a visible form of cognition.

3) Examination of interaction at multiple time scales supports understanding of how cognitive functions may be distributed in time and space. Events at smaller time scales derive meaning from their embedding in sequences and histories of longer time scales (Ibid). A multiscale perspective is central to Cultural-Historical Activity Theory (Cole & Engeström, 1993) and Social Semiotics or situated meaning-making (Lemke, 1997), also sources of inspiration for this research in a museum.

Primary data — Video data collection

Video recording provides a stable record of activity that enables repeated viewing and detailed analysis. To explore how children use the exhibits in a natural history museum, our research team video-recorded multiple fourth-grade classes using paleontology and geology exhibits in a bilingual exhibition entitled *Fossil Mysteries/Misterios fósiles*.

The fourth-grade students in this study participated in a museum immersion program, in which they spent several weeks of their school year at various museums. These students are characterized as low socio-economic status. Over 90% are classified as English Language Learners; approximately 70% are Spanish-English bilinguals. Parents granted permission for the children's research participation on a form made available in English and Spanish.

Over several months, we recorded children in two different circumstances: when the students could freely explore the exhibition with minimal adult intervention and when they participated in a structured lesson in the plate tectonics gallery (figure 3.1). In the "free explore" mode, members of the research team focused video cameras on one boy and one girl in each of three classes. Some children also wore head-mounted video cameras. Our video record includes

third-person perspective for three children's exhibition experiences and both third-person perspective and first-person perspective (shot with the head-mounted camera) for three children. Including the first-person perspective video increases the information in the record of activity, an issue discussed in more detail below. Additional stationary video cameras recorded interactions at three interactive exhibits.

Free explore (minimal* formal instruction in exhibition)					
class 1	11/9/09	Fossil Mysteries	photos, field notes	social groups	
2	11/16/09	Fossil Mysteries	audio/video: 3 rd person, audio	1 boy, 1 girl	40 min each
3	11/30/09*	Fossil Mysteries	audio/video: specific exhibits, 1 st and 3 rd person	1 boy, 1 girl	35 min each
4	12/07/09*	Fossil Mysteries	audio/video: specific exhibits, 1 st and 3 rd person	1 boy, 1 girl	40 min each
Lesson (teacher-led structured activity in the exhibition and a writing assignment)					
class 1	2/23/10*†	Fossil Mysteries: Plate Tectonics	audio/video: 1 st and 3 rd person	2 boys, 2 girls (same kids as 11/9/09)	30 min each
4	4/21/10	Fossil Mysteries: Plate Tectonics	audio/video: 1 st and 3 rd person	1 boy, 1 girl (same kids as 12/07/10)	15 min, 25 min
Primary Data: Video, focal participant interactions with exhibits, "Free explore" mode					230 minutes
Video, focal participant interactions with exhibits, "Free explore" and "Lesson" total					11 hours
Supplemental Video * stationary video cameras focused on interactive exhibits, †additional 3 rd person video of six additional kids					5 hours
Secondary & Tertiary Data: Coded Video, annotated in great detail					166 minutes

Figure 3.1. Video data collection schedule with fourth-graders in a natural history museum. The research team collected data when opportunities were available, based on the museum immersion program's schedule of classes using *Fossil Mysteries*. The methods and results reported here focus on children's activity in "free explore" mode, although the children can never be completely free of well-practiced classroom patterns of interaction between children and adults.

This research focuses exclusively on children’s interactions in “free explore” mode, to investigate how children use the exhibits with minimal adult intervention. Collecting and analyzing the whole data set (11+ hours) has enriched my understanding of the children, their patterns of social interaction, their cognitive development, and the range of possible uses of the exhibits. In addition, my participation in the design and development of the exhibition provides additional expertise in interpreting the children’s actions, drawing on knowledge of the content and affordances of each exhibit, and the spatial and conceptual organization of the exhibition as a whole.

Video perspectives: First and third person

Video recorded from two perspectives—the child’s point of view and the researcher’s point of view (figure 3.2)—offers insights into how children use the museum exhibits. This dual-perspective provides exceptionally rich data about children’s perceptual and social experiences while interacting with exhibits. The richness derives from the complementarity of the two perspectives. Charles Goodwin asserts that the camera angle constitutes a theory about what the researcher deems to be, or not to be, important (1994). The choice to record both first-person and third-person perspectives—to capture what is within the participant’s field of view and the context of his/her activity—makes several theoretical commitments. Two camera views provide more information about the world as encountered and manipulated by the child. Pushed into the foreground we see the consequences of perceptual engagement, bodily activity especially involving the hands, interaction with objects, and various uses of language for children in the museum. A genuine effort to see the museum from the children’s perspective has resulted in a fuller description of how children use the museum and make sense of their museum experience.



Figure 3.2. Two synchronized streams of video, the child's perspective on the left and the researcher's perspective on the right, provide a rich record of children's activity in the museum.

The first-person perspective, shot with a head-mounted camera, allows the researcher to see what is within the child's visual field and therefore, what is available for visual perception.¹ An approximate view of the child's visual field, combined with eye gaze from the third-person perspective, allows triangulation of the objects of their visual attention and, therefore, referents of speech. Head movements and rapid shifts of visual attention are much more salient with the first-person perspective video. The head-mounted camera puts the recording device *inside the activity*, capturing views and a sense of the experience that would be impossible otherwise. In some cases, the first-person video records actions of the hands, responses of objects (specifically interactive displays), actions of others (including facial expressions) that the third-person view often misses due to occlusion in the line of sight between the camera and the target of attention. Coupled with the first-person video, children wore a digital audio recording device. In this way, we captured all the children's speech, speech directed toward others and self-directed speech, even when only whispered.

In addition to these perceptual aspects, less tangible benefits result from integrating first-person audio/video in the analysis. For researchers who remain outside the children's activity by the facts of physical existence, the first-person audio/video expands empathy for the

child at the center of the activity. A deeper sense of the emotional dimensions of their exploratory processes, their anticipation, excitement, and moments of frustration comes from the child at the center of the analysis, literally and figuratively. With my professional involvement in the creation of the exhibition, I can imagine a range of possible engagements with the exhibits. I can see the children's interactions in relation to this range of possibilities. I see when the physical design or social dynamics open or block access to objects and ideas. Despite my awareness and observation of many possibilities, the children still surprise me with their creativity as they interact and make meaning with what the museum makes available. Getting inside the children's activity has challenged and expanded my notions of what might constitute *learning* in the museum.

The third-person perspective, recorded in a traditional manner with hand-held cameras by me and my research assistants, documents the children's activity in context. We aimed to capture the most informative views, keeping the focal participant's face, hands, and everything in between, within the camera frame. Some things made achieving this goal difficult: children's rapid movements, visual occlusion due to exhibits and other people, efforts to respect the social/personal space of participants, managing too many cameras (hand-held, head-mounted, and stationary), and not maintaining disciplined continuous focus on one participant for the entire gallery visit. By reflecting on our practice of video recording and acting on lessons learned, the quality of the video data improved with each subsequent session.

Lessons learned about recording video

Video recording people as they interact and move through space presents many trade-offs and challenges. The researcher wants to capture the most informative data for interaction

analysis. Wide views may include more context at the expense of detail and resolution of manual activity, gaze direction, or facial expressions. The researcher may want a frontal view of the activity, yet remain unobtrusive to the participants. Objects in the environment may obstruct optimal camera angles, so working the camera requires on-the-fly judgments to adapt to changing configurations of people and objects in space. From my experience in shooting and analyzing video for this study of multimodal interaction, I share my lessons learned, drawing on frustrations and delights.

For multimodal analysis of interaction, the most informative camera angle captures the focal participant's face, torso, arms and hands, and objects involved in interaction. The spatial layout of the environment may not permit a frontal view, so a side-view may be the only option. Moving away from a profile view around the back of the participant results in potential loss of critical information about eye gaze, facial expression, visual attention, and activity of the hands. With the camera in front of the participant, objects of visual attention may be outside the camera's view. A first-person video camera (head-mounted or hat-mounted) captures the visual field of the participant, often including objects of attention, referents of speech, and actions of the hands.

Numerous software applications for video analysis permit synchronization of two or more video sources.² The continuity of a participant's activity may be critical for analysis, so the videographer must resist the temptation to turn the camera away from the focal participant where something more exciting might be happening. To collect high quality video data on interaction sequences requires the discipline to stick with the focal participant. The video camera's built-in microphone may not provide sufficiently high quality audio. Wireless lapel microphones or digital audio recorders worn by participants offer viable alternatives. If

recording multiple streams of data (video and audio), create a distinct audio/visual signal recorded on all media, such as a brisk hand-clap, after you start recording. This provides a clear signal for synchronizing all the data streams for editing and annotation. If possible, use recording devices with the same frame rate for maintaining consistent synchronization for long duration recordings.

Mixed methods applied to an exhibition case study

This research project began with an exploratory objective. Recognizing that the phenomena of interest—children’s use of exhibits—are inseparable from their context, the research proceeded with observational methods *in situ*, in a natural history museum. A mixed methods paradigm integrates qualitative and quantitative analyses. With the results of the early exploratory and descriptive case studies and processes of induction, I sought to articulate organization apparent in the children’s behavior in the museum. Building on those results, I strived for richer descriptions and, in some cases through deductive processes, proposed explanations for behavior. Explanation, based on case studies, can ignite contention. However, when the research question relates to *How* a process can occur and the consequences of that process, rather than *How much*, *How many*, or *How big is an effect*, case studies can provide the method of choice. The descriptive and explanatory generalizations derived from case studies expand theory by empirically showing what is possible (Yin, 2009). If people expect that children only passively receive the museum’s messages, or never read exhibit text, or randomly bounce from one exhibit to the next, a single case study with contrary evidence can show that these expectations are unfounded. Besides expanding theory, this research involves targeted quantification to understand the abundance, distribution, and co-occurrence of specific

behaviors relative to the designed environment. The statistical results are descriptive, and not intended for making quantitative inferences about populations of fourth-graders or other museum visitors. I seek to describe a human cognitive ecosystem with phenomena of great complexity, in part due to their inherence in context. To distill this complexity and reduce dimensionality to describe patterns required a qualitative stance.

Quantitative Analyses

The quantitative analyses in this research focuses on determining the magnitude of particular cognitive phenomena. A goal of cognitive ethnography is to document the occurrence of cognitive events (i.e. events of a scale determined by the researcher), and discover which events are common versus rare. To describe a cognitive ecosystem of children in a natural history exhibition, a coding scheme inspired by micro-ethology methods (described below) supported identification of perceptual-motor forms of engagement. Multimodal analysis resulted in description and quantification of cognitive functions associated with forms of talk, touch, and gesture. A straightforward counting of the occurrence of forms of engagement and their cognitive functions allowed calculation of ratios of different types of form and function. These ratios provide a measure of relative abundance and scarcity of particular cognitive events within the exhibition among the focal participants.

Qualitative Analyses

The qualitative analyses provide the essential substance of this dissertation. The attempt to understand and categorize the cognitive forms and functions of children's action in the museum required qualitative interpretation prior to quantification, hence the development of coding schemes for this purpose. Coding when a child looks at or touches an object relies on a

binary perception-based judgment. In contrast, to assign a code for the cognitive function of an action requires integration and analysis of information across multiple dimensions. To code and subsequently quantify the cognitive function of any action requires qualitative interpretation.

Qualitative description serves as a vehicle to interpret and represent the complexity of human mind in action with artifacts. Statistics and mathematical models alone cannot sufficiently describe rich cognitive ecosystems, such as children exploring a museum. The qualitative results that follow contain generalized descriptions of cognitive phenomena of interest, their observable defining features and component parts, and how the parts assemble and get coordinated in action. Brief vignettes from the video data provide specific details that illustrate broader classes of phenomena. Some vignettes include multimodal transcripts to provide more detailed representations of an activity system that interweaves language with social and physical interaction.

Secondary data — Coding the video

Confronted with a mountain of video data, the researcher must learn how to see the contours of activity. I became familiar with this children-in-a-museum ecosystem and its complex terrain not by following a linear path, but by multiple traversals forward and back through the video. The process of re-presenting the primary video data—creating a *cascade of inscriptions* (Latour, 1986)—enabled me to see patterns made visible by reducing the complexity of the phenomena in a principled way. The circular and iterative process involved multiple, sometimes non-linear, steps:

- Index the video to mark and label events, organized in databases,

- Develop coding schemes, based on theory and museum practice, to generate data for analysis of behavior,
- Annotate the video using the coding schemes in audio/video annotation software (ELAN, developed by the Max Planck Institute, <http://tla.mpi.nl/tools/tla-tools/elan/>),
- Generate databases based on the coded video, used for specific analyses.

Simultaneously, I identified and wrote case studies of interesting interactions. The process of creating systematic structures for indexing and coding brought me into deep and sustained contact with the video data. Through this process, which disciplined my perception, I enriched my understanding of this ecosystem in a qualitative multidimensional sense. Analogous to Goodwin's (1994) assertion that the camera angle constitutes a theory, Bakeman and Gottman suggest that a coding scheme constitutes a hypothesis about what behaviors and distinctions will reveal meaningful patterns in human interaction (1997, p.15, p.36). Coherent results suggest that the hypothesis instantiated in the ontology of the coding scheme deserves support, i.e. the distinctions and dimensions that define the coding scheme truly matter.

The foundational multimodal coding scheme: Look, Touch, Talk, Gesture

The coding scheme, used to generate secondary data from the video, derives from theory related to embodied, situated, and distributed cognition. A fundamental premise in distributed cognition theory provides the grounding for the coding scheme—that some forms of cognition can be directly observed. Allocation of attention, sequences of action, and expressions in speech and gesture all embody trains of thought (Alac & Hutchins, 2004). The coding scheme focuses on observable aspects of perception and action that relate to exploring the museum environment and expressing meaning, revealing cognitive events in the children's coordinated

adaptation to resources made available in the museum. To address the question—How do children use the museum exhibits?—we must look at what they do. Seeing what children actually do, we can make inferences about how design influences, shapes, and constrains activity.

Both theory and observation ground the primary coding scheme. Coding categories relate to exploratory and expressive perceptual-motor modalities: Look, Touch, Talk, and Gesture. Each code also contains information about children's modalities in relationship with physical and conceptual resources in the museum environment.

Look: For most humans, vision is the dominant perceptual modality for exploring the world and guiding action. Vision plays a critical role in navigating physical space, selecting what to engage with, and coordinating motor action sequences whether a child is walking or manipulating an object. The code for looking behavior captures information about overt visual attention (i.e. orientation of the eyes toward a target). Behavioral measures of covert attention (i.e. what specific features one attends to within the visual field, not restricted to the foveated region) are indirect at best. Pointing indexical gestures or indexical speech may suggest the objects of visual attention in finer-grained detail—another value of multimodal analysis. This study focuses on when children overtly focus visual attention on museum exhibits. Visual attention is the first criterion for determining an event relevant for analysis.

The code **Look exhibit** denotes when the child focuses visual attention on an exhibit while standing or sitting within an arm's length. **Visual target** signifies when the child focuses visual attention on an exhibit, often while in motion, and sustains visual attention until getting within arm's reach.

Touch: To account for the uniqueness of human cognition—on multiple time scales, evolutionary, cultural-historical, developmental, and in-the-moment—the human hand plays a central role in thought and action. To understand how children use museum exhibits, and the cognitive consequences of those uses, we must look at what they do with their hands.

The remarkable dexterity of the human hand allows a multitude of pragmatic and epistemic actions (Kirsh & Maglio, 1994). The form of objects, in the museum or anywhere else, constrain the range of possible functions of touch. Manual dexterity and functional action require cognitive control, a requirement and consequence of physical engagement between a body and an object. When the object is an artifact (i.e. an object designed by humans), the cognitive labor that defines the range of possible engagements (or affordances (Gibson, 1979)) is distributed across the acting agent (a child in a museum) and other agents who shaped the object's design (museum designers), including those who may be invisible and forgotten in the broad sweep of cultural history.

The code **touch exhibit** marks when the child's hands contact exhibit cases, graphic panels, or interactive interfaces such as a handle or knob, all elements that serve to frame and support the "museum objects." **Touch object** indicates when the hands contact the museum focal objects: rocks, fossils, specimen-casts, and models, all of which have textural variety and information. Technically speaking, exhibits are objects, and museum objects are part of museum exhibits. Distinguishing between the *exhibit* as support and museum *object* as the exhibit's focal point draws from the parlance of museum practice, and from the different affordances and tactile informativeness of exhibits and objects. Consequently, we have need for a differentiating code. **Manipulate** requires manual touch, but involves effecting some kind of change to the object, such as pushing a lever or spinning a dial that makes an exhibit move. Not all exhibits are

manipulable. Museum professionals call manipulable exhibits “interactives.” Interactive exhibits allow for reciprocity; when a user takes action, the exhibit responds in some perceivable way (McLean, 1996).

Talk: Speech serves an indispensable function coordinating thought and action within and among people. As children talk to themselves and with other people, they combine symbolic and indexical capacities of language (Deacon, 2012). They make meaningful statements that link the surrounding environment with previous, present, and anticipated sequences of action. Language provides a powerful tool, for coordinating activity, mediating between the experience of self and others, and connecting the here-and-now with some other then-and-there, real or imagined (Vygotsky, 1934/1986). All multimodal events included in the following analyses meet two criteria: 1) the child directs visual attention to a museum exhibit, 2) the child talks about the exhibit’s content.

Embedded in the creation and experience of museum exhibits lie cultural practices of representation. When used, museum objects act as symbolic tools. As symbolic tools, they express a dual nature, both material (physical and concrete) and ideal (related to the realm of ideas) (Ilyenkov, 1977; Cole, 1995; Cole & Gajdamaschko, 2007; Wertsch, 2007). Speech reveals the cognitive reality of this dual nature, which need not penetrate conscious awareness. The coding scheme for the children’s talk highlights this dual nature of material and ideal by marking when children refer to the **concrete** and perceivable aspects of museum objects versus when they refer to what the designers intended the objects to represent, what is not perceivable and is therefore **abstract**. Yet this dichotomy does not adequately capture real-world talk in action. In a single utterance or idea-unit (a clause that expresses a single idea (Mayer, 1983)), a child may make reference to both the concrete and abstract. In the statement, “that’s the lava,” the

deictic “that” refers to the concrete object, while “lava” refers to what the exhibit represents for the child in that moment. When the child uses the concrete object to anchor the abstract concept (Hutchins, 2005), the utterance receives the code **concrete/abstract**. The particular challenge of distinguishing different types of utterances led to the development of a decision tree to support greater consistency in the assignment of codes (figure 3.3). **Read aloud** designates a child’s speech when reading the exhibit text out loud.

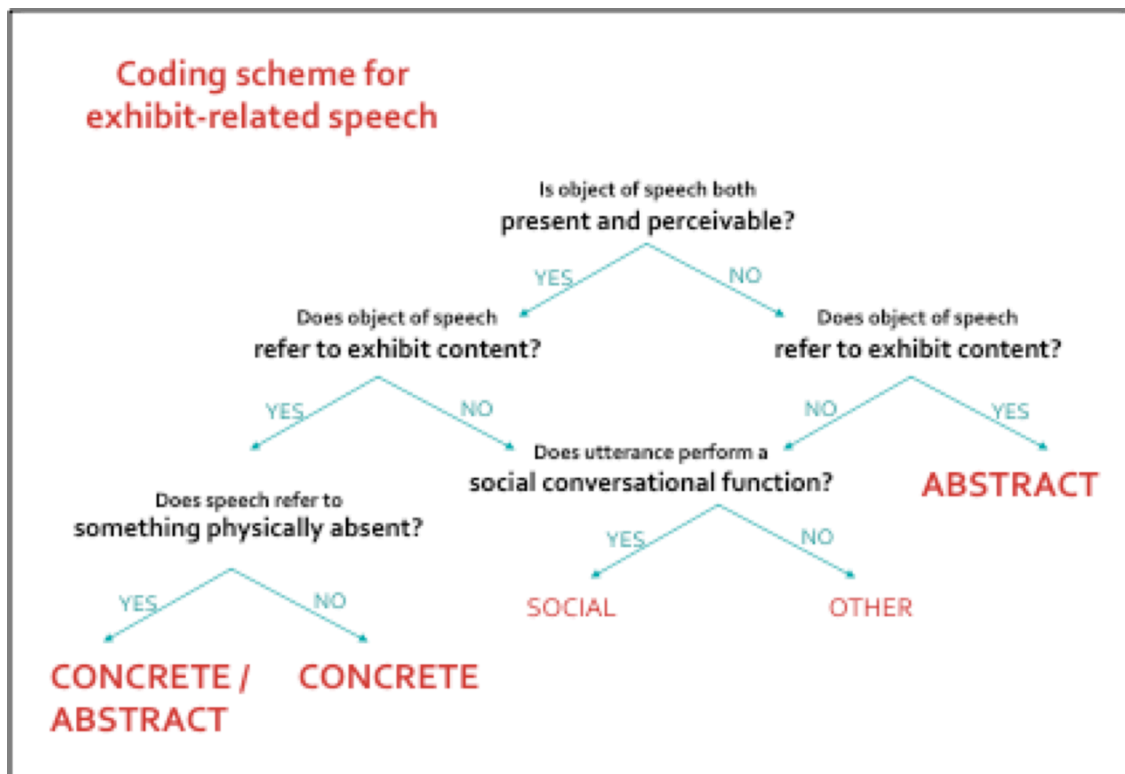


Figure 3.3. Coding scheme for speech. With the recognition that any utterance can perform multiple functions, the research team developed and deployed a decision tree to distinguish particular kinds of exhibit-related speech from non-exhibit related speech. Before entering this decision tree, the researcher asked “Is the child reading aloud?” If YES, code as Read aloud. If NO, ask “Is the object of speech both present and perceivable?” and follow the coding scheme above.

Gesture: An instrumental tool for thought and a medium for communication and coordination, gesture can serve many functions for individuals and social groups. This coding

scheme focuses on manual gestures. Drawing on multimodal discourse analysis, which employs Piercian semiotic theory, this coding scheme identifies two forms of manual gestures—indexical and iconic (Alac, 2011; Alac & Hutchins, 2004). Their cognitive functions follow from their form (Kendon, 2004). With **indexical** gestures, the participant points with all or part of the hand toward an exhibit element. Indexical gestures index and therefore direct attention to objects in the environment. With **iconic** gestures, a participant uses the body to represent entities or actions, usually with form-to-form mapping (Taub, 2000) between the gesture as sign and the object or action represented (Peirce, 1902). **Other** gestures include head nods, shoulder shrugs, and various forms of palm up gestures. The final analysis does not include “other” gestures.

The coding scheme and iterative development

Development of the coding scheme (described above) involved refinement through multiple iterations. The first phase of the study involved broad exploration. The initial coding scheme was expansive and inclusive, with codes for various physical actions, social interactions, and uses of language (appendix 2A). Using an expansive coding scheme is expensive in coding time. Our research team of four people developed the coding scheme and annotated video of four children totaling 60 minutes, which amounted to hundreds of hours of work.

With so many potential interesting questions to pursue, the time-intensive process ultimately led to a reasoned pruning of the coding scheme to address the question: How do children use the museum exhibits? The initial coding scheme made explicit my biases as a museum practitioner and cognitive scientist. At the same time, by being so broad, the coding scheme allowed patterns to emerge from the video data, inviting deeper inquiry resulting in this dissertation.

The exploratory phase of this study had several beneficial outcomes. With the coding scheme as a structure for observing children's interactions in the museum, I was compelled to watch the video closely, carefully, and repeatedly. I learned how to see cognition in action by tuning my perception to the children's multimodal behaviors at multiple time scales. The dialectic of exploration and discovery defined the research questions, refined my methods, and resulted in a leaner coding scheme. (See appendix 3B.) This process supported defining an ontology of situated activity relevant to my inquiry, highlighting features in the museum ecosystem such as event boundaries on different time scales, forms of perceptual-motor engagement, use of expressive modalities, and use of museum resources.

The final coding scheme targets the research questions: *How do children use exhibits in a natural history museum? How do they make sense of their multisensory experiences?* All analyses focus on children's engagements with exhibits, specifically multimodal events involving exhibit-related speech. The resulting data represents six children's activity in four galleries of the exhibition (in which audio and video quality permit greatest fidelity in detailed coding) for a total of 166 minutes, comprised of 231 events defined by sustained visual attention on an exhibit. The video data has 30 frames per second; a frame-by-frame analysis allows for coding of behavior at a resolution of 33 milliseconds.

Lessons learned about coding video

In sum, through my own exploratory process, I arrived at some generalizable principles about coding video. These principles, also articulated by others, directly relate to the costs and benefits of coding. Specifically:

- Don't rush to create a coding scheme. Spend time watching, discussing, indexing, and describing what you find interesting and why.
- A behavior is interesting and you can code it, but that doesn't mean you should.
- Coding schemes should directly address your research question.
- Definitions of each code should be made explicit in writing and updated to reflect refinements during the process of developing the coding scheme.
- Keep detailed notes during the coding process that include questions, conundrums, and justifications for applying the code to inform code refinement and later analysis.
- Observable behavior (not inferred mental or emotional states) will provide a more reliable basis for your codes.
- The coding scheme should have a clear structure of hierarchy and exclusivity, as best describes relationships among behaviors.
- The level of the coding scheme should correspond with the level of analysis, plus an additional, more detailed level to support inferences about structure and function.
- Inter-coder reliability measures make most sense with simple coding schemes. The complexity of the coding scheme for this research (with onset and offset times, multiple dimensions, and multiple codes within each dimension) presented tremendous challenges for standard measures of reliability. If the code is well suited to reliability testing and coded data will be used for quantitative analyses, test for inter-coder reliability, early and often, to aid in training coders.
- Anticipate that the process of coding video will take more time than originally expected.

(Cf. Bakeman & Gottman, 1997).

Organizing and interpreting the coded video

The inquiry focuses on how children bring their embodied cognitive process-oriented resources (perception, action, internal and external representation) into coordination with physical-conceptual resources of the museum. To describe how the children use the exhibits, and the cognitive consequences that result, an interpretive framework addresses three broad themes: How children engage with **objects**, take **action**, and create meaningful **representations** of ideas in the museum. The identification of cognitive phenomena and selection of illustrative examples result from the dialectic of theory (embodied, situated, distributed cognition), methods (as described here), and results.

The analytic framework of objects, actions, and representations stems from a fundamental ontology in cognitive science, particularly cognitive linguistics. Langacker's cognitive grammar theory (1990) asserts that language and its meanings do not reflect a free-standing system of formal logic. Rather, all aspects of language, including grammar, carry symbolic content grounded in human cognitive processing. That languages have grammatical structures such as nouns and verbs reveals foundational aspects of human perception and the exigencies of thought and communication. In this research, the analytical organization of the children's multimodal speech events derives from their cognitive experience, based on the focus of their speech: museum objects, their actions relative to those museum objects, and when they experience museum objects as representations of things not physically present.

The analytic framework of objects, actions, and representations also reflects a primary ontology in museum studies. The foundation of museum practice rests upon objects deemed worthy of collection, research, and display in exhibitions. Objects lie at the heart of museums'

reason for being, often for their representational value (Duensing, 2002). In a natural history museum, for example, objects may represent moments in time—from a living community, an evolutionary process, an extinction event, and more. Traditionally, looking and learning defined the actions associated with museum-going. The emergence of touchable museum collections and hands-on science centers has expanded the repertoire of possible actions in a museum (Schwarzer, 2006; Pye, 2008), as have expectations for greater audience engagement and participation (Pollock & McLean, 2008; Simon, 2011).

This research draws on ecology of biological species as a framework for describing a learning ecosystem and its “species” of engagement among children in a natural history museum. Ecosystem scientists find and name species; they describe their forms and their functional roles based on ecological relationships and processes among living and non-living things. In a cognitive ecosystem of children in a museum, the fundamental category systems define the forms of engagement using the content of speech as a pivot point: concrete object-oriented, concrete action-oriented, and blending of concrete and abstract, which is therefore, representational.

The functions of those verbal forms of engagement derive from multimodal discourse analysis in a cognitive ethnography framework. The interpretation of function cannot come from a single word or a single act. The interpretation of cognitive function requires analysis of an event (in this research, a multimodal event that includes speech) in a sequence of activity unfolding within multiple social-cultural-material contexts.

The forms of engagement defined in this research—concrete object-oriented, concrete action-oriented, blending of concrete and abstract—support various functions. The categories of functions come from the most concise description of the activity based on observation. Pre-

existing categories did not guide coding of the children's multimodal engagements. Rather, the categories emerged from the effort to describe cognitive function based on observation of the children's activity in context and the consequences of that activity. Therefore, the categories of cognitive functions resulting from the children's engagements are descriptive, not exhaustive.

The multiple coding schemes used in this research reflect a dialectic between theory and observation; relevant theory that precedes this research come from of observation. That prior research helps define what to look at to understand the organization of activity related to perception, representation, and meaning-making. All category systems provide a way to structure the flux of experience. The categories employed in this research provide a way into the complexity of this social-cultural-material ecosystem.

Among the categories used to parse this complex human ecosystem, the observed cognitive functions are described as follows. Among the multimodal engagements defined as **concrete object-oriented**, children were observed to name objects (as statements or questions), ask "what is it?", categorize objects (as statements or questions), describe features of objects, describe relations between objects, or offer an evaluative judgment, usually with positive valence. Among the multimodal engagements defined as **concrete action-oriented**, children were observed to use speech to direct the attention of others, tell others what to do, coordinate turn-taking with exhibits, make reference to one's own activity (looking for rocks, video recording, reading), and sonify or make sounds to accompany their activity. Their behaviors of touching exhibits and museum objects suggested other cognitive functions, including to physically anchor their bodies (leaning on graphic panels), simultaneously occupy physical and social space, drive tactile stimulation, explore relationships between manual movement and visible changes in the exhibits, direct attention of self and others, and enact representations

through environmentally coupled gestures (Goodwin, 2007). When children **blend concrete and abstract, thus making representations** in their activity, they were observed to use speech to name abstract entities (as statements or questions), ask “what is it?”, describe relations, imagine alternative realities, link present experience with episodic memory, and sonify.

These categories describe the cognitive functions of children’s multimodal engagements. Observation of the children provides the basis for the categories. The category labels provide a concise and parsimonious description of function based on the cognitive consequences observable in perception, action, and interaction with the social and material context. Describing the relative abundance and scarcity of cognitive functions derives from the undeniably human process of integrating many behavioral variables to arrive at a single data point (i.e. assignment of a code for cognitive function).

Using multimodal discourse analysis in a cognitive ethnography framework, this research addresses what Greeno calls out as the essential elements of a learning ecosystem: activity structures, participation frameworks, discourse structures, and knowledge structures (Greeno, 2006). To animate the analysis of this cognitive ecosystem, presentation and interpretation of “specimens of activity” address the many relevant variables related to distribution of cognitive labor, i.e. the contributions by multiple social participants, their engagement of perceptual-motor modalities, and recruitment of museum resources across multiple timescales varying from milliseconds to several minutes. The research began with an attempt to discover and describe the organization of children’s activity in the museum, evolved in the exploratory process, and settled into a simple formulation of the research question, a fundamental inquiry that has, to date, not been sufficiently addressed:

How do children use exhibits in a natural history museum? How do they make sense of their multisensory experiences?

Observational research, division of labor, and professional vision

Observational research requires multiple steps of interpretation. The process of interpreting the children's activity involves numerous translations of behavioral interaction from the primary video to inscriptions that make individual differences and general patterns visible. This process, of a complexity often underestimated, requires a human observer to serve as the instrument that generates data. We accomplished this task in several stages of defining, refining, and applying coding schemes—all processes that require *professional vision*, the ability to see important distinctions in phenomena and represent them for public scrutiny.

Professional vision, as defined by Charles Goodwin (1994), involves a way of seeing established through socially negotiated and contested discourse. Each individual sees the world uniquely, but with practice and experience, one can learn to see in new ways and develop expertise in various domains such as identifying geologic features, or coding facial expressions based on the muscle groups involved. Goodwin articulates three discursive practices that comprise professional vision in any domain: coding schemes, highlighting, and production of material representations. Coding schemes transform an undifferentiated field into defined objects, as when a geologist segments an exposed rock face into layers of rock with names and ages. Practices of highlighting serve to draw attention to objects of interest through various means, with a gesture of pointing a finger, a label, or putting a bold outline on a map. Material representations, such as models or diagrams, selectively give physical or graphical form to

objects of importance as determined by a community of practice. Material representations support processes of perception, interpretation, and understanding.

The transformation of video data into indexed lists, annotations of behaviors that comprise activity, databases that selectively quantify aspects of activity, and qualitative descriptions of activity—all these require professional vision and involve coding schemes, highlighting, and production of material representations. The coding schemes used to annotate video in this research highlights aspects of the children’s activity and results in material representations (figure 3.4). However, applying our coding scheme ranged from easy to difficult. When the primary video provides a clear image (with adequate brightness and no obstructions), one can easily determine if the child is or is not touching something. One must also see and understand the distinction between “touch-object” (e.g. a rock and/or fossil specimen) and “touch-exhibit” (e.g. a graphic panel). Interpreting language use presents a greater challenge.

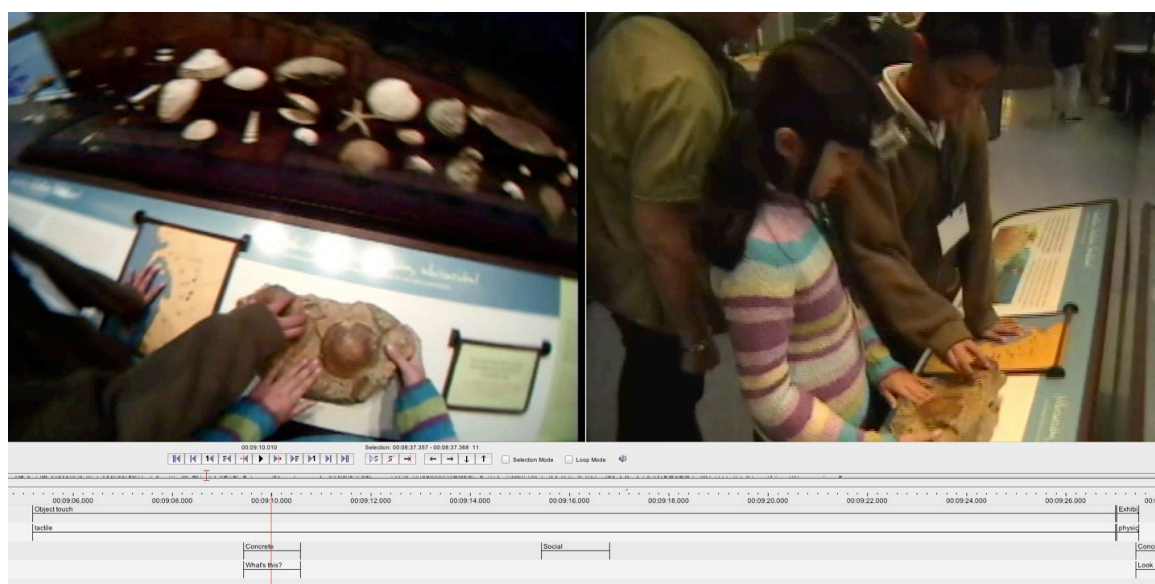


Figure 3.4. Applying the coding scheme highlights aspects of activity through annotation of video. This effort results in material representations of video annotations and the cascade of inscriptions that follows. ELAN software allows users to annotate video with customized coding schemes. Child’s perspective on left; researcher’s perspective on right.

Assigning a code to a child's utterance involves more than listening to the words. The meaning of spoken language depends on its context of use, which includes prior speech, gesture, and objects in the participants' shared perceptual and conceptual common ground (Clark, 1996; Sebanz, Bekkering, Knoblich, 2006). The coder must remain sensitive to all these aspects of action and setting. A deep truth resides in the statement "you had to be there." But even when one can "be there," misunderstandings arise. Fortunately, video allows repeated viewing to track the many informational streams and listen carefully to every word as many times as necessary. Expression in language varies from precise to ambiguous, presenting another set of challenges. As an illustration, designate a code to the following sentence by applying the coding scheme for speech (in figure 3.3), "Why do we have earthquakes here?" One research assistant designated this as *abstract*. But what about the word "here"? "Here" is both present and perceivable, and therefore *concrete*. Earthquakes, physically absent in this case, qualify as *abstract*. Consequently, I coded this utterance as *concrete/abstract*.

My research assistants and I did not always agree on how to assign codes to the children's behavior. Some disagreements had little or no impact on the current analyses, particularly related to onset and offset times for some behaviors.³ The differences in coding of greatest concern relate to interpretations of the children's speech. I attribute the differences in coding to the following differences in coders' judgments about: identifying the words spoken; disambiguating the focal participants' voices from the voices of other children; lumping or splitting sequences of words into one or many utterances; tracking the integration of speech and gesture (coupled with the environment) of multiple participants in order to render meaning in the utterance; recognizing objects and text in the exhibits to which participants refer.

We make categorical judgments about speech depending on an understanding of activity in context. And judgments about activity and context depend on an understanding of speech. From these entangled relations results different interpretations of the video and applications of the coding scheme. Some differences in coding can be overcome with more training and greater specification in the coding scheme. Other differences in coding could be corrected with much greater difficulty, because they relate to professional vision acquired through extensive experience and a lot of time. My professional vision of the exhibition itself (i.e. knowing the content of the label text, knowing what and where the elements are) came from serving as exhibit developer/designer for the exhibition. My professional vision related to the children's behavior stems from hours and hours of watching, coding, and analyzing the video. To train research assistants to this level of professional vision may be possible with a tremendous investment of time. In the final cost-benefit analysis, I chose to review all of the coding and revise it myself when I determined that revised codes provided a more accurate representation of events. The coding data for look, touch, manipulate, gesture, and read was very consistent among coders. The coding data for speech was less consistent.

All data sets have some noise, which the researcher seeks to reduce by fine-tuning their data collection instruments. To generate the most accurate data set possible compelled me to participate in coding the video. Using data that I coded myself presents a risk of researcher bias. The calibration of my primary research instrument—my professional vision—depends on more than my own commitment to professional integrity. Adherence to operationalized definitions in the coding scheme (which I referred to routinely, especially when coding speech) provided a consistent structure to bound my judgments.

By tuning our perception, we can see meaningful structure in interaction that constitutes both cognitive activity and the residua of cognitive activity (Hutchins, 1995). By attempting to understand activity from the participants' point of view (taking an endogenous versus an exogenous perspective), we gain a deeper understanding of the potential meanings of action and interaction (Stevens, 2010). The endogenous perspective entails a respect for the children and a trust in the video data. When the children's actions violate my expectations, I look closer. I double-check the code and the interpretation. "The wonderful thing about observational research is that it maximizes the possibility of being surprised." (Bakeman & Gottman, 1997).

What does this research have to do with learning? And how does a concern for learning raise methodological issues? I have chosen to conduct *a cognitive ethnography of an exhibition*—not individuals—to understand the consequences of design and potential gateways and barriers to learning. Children's use of the exhibits helps us to see the exhibition's affordances from the children's point of view. First-person video from head-mounted cameras increases access to this point of view. If attention and engagement are prerequisites of learning—what aspects of the physical environment attract and engage? If motivation and curiosity drive learning—where do we see evidence of the children's enthusiastic engagement and inquiry? If we focus on children's expressions of conceptual knowledge that transcend the here-and-now—how do children make use of conceptual resources in the museum and represent their knowledge? If we define learning as behavioral adaptation and adjustment—how do the children make use of the museum's resources, and where do we see children adapt to novel situations they find themselves in, in the museum?

Instead of measuring the children's performance on pre- and post-tests expecting a measure of *learning as a product*, this research investigates how children's engagements reflect the potential for *learning in process* as they use the museum's resources. By finding patterns in the forms and cognitive functions of children's engagements, we can make inferences about the cognitive processes at work. Through observation, we expand our understanding of the range of possibilities and predispositions in children's cognitive functions. We can use this knowledge to reverse engineer the forms of exhibits and learning environments that support a wider variety of beneficial, distributed cognitive functions and discover how museum resources can better serve as tools for learning.

Appendix 3A: Exploratory Phase: Coding Scheme #1

Physical				
<u>Look</u> search visual target look-specimen look-interactive look-graphic look-diorama look-mural look-model look-video look-other person look-other do interactive	<u>Touch</u> touch-specimen touch-interactive touch-model touch-panel touch-other person touch-other <u>Manipulate</u>	<u>Gesture</u> Iconic Indexical Palms up Shoulder shrug	<u>Affect</u> positive negative	<u>Body language</u> (extremes) frustration boredom delight
Social				
<u>Social Group</u> solo kids teacher teacher & kids researcher	<u>Social Attention</u> joint social redirect	<u>Resource use</u> fight over resource take turns work together demonstrate wait	<u>Goof/tease</u>	<u>Teacher interaction</u>
Language use: Talk				
<u>Language</u> Spanish English Mixed-one sentence	<u>Social</u> Self-talk Talk with others	<u>Content 1</u> operation percept concept percept/concept memory equipment social ambiguous	<u>Content 2</u> question	
Language use: Read				
<u>Language</u> Spanish English Mixed-one sentence	<u>Mode</u> Aloud Silent	<u>Social</u> Joint Individual Audience		

The research team developed the coding scheme through an iterative process of observing behavior on video, then defining and refining categories and labels to describe actual observed behaviors. My initial naïve plan to code everything listed above quickly proved unwieldy. This coding scheme focused attention on activity of primary interest, and served its purpose in the first exploratory phase. This dissertation research uses much leaner coding schemes targeting specific research questions, made possible by an expansive open-ended exploration at the beginning.

Appendix 3B: Descriptive & Explanatory Phase: Coding Scheme #2, Multimodal Engagement

General Terms

Event

When a child (with or without others) focuses attention on an exhibit with more than a glance (>.5 seconds), we label this as an event, also an interaction event or exhibit interaction.

The beginning of an event always begins with visual target if and only if visual target leads to look exhibit.

Participants

Children/students and adults/teachers engage with individual exhibits and interact with each other within the exhibition.

Interaction

When more than two things come into a sphere of mutual influence (people and objects).

Coding Terms

Look

Visual target — When an object enters into the center of the participant's visual field and stays there for more than .5 seconds.

Look exhibit — When the exhibit enters into and stays in the center of the participant's visual field for more than .5 seconds, and the child is within arm's reach of the exhibit graphic panel. (For this coarse-level coding, we will not code brief looks away while the body remains oriented toward the exhibit, the exhibit remains the attentional focus (as suggested by other modalities), and gaze returns to the exhibit for more than .5 seconds.)

Touch

Exhibit touch — When the participant touches some part of the exhibit that is a graphic panel, graphic holder, or vitrine, but not an actual specimen (rock, fossil, or cast), a model, or an interactive.

Touching a bench, stool, or handrail does not count as exhibit touch.

Object touch — When the participant touches some part of the exhibit that is not a graphic panel, graphic holder, or vitrine, but is an actual specimen (rock, fossil, or cast), a model, or an interactive.

Manipulate — The participant manipulates an exhibit such that the action effects a change in the exhibit. Can be digital or mechanical.

Talk — Parse speech by utterance (not word-by-word). An utterance comprises a thought, and may contain a subject and a predicate. Subjects and predicates may be explicit or implicit.

Abstract — When the content of the speech refers to abstract ideas related to exhibit content that include things or events that aren't physically present (earthquakes, evolution), that relate to generalizable principles (how things work in the abstract, such as processes/phenomena in time or space), and what abstract notions exhibit objects appear to represent ("go back to the future"). To count as abstract talk, the utterance must refer to the abstract conceptual content of the exhibit. Otherwise, code it as social or other.

Concrete — When the content of the speech refers to perceivable aspects of tangible concrete objects that are physically present in the exhibits. Concrete talk includes questions and comments related to the identity of an object (what's that?), to label its name or category (it's a fossil), an object's features (big, dark, smooth), an object's behavior (that thing moves slowly), or the ways that people's bodies can engage with concrete objects.

Abstract / Concrete — If a single utterance contains both abstract and concrete content in referent to the exhibit, we will code it as Abstract / Concrete.

Social — All speech, at some level, performs a social function. For this project, we will code it as social when the speech does not seem to overtly refer to abstract, concrete or both abstract and concrete exhibit-related content, but relates more directly to coordinating social activity ("let's go over there").

Spanish — This code will flag words that are spoken in Spanish. Fluent Spanish-speakers will code the content of this speech.

Other — Talk that doesn't clearly fit into one of the above categories and does not overtly refer to exhibit content.

Read Aloud — The participant reads text on the panel out loud. Gaze direction and use of hands provide information to help discern if the participant is reading.

Gesture

Indexical — The participant uses part of the body (most often the hand) to point to some element in the display.

Iconic — The participant uses the body to represent an object or idea.

Other — The participant makes a gesture that is neither clearly indexical nor clearly iconic.

Read

Read — The participant presents some compelling evidence that s/he is reading silently (e.g. tracing the text with a finger while gaze follows, or moving the head in a horizontal motion at a reading pace).

¹ The head-mounted camera does not provide the exact location of gaze fixation. We did not use eye-tracking equipment.

² Many video annotation applications exist. For this research, the team used ELAN for coding video and ChronoViz for visualization. The Max Planck Institute developed ELAN (<http://tla.mpi.nl/tools/tla-tools/elan/>). Adam Fouse, UCSD DCog/HCI Lab, developed ChronoViz, supported in part by NSF Grant 0729013, “DHB: A Multiscale Framework for Analyzing Activity Dynamics” (<http://chronoviz.com/>).

³ For example, the point of transition between visual target and look exhibit depends on the child’s distance of one arm’s length from the exhibit. Small differences in estimating this difference resulted in time differences between coders of less than one second. That the coding differences had no impact on the analyses suggests that those codes were unnecessary and could have been omitted from the coding scheme. However, the coding process has outcomes beyond generating a dataset for quantitative analysis, most importantly attuning the researcher’s perception to the nature of the participants’ experience.

References

Alac, M. (2011). *Handling Digital Brains: A Laboratory Study of Semiotic Multimodal Interaction in the Age of Computers*. Cambridge, MA: MIT Press.

Alac, M., Hutchins, E. (2004). I see what you are saying: Action as cognition in fMRI brain mapping practice. *Journal of cognition and culture*, 4.3.

Bakeman, R., Gottman, J. (1997). *Observing Interaction: An Introduction to Sequential Analysis*. Cambridge, MA: Cambridge University Press.

Clark, H. (1996). *Using Language*. Cambridge University Press.

Cole, M. (1996). *Cultural Psychology: A Once and Future Discipline*. Cambridge: Harvard University Press.

Cole, M. & Engeström, Y. (1993). A cultural-historical approach to distributed cognition, in *Distributed cognitions: Psychological and educational considerations* (1–46). Cambridge: Cambridge University Press.

Cole, M. & Gajdamaschko, N. (2007). Vygotsky and Culture. *The Cambridge Companion to Vygotsky*. Cambridge, MA: Cambridge University Press.

Deacon, T.W. (2012). Beyond the Symbolic Species, in T. Schilhab et al. (eds.), *The Symbolic Species Evolved*, Biosemiotics 6, 9.

Duensing, S. (2002). The Object of Experience. In S. Paris (Ed.) *Perspectives on Object-Centered Learning in Museums*. Mahwah, NJ: Lawrence Erlbaum Associates.

ELAN, Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands, <http://tla.mpi.nl/tools/tla-tools/elan/>.

Fouse, A., Weibel, N., Hutchins, E., Hollan, J. (2008). ChronoViz: A System for Supporting Navigation of Time-Coded Data. *Proceedings of ACM Conference on Human Factors in Computing Systems*, 299-304, 2011.

Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Goodwin, C. (1994). Professional vision. *American anthropologist*, 96(3): 606–633.

Goodwin, C. (2000). Action and embodiment within situated human interaction. *Journal of Pragmatics*, 32, 1489–1522.

Goodwin, C. (2007). Environmentally Coupled Gestures. In *Gesture and the Dynamic Dimensions of Language*, edited by Susan Duncan, Justine Cassell, and Elena Levy. Amsterdam/Philadelphia: John Benjamins: 195-212.

Goodwin, C. and Goodwin, M.H. (1996). Seeing as situated activity: Formulating planes. *Cognition and communication at work*. Y. Engeström and D. Middleton. Cambridge, Cambridge University Press: 61–95.

Greeno, J. (2006). Learning in activity. In K. Sawyer (Ed.) *The Cambridge Handbook of the Learning Sciences* (79–96). New York: Cambridge University Press.

Hutchins, E. (1995). *Cognition in the Wild*. Cambridge, MA: MIT Press.

Hutchins, E. (2005). Material anchors for conceptual blends. *Journal of Pragmatics*, 37: 1555–1577.

Hutchins, E. (2010). Cognitive ecology. *Topics in Cognitive Science*, 2(3): 1–11.

Hutchins, E. (2012). Concepts in practice as sources of order. *Mind, culture, and activity*, 19:3, 314–323.

Ilyenkov, E.V. (1977). The concept of the ideal. In *Philosophy in the USSR: Problems of dialectical materialism*. Moscow: Progress.

Jordan, B. & Henderson, A. (1996). Interaction Analysis: Foundations and Practice. *The Journal of the Learning Sciences*, 4(1): 39–103.

Kendon, A. 2004. *Gesture: visible action as utterance*. Cambridge: Cambridge University Press.

Kirsh, D. and Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science*, 18: 513–549.

Langacker, R. (1990). *Concept, Image, Symbol: The Cognitive Basis of Grammar* (1–32). Berlin, New York: Mouton de Gruyter.

Lemke, J.L. (1997). Cognition, context, and learning: A Social Semiotic Perspective. In D. Kirshner and Whitson, J. (Eds.) *Situated Cognition Theory: Social, Neurological, and Semiotic Perspectives* Mahwah, NJ: Lawrence Erlbaum Associates.

Lemke, J. (2000). Across the Scales of Time: Artifacts, Activities, and Meanings in Ecosocial Systems. *Mind, Culture, and Activity*, 7(4), 273–290.

Mayer, R. (1983). Can you repeat that? Qualitative effects of repetition and advance organizers on learning from science prose. *Journal of Educational Psychology*. psycnet.apa.org

McLean, K. (1993). *Planning for People in Museum Exhibitions*. Washington DC: Association of Science & Technology Centers.

Norris, S. (2011). Discourse in Action: Introducing Mediated Discourse Analysis. *Studies in Multimodality : Multimodality in Practice : Investigating Theory-in-Practice-through-Methodology*. Florence, KY: Routledge.

Pollock, W., McLean, K. 2008. *Visitor voices in museum exhibitions*. Washington: Association of Science & Technology Centers.

Pye, E. (2007). *The Power of Touch: Handling Objects in Museum and Heritage Contexts*. Walnut Creek, CA: Left Coast Press.

Rosch, E. (1981). Categorization of natural objects. *Annual Review of Psychology*, 32:89–115.

Sacks, H. (1992). "Lectures on Conversation, Volumes I and II" Edited by G. Jefferson with Introduction by E.A. Schegloff, Blackwell, Oxford.

Sawyer, R.K. (2006). Analyzing collaborative discourse. In K. Sawyer (Ed.) *The Cambridge Handbook of the Learning Sciences* (79–96). New York: Cambridge University Press.

Schegloff, Emanuel (1992) Introduction. In Harvey Sacks, *Lectures on Conversation* (Vol.1: Fall 1964-Spring 1968). Oxford, Blackwell: ix-lxii.

Schwarzer, M. 2006. *Riches, rivals and radicals: 100 years of museums in America*. Washington: American Association of Museums.

Sebanz, N., Bekkering, H., Knoblich, G. (2006). Joint action: bodies and minds moving together; *Trends in cognitive science*, Vol. 10, No. 2, 70–76.

Simon, N. 2011. *The Participatory Museum*. Santa Cruz, CA: Museum 2.0.

Stevens, R. (2010). Learning as a members' phenomenon, in *National Society for the Study of Education*, Volume 109, Issue 1, (82–97). New York, NY: National Society for the Study of Education, Columbia University.

Taub, S. (2001). *Language from the Body: Iconicity and Metaphor in American Sign Language*. Cambridge, MA: Cambridge University Press.

Wertsch, J. (2010). Mediation. In Harry Daniels, Michael Cole, and James. V. Wertsch (Eds.), *The Cambridge Companion to Vygotsky*, 178–192. Cambridge, MA: Cambridge University Press.

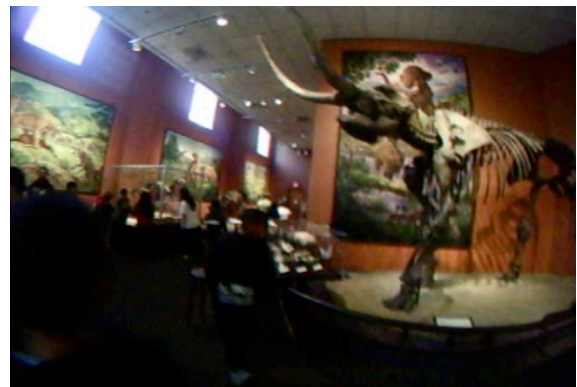
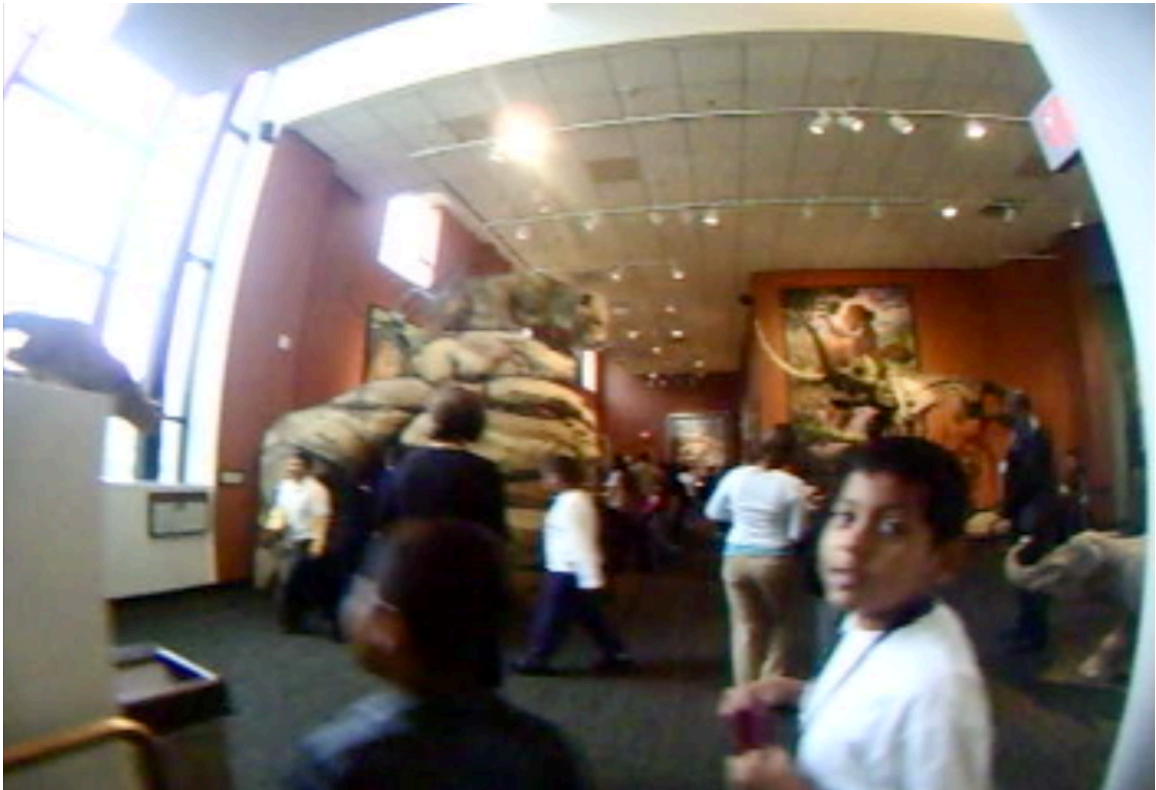
Williams, R. (2006). Using cognitive ethnography to study instruction. *Proceedings of the 7th international conference on learning sciences*, 838–844.

Wittenburg, P., Brugman, H., Russel, A., Klassmann, A., Sloetjes, H. (2006). ELAN: a Professional Framework for Multimodality Research. *Proceedings of LREC 2006, Fifth International Conference on Language Resources and Evaluation*.

Vygotsky, L.S. (1934/1986). *Thought and Language*. Cambridge, MA: MIT Press.

Yin, R.K. (2009). *Case study research: Design and methods*. Thousand Oaks, CA: Sage, Inc.

4 Free to explore the nature of objects



Figures 4.1 a–c. Children move through the museum, exploring numerous kinds of objects, many unique to the museum setting. Figure 4.1 a. This gallery contains a model of a ringtail, a sandstone cave with animals and fossils inside, a giant American lion peering down from above, murals by William Stout, a mounted mastodon skeleton (cast), and touchable mastodon baby walking across the gallery floor. (Images recorded in sequence, from a child's perspective.) Figure 4.1 b. Moving into the gallery, the title wall *Fossil Mysteries / Misterios fósiles* comes into view. Figure 4.1 c. A giant mastodon's tusks loom overhead.

In natural history museums, children look at, touch, talk about, and gesture with objects. In the paleontology and geology exhibition under study, specimens and models comprise the most abundant resource unique to the museum setting, a design decision consistent with museum traditions (figures 4.1 a–c). A dominant aspect of the children’s activity in the museum includes engagement with objects, and the cognitive functions of these engagements demands description. When the children are free to explore the museum (not participating in a structured lesson in the galleries) they talk about the specimens and models more than any other conversational topic. They explore facets of a tacit question and express variations on a theme—*What is it?*

The analysis in this chapter focuses on six fourth-grade students’ multimodal engagements with museum exhibits that include object-oriented concrete speech. When the case study children engaged with exhibits (defined by their allocation of visual attention) roughly half of those events involved speech. Episodes of speech served as a target for analysis, but the analysis is not limited to speech. When children engage with exhibits, they use other perceptual-motor modalities in concert with speech. In fact, the children were 2.5 times more likely to talk about the exhibits after touching an exhibit panel, interactive interface, or museum object than if they had not touched any of those things.

This research examines how, when, and where children look, touch, talk, and gesture. The analysis includes modalities that co-occur with speech. This multimodal analysis supports interpretation of the various functions of object-oriented concrete speech. These functions include references to an object’s identity, features, classification, or the participants’ evaluative judgment of an object.

In the museum ecosystem, forms of engagement serve various exploratory and expressive functions. Like diverse *species of engagement*, they vary in form, and they vary in cognitive function. These different types of engagement also vary in abundance and distribution, and their occurrence bears direct relationships with the physical environment. Children used concrete object-oriented speech throughout the exhibition with all kinds of objects—those that they can only look at (54%), those they can touch (29%), and less frequently with those they can manipulate (22%).¹ With manipulable interactive exhibits, they were more likely to use a blend of concrete-abstract speech, a subject of deeper discussion in chapter 6.

Brief vignettes from the video corpus illustrate the forms and functions of children's engagements in the museum. Quantitative results convey the magnitude of their occurrence. Two detailed descriptions (with multimodal transcripts) show how children use multiple modalities in various combinations as they explore objects and express ideas. When children engage with museum objects and use concrete speech, they sometimes elaborate on their object descriptions. However, combinations and sequences of these modes of engagement do not appear to add up to different functions for the children's actions. The cumulative effect remains to name, to describe, to classify, to evaluate. With other modes of engagement (particularly involving manipulation of interactive exhibits and concrete/abstract speech), new functions emerge in sequences of action (see chapter 6). When children engage with concrete objects, their actions—to name, describe, classify, and evaluate—satisfy their fundamental question of *What is it?*

When manipulating an exhibit, the range of possible actions and outcomes expands. The question *What can I do?* becomes more interesting with affordances for interaction that go beyond looking, touching, and talking. Similarly, concrete/abstract speech expands the world of

possible engagements and outcomes. Concrete/abstract speech opens up the realm of imagination, grounded in, yet unconstrained by what is physically present and perceivable.

When children see museum objects as representations, the question *What is it?* transforms into *What does it mean?* The act of seeing goes beyond perception and categorization, and ventures into imagination, analogy-making, generativity, and multiple meanings.

Multimodal engagements with concrete exhibit-related speech

Children use speech in coordination with eye gaze, body orientation, gesture, touch, and manipulation to achieve cognitive accomplishments in the museum. Aggregating the results of the coded video data of the case study children shows the relative abundance and scarcity of particular functions of object-oriented concrete speech events (figure 4.2). Of the children's concrete speech focused on objects, almost half the multimodal speech events involve naming, asking a specific name, or asking the generic question *what is it?* More than a quarter of object-oriented speech events express an evaluative judgment, tacitly applying a category system of "things I like" and "things I don't like." Almost one fifth involve descriptions, mostly adjectives that describe features of objects; a small percentage describes spatial or temporal relations among objects. Just under 10% of concrete speech events relate to classification: real or fake, rock types, dead or alive, female or male.

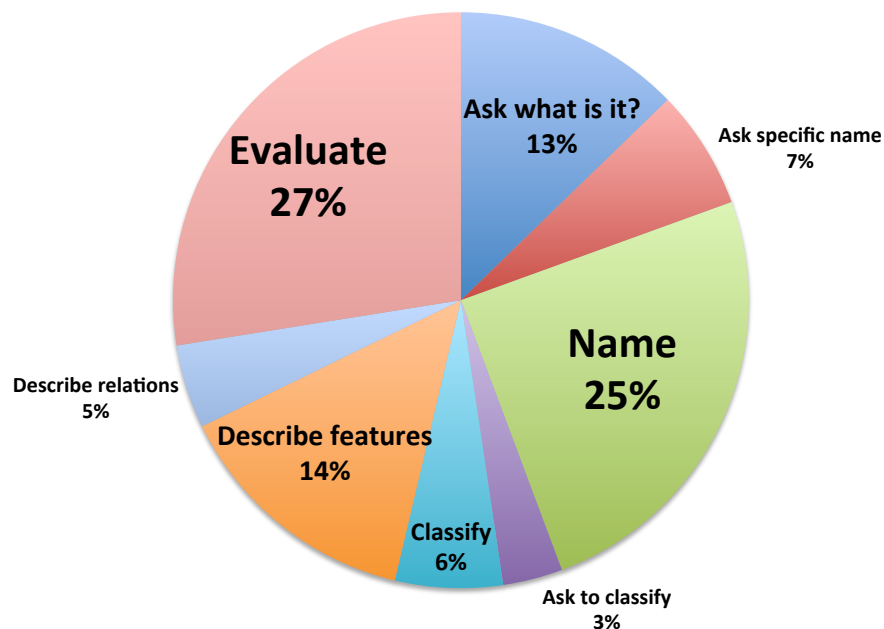


Figure 4.2. Functions of object-oriented concrete speech events (5 children, $n=149$ multimodal speech events). Aggregating the data from the five children who used object-oriented concrete speech shows both the range of possibilities and the relative abundance of different functions of multimodal engagements. Analysis is based on annotated video for six children in the first four of six galleries of an exhibition. One child did not use concrete speech focused on objects during the annotated sessions, hence the chart shows data for five children.

Children often combine concrete object-oriented speech (the most abundant speech form) with pointing indexical gestures (the most abundant gesture form). Concrete speech and indexical gestures serve related functions—they refer to observable objects or features and direct the attention of self and others. With finer resolution, concrete speech and indexical gestures serve different yet complementary functions—speech can differentiate an object from its background by using a name or descriptor, and a pointing gesture guides visual attention to the target. In this very simple and ubiquitous form of engagement (concrete object-oriented speech with indexical gesture), children distribute the cognitive labor involved in naming and describing objects and managing the attention of self and others across multiple modalities.

The children's actions and the functions of their engagements show individual variability. The data for each child provides a glimpse of a behavioral profile. (More on behavioral profiles in chapter 3.) Two charts show the different distributions of these forms of interaction for two children. During his museum visit, one boy showed greater functional diversity in his engagement with objects than another boy in a different class on a different day, even though these boys used the exhibits in similar ways otherwise. This series of charts (figures 4.3a, b) illustrates both the value and limitations in aggregating the case study data. As shown here, dis-aggregating data shows interesting details about individual variability. Aggregating data smooths out individual variability, for the researcher in search of patterns in the data. The descriptive (not inferential) statistics in this study provide a qualitative sense of the relative abundance of phenomena of interest.

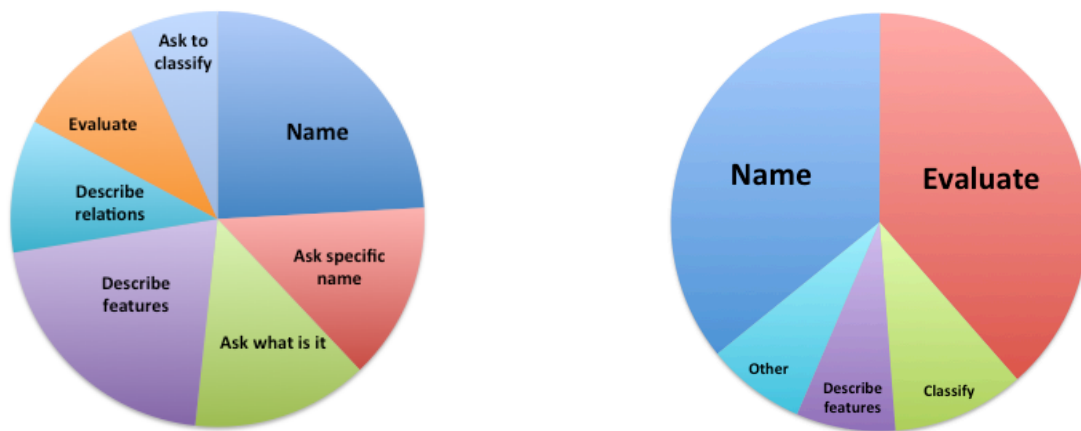


Figure 4.3 a,b. Functions of object-oriented speech events, contrasting two different children. Figure 4.3 a. One child's object-oriented speech accomplishes a wide range of cognitive functions, with fairly even distribution, n=29 multimodal speech events. Figure 4.3b. The functions of naming and evaluating dominate another child's object-oriented speech, n=39 multimodal speech events.

Object-oriented engagements and cognitive functions

Children explore *what things are* in various ways. They ask questions, name, classify, describe, evaluate, and make links among visible objects. In the museum, children practice skills of identifying and talking about specimens and models—common cultural practices applied to uncommon objects.

Children ask *What is it?*

One question and its variations hold a prominent place in the children's speech: *What's this? What's that? What is it?* The case study children, and their classmates, express this question often, like a leitmotif in the meaning-making soundscape of museum interaction. The explicit verbal form of the question *what is it* comes early in an interaction with an exhibit, or when a child encounters a previously unnoticed object in a display. This question carries a social dimension—with few exceptions, the children asked this question in speech directed toward others. Children use the question *what is it*, often in combination with an indexical

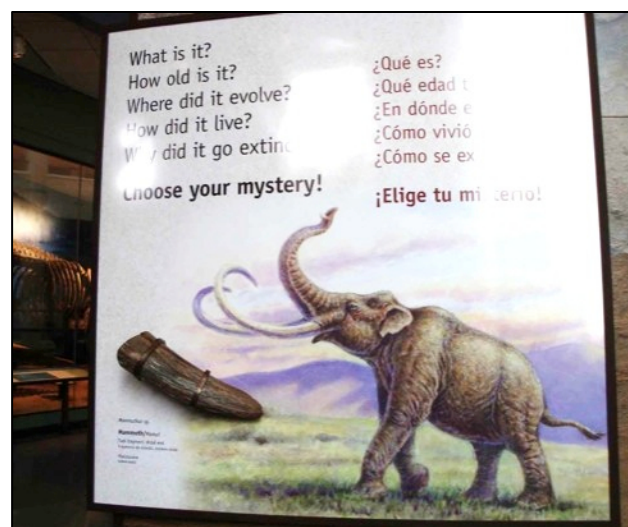


Figure 4.4. Graphic panel with an introduction to the exhibition themes and a touchable specimen of a partial mastodon tusk fossil.

gesture, to indicate the focus of their attention and recruit another's attention. When children ask *what is it*, adults more frequently respond to the question; children seldom respond.

An exhibit with the fossilized tip of a mastodon tusk and an illustration of an adult mastodon (figure 4.4), caught the visual attention of all the children. Four of the six case-study children touched the fossil tusk. Two children looked, touched with an indexical gesture, and explicitly asked a nearby adult “What is this?” although they did not perform these actions in the same manner or the same order (figures 4.5a–c, 4.6a–c). The adults responded by showing how the 3D specimen “fits” into the animal by pointing to the tip of the 2D mastodon tusk. One adult also pointed to and read the label text (figures 4.6a–c).

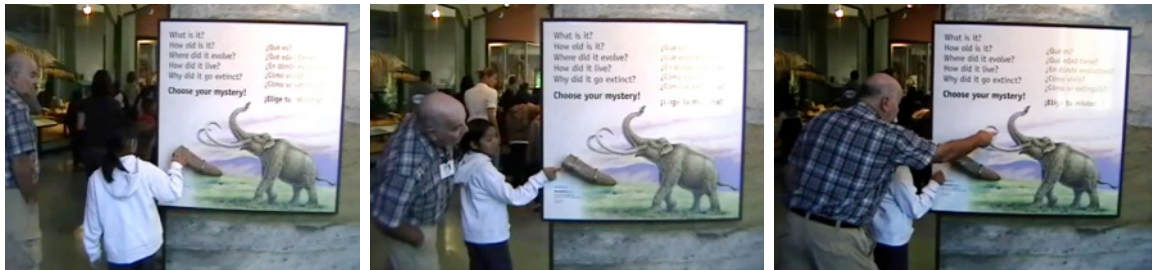


Figure 4.5 a–c. A child first looked at the mastodon tusk, touched it, asked her classroom teacher “What is this?” and pointed to the fossil. He responded “That is supposed to be right here,” using a series of indexical gestures to link the illustration of the mastodon to the fossilized partial tusk.



Figure 4.6 a–c. Another child looked at the mastodon tusk, asked an adult “What is this?”, then simultaneously touched and pointed at the specimen. The educator said “It looks like part of the tusk,” and pointed to the illustration to indicate where the tusk fragment would fit with the animal. She then looked to the label to confirm and said, “Oh wait, yea, tusk fragment,” and pointed to the text.

What is it? indicates attentional focus and curiosity among museum visitors. When paleontologists encounter a fossil, they also ask *What is it?* The exhibition team created this introductory panel to express a series of fundamental paleontological questions, and to emphasize that every fossil and rock provokes questions and potentially holds answers.

However the questions and answers expressed in text alone do not attract and engage. The title wall defined the scope of the exhibition's content, with no objects and no imagery. To save time and money in the push before opening the exhibition, the team created a panel with text only (in English and Spanish): "Enter a world of fossils, discovered and studied by this museum. Explore 75 million years of change in our region—Southern California and Baja California. Uncover long buried mysteries of life and death. Past and present connect and curiosity awakens. What mysteries will these fossils reveal to you?" (Figure 4.7).

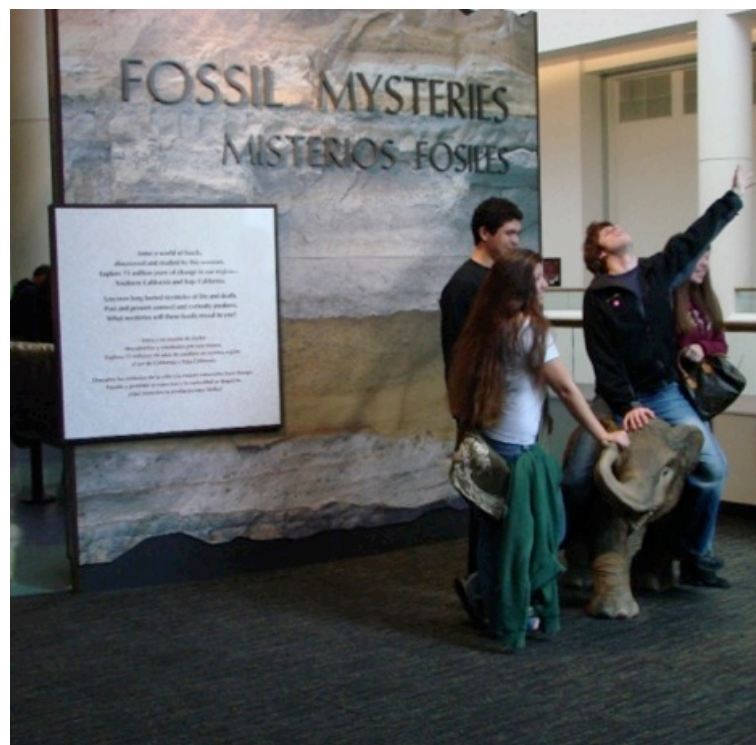


Figure 4.7. When *Fossil Mysteries* opened, the title wall included text only mounted on a photograph of sedimentary rock layers. Observation revealed that visitors tended to focus their attention elsewhere.

A summative evaluation just after the exhibition opened to the public involved observing and recording behavioral interactions with exhibits. Not a single adult or child participant looked at the text-only panels ($n=50$), despite a prime location at the exhibition entrances. After completing other major exhibition projects, the team turned their attention back to *Fossil Mysteries* and made changes based on the summative evaluation results.

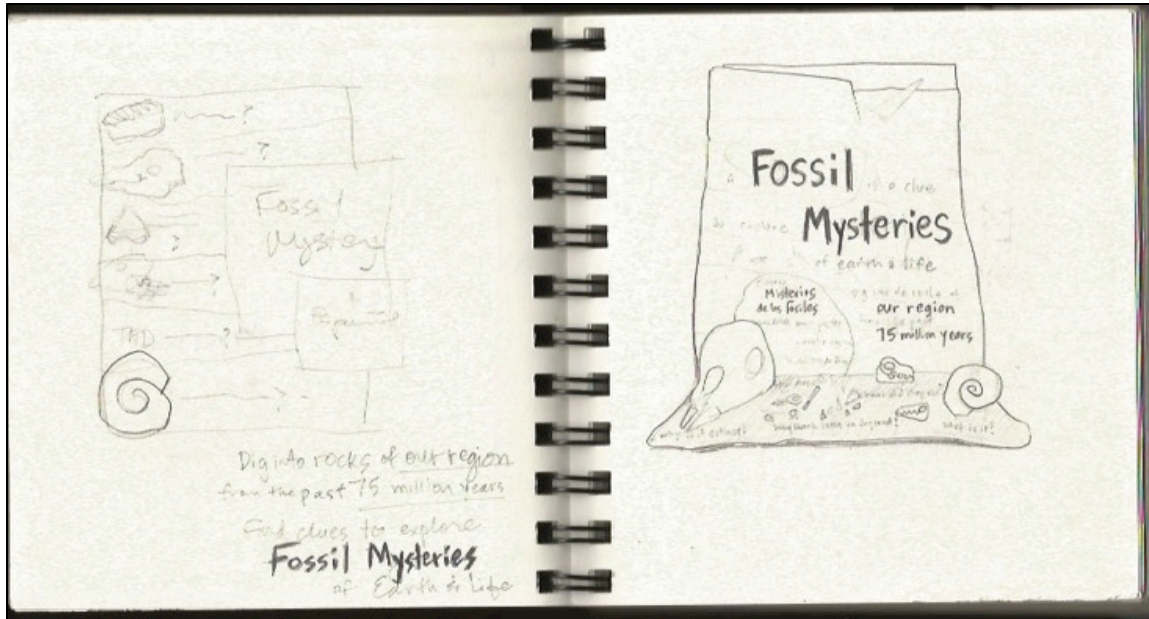


Figure 4.8. Touchable fossils feature prominently in preliminary sketches for the *Fossil Mysteries* title wall. Pencil traces remain as a visual record of exploring options and dialogue between two team members, years before the exhibition opened.

Returning to the original impulse for the title wall (figure 4.8), the team designed and constructed new panels with mounted touchable fossils. Two title walls—one for each exhibition entrance—anchor the exhibition’s sweep of time, from the Ice Ages to the time of dinosaurs (figures 4.9a–b). Revised bilingual text focuses on the exhibition’s essence: the process of inquiry. “What is it? How old is it? Where did it evolve? How did it live? Why did it go extinct? Choose your mystery!”

The accompanying orange label states “All the plants and animals featured in *Fossil Mysteries* lived in our region at different times during the past 75 million years.”



Figures 4.9 a, b. Each title wall now includes a touchable fossil. Although they appear superficially similar, one fossil comes from the tip of a mastodon tusk, the other from the horn core of a ceratopsian dinosaur.

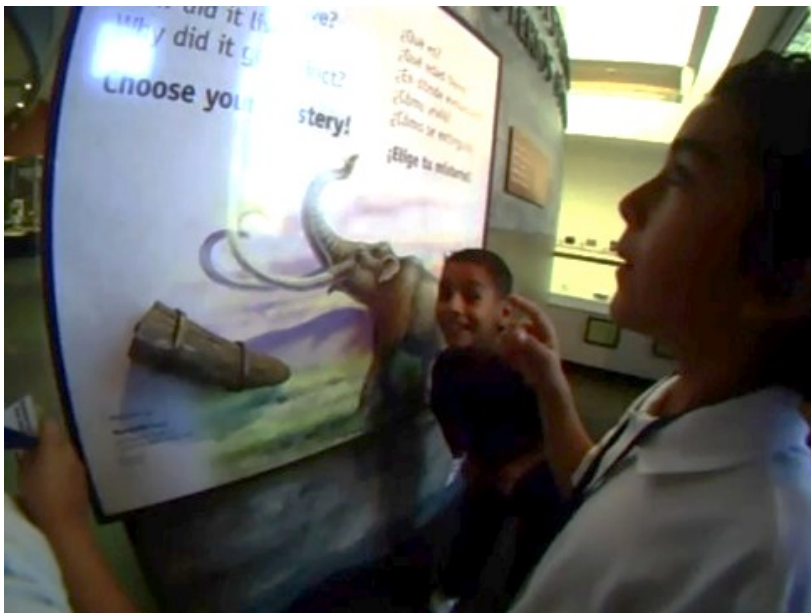


Figure 4.10. A fourth-grade child read the title wall text out loud, with classmates nearby. This video still comes from the head-mounted camera worn by a focal participant.

Among the children observed in three fourth-grade classes, the addition of a three-dimensional touchable specimen dramatically changed the panel's effect on visitors' attention. All six case-study children looked at the fossil, four touched it. Some case study children listened while their classmates read the exhibit text (figure 4.10).

The exhibition presents objects, images, text, and other media—all competing for visitors' attention. For a child to wonder *what is it?*, attention is the first prerequisite. An unfamiliar mysterious object, in a rich visual context, pushing into the child's space and accessible to touch, compels attention, and sometimes verbalization of the question "What is this?"



Figure 4.11. A fourth-grader looked at and touched the fossil tusk fragment on the revised title wall. The head-mounted camera (left) provides the child's changing perspective on the object.

Children ask *Is it a _____?*

The children also ask if an object is something specific, such as "It's a horse?" or "Fossils?" Often, other children and adults left these questions unanswered. The exception to this trend occurred in interactions between students and a teaching assistant. The children

answered the adult's verbal quiz, "Do you know what type of rock this is?" (See figures 4.43,44.) In those cases, the adult evaluated the correctness of the children's answers, given in question format (e.g. "Basalt?" "Entrusive?"), using a common classroom discourse structure, the teacher inquires, the student responds, then the teacher evaluates the student's response (Mehan, 1979). Some teachers tended to ask questions seeking a specific answer, whereas others asked open-ended questions that could involve exercising perceptual skill, or critical and creative thinking. Asking known-answer questions is a discourse structure unique to expert-novice interactions in Western schools and families, and is very uncommon or non-existent in the discourse of scientific and artistic professional practices (Heath, 2007).



Figure 4.12 a, b. A child first looked at, then talked about, and later manipulated a sabertooth cat skull and jaw. Figure 4.12 a. This view from a child's perspective accompanied his question, "Sabertooth?" Figure 4.12 b. Asking "Sabertooth?" indicated the object of his attention. Body placement put him in position to take a turn with the interactive exhibit became available.

Sabertooth?

When a child approached a sabertooth cat skull and asked "Sabertooth?" then placed his hand on the graphic panel in front of the display, he asked a question, while inserting himself into the turn-taking structure of the social group (figure 4.12a). One child responded, not to the

question about the object's identity, but instead said "I was next," while another child moved the lever that opens the sabertooth jaw. In this case, his question served a social function.

In the physical and conceptual space of the museum, children parse the visual world into differentiable objects and name them. They also negotiate the social world, vying for access to exhibits, with interactive exhibits at a premium. None of the children answered the boy's question about identity, but within nine seconds, he got his turn with the sabertooth skull and proceeded to open and close the jaw (figure 4.12b).



Figure 4.13. Video still of sabertooth cat skeleton from head-mounted camera recorded five minutes before the child's interaction with the sabertooth jaw shows the skull in context of the whole animal.

This child could have posed a *what is it* question in various ways. Is it a skull? Is it a cat? Is it moveable? Instead, he chose "Sabertooth?" This single label marked the identity of the object at a level of informativeness that is neither too broad nor too narrow, using a category name that provides "maximum information with the least cognitive effort" (Rosch, 1978). "Sabertooth" may not be a basic-level category in Linnaean taxonomy or in a category scheme applied from the outside. However, from the child's perspective in this context, category

structure emerges through experience with exemplars, not satisfaction of criteria. Many categorical labels fit this object, but “sabertooth” efficiently conveys neither too much nor too little information.

The child made no overt reference to the sabertooth cat skeleton nearby (figure 4.13), although it occupies a prominent place in the gallery and the children’s shared physical context. A design consequence of space constraints, the skeleton stands behind the children when they face the sabertooth cat skull. Based on observed interactions with other displays, one might speculate that a different placement of the skeleton and skull, which allowed for side-by-side viewing, would elicit speech about their shared features and part-whole relationship.

Another boy on a different day, moving rapidly from one display to another, came upon a fossil walrus skeleton, mounted upside down to represent its feeding position in life. He moved around the object, looking from multiple angles, and spoke without directing his speech to anyone in particular (figures 4.14a–e). “Hey look. (260ms pause) What’s this? (410ms) I don’t see. (530ms) Sabertooth?” The teacher responded quickly (200 ms latency) with a non sequitur, a rejection of his conversational bid, restating the question posed by the teachers at the beginning of their gallery visit, “Do you see any rocks though? Do you see a rock?” The child, in seeking a name for this fossil specimen, expressed his experience of perceptual similarity between the sabertooth cat and walrus—they both have dramatically enlarged upper canines (figure 4.15). From his use of the exhibit and interaction with the adult, we have no evidence that he got an answer to his question, “Sabertooth?”



Figure 4.14 a–e. A child looks at a mounted fossil walrus skeleton from multiple angles, saying “Hey look. What’s this? I don’t see. Sabertooth?”



Figure 4.15. The same child looked at, manipulated, and talked about a sabertooth cat skull four minutes before expressing his perception of visual similarity with the walrus skull by asking, “Sabertooth?” The teacher did not respond to his question in the presence of the walrus. Rather, she redirected the conversation saying, “Do you see any rocks?”

Children name and describe objects

When children name objects in the museum, they tend to use basic-level category names (Rosch, 1978). Examples include rock, lizard, bird, horse, ribs, heads. These basic-level category designations provide maximal information; they maximize the shared attributes among category members and they minimize the shared attributes by non-members of that category (Ibid). Similarly, children described objects with simple, yet informative adjectives that often conveyed profoundly salient qualities of objects (e.g. big, tiny, rough, shiny, heavy). Sometimes children named or described objects in isolated utterances. In one exuberant multimodal example, as a student looked at a 26-foot sea cow model mounted overhead (figure 4.16a), he stretched up on his toes, reached his arms completely overhead, and with exertion said, “Giant!” (Figure 4.16b.)



Figure 4.16 a, b. Children respond to objects in the museum in individually unique and similar ways. Figure 4.16 a. A mounted cast skeleton of a giant extinct sea cow, with sculpted skin on one side, attracts the attention of many children. Figure 4.16 b. After seeing the giant sea cow, one child extended his entire body in an exuberant iconic gesture and exclaimed “Giant!”

In the event-based case studies that follow, we see how the children name and describe objects in more extended conversations. In addition, we see examples of how the children manage attention with speech and gesture, and integrate other actions into their discourse.

Although code-switching between English and Spanish is not a focus of this research, the transcripts document the language as originally spoken by the children, reflecting the fluidity of movement between two languages, for some children more than others.

Fossil shells, teeny, tiny shells

When two children looked at, touched, and talked about a display of fossil marine invertebrates, the *what is it* leitmotif pervaded their engagement. Discussion of concrete objects dominated their speech, a recurring pattern in the children's engagements with museum specimens. First the boy directed the girl's attention to the display case. The girl asked "What is that? What's that?" then answered her own question, "they're shells." Throughout the engagement (which lasts 1 minute 17 seconds, longer than the majority of exhibit engagements) the children took clear conversational turns, the boy blending English and Spanish, oftentimes within the same phrase. Maintaining social contact through the rhythm of conversation seemed equally, if not more, important than discussing the fossils on display, and the specimens provided a sufficiently interesting object of joint attention. In the museum, the children practice identifying objects while they exercise social conversational skills.

The activity of naming and describing objects served as the backbone of their engagement with the exhibit ("they're shells"; "little tiny, teeny tiny shells"). They directed each other's attention ("look right here"; "mira, mira" [look, look]). They asked and responded to questions ("what's this?" "A fossil, I think"). In a few instances, they offered interpretation ("la quebro su su mano," [the starfish broke its hand]) and evaluation ("I like these kinds"). The children skillfully used prosody to guide and maintain the attention of others, as when the girl says, "I like these ones, they're tiny tinyeeeeee," protracting the long e sound in a high pitch.

We also see evidence of possible sound symbolism in a subsequent interaction described below, in which a giant fossil whale skeleton (“It’s so biiiiig”) presents a stark contrast to the teeny tiny shells.

Their conversational topics focused on concrete, perceivable objects—not how the objects represent concepts of ancient habitats and how fossils enable mapping of paleoenvironments. An adult teaching assistant interjected the theme of rock classification into the children’s conversation, but the girl redirected the conversational flow with “Look at this big shell.” The teacher, in a very quiet voice, weakly re-asserted her conversational theme driving toward classifying the rock as sedimentary (“you see rocks on the shells too?”), but the two children returned to their project of naming objects and maintaining joint attention between them.

Transcript: Girl (M) and Boy (R) engage with fossil marine invertebrates

(1 minute, 16.5 seconds)

Bold text highlights how the children used speech to **name and describe the objects**.

Underlining indicates directing attention with speech and/or gesture. Italics indicate *what is it* questions. Text in parentheses indicates (actions). Text in brackets indicates translations of Spanish speech into [English].

R: Oh, look right here (touches M’s arm, points to display of fossil shells)

M: *What is that? What’s that?* Be careful, R (touches graphic panel, leans in to look closely)

(Audible intake of breath, figure 4.17) Oh, **they’re shells**

R: **Tiny, tiny.** Aquí, mira [Here, look] (points at shells in case, figure 4.18)



Figure 4.17. Two children, R and M, look at marine invertebrate fossils.

M: Oh let me see, let me see. **Little tiny, teeny tiny shells**

R: **Son chiquitos** [They're really small]



Figure 4.18. R points at tiny fossil shells in a display case.

M: Ooooh

R: Mira, mira [Look, look], look at them (points at shells in case, figure 4.19)



Figure 4.19. R points at tiny fossil shells a second time.

M: **They're so tiny**

Teacher: There're some right here (points to touchable fossil sanddollars) Can you tell me about that?

R: Aquí dice, aquí dice, aquí dice [Here it says, here it says] (Lifts graphic flip panel with maps, points to legend, then closes flip panel, figure 4.20)

M: *What's thisss?* (while touching fossil sanddollars, figure 4.20)

R: **A fossil**, I think. Because look, it has **shells** (points to and touches fossil sanddollar)

Teacher: *Could it be **sedimentary**?* (child continues touching fossil, figure 4.20)



Figure 4.20. R points to a map under a flip panel, while M and another child touch fossil sanddollars in sandstone.

M: Mmmaybe (continues touching fossil, figure 4.20)

R: Yea

Teacher: Possibly, because, because why...

R: Because **it's broken** from right here (touches side of rock which surrounds the fossils)

Mejor es [it's probably]... **sedimentary, metamorphic**, orrr... (counting on fingers)

M: Look at this **big shell** (taps R's arm, turns, points to large clam shell in case, figure 4.21)

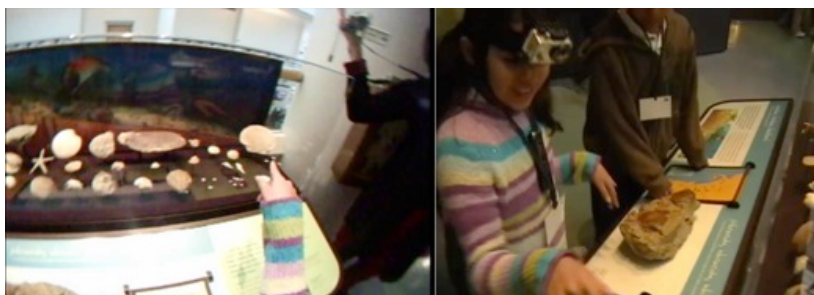


Figure 4.21. M speaks and points at a big shell, redirecting her friend's attention.

Teacher: (Inaudible)...more **shells**...(inaudible)...you see **rocks** on the **shells** too...

(inaudible)...can you see?

R: Oh **this is a fossil**, look, mira, este [look, this] **starfish** (points at fossil sea star in case, figure 4.22)

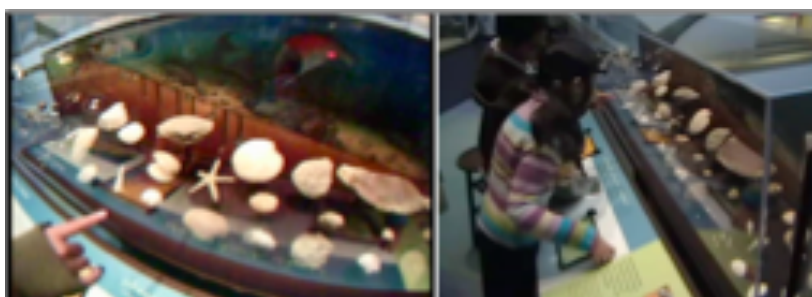


Figure 4.22. R points to fossil sea star in a display case.

M: It's a **starfish**

R: Y la quebro su su **mano** que [And it broke its its hand] (makes chopping gesture with right hand on left arm) Oh I like these kinds. I like this one (points to illustration on graphic panel) This one's a **snail**

M: I like these ones (points to very small clam fossils in case) **They're tiny tinyeeeeee**

R: I wanna find one of those once

Mira aquí eso la taches te pica [Look here, you touch it and it pricks you] (points at sea urchin illustration on panel, figure 4.23)



Figure 4.23. R points at sea urchin illustration on a graphic panel.

Nos vamos aquí [let's go here] (turns 180° and points to fossil whale skeleton, figure 4.24)



Figure 4.24. Video still from child's point of view. "Nos vamos aquí."

Coding Discourse Themes

- C** Concrete
- A** Abstract
- CA** Concrete / Abstract
- O** Object
- R** Relation



Figure 4.25. Coding discourse themes provides one way of seeing conversational structure.

Coding of discourse themes reveals dominant aspects of how the children used the exhibit of fossil marine invertebrates (figure 4.25). The coding scheme for concrete, abstract, and blended concrete/abstract speech (see figure 3.3 and appendix 4A), when combined with analysis of parts of speech, makes visible another conceptual structure. The children use nouns and adjectives to refer to *objects*. With verbs and prepositions they speak of *relations*.

- CO** what?
- CO** shells
- CO** tiny, tiny
- CO** teeny, tiny
- CO** chiquitos
- CO** tiny
- CO** fossil, has shells
- CO** sedimentary? (T)
- CO** broken
- CO** sedimentary, metamorphic
- CO** big shell
- CO** more shells, rocks on the shells (T)
- CAOR** fossil, starfish
- CO** quebro su su mano [broke its hand]
- CO** snail
- CO** tiny, tinyeeeeeee
- CAOR** la taches te pica [touch it, it pricks you (urchin)]



(T) = teacher's speech

Figure 4.26. Coding the conversation by turns shows how discourse themes revolved around concrete objects, i.e. a diversity of marine invertebrate fossils. The children did not discuss abstract concepts related to mapping ancient environments.

So children can talk about concrete objects, concrete relations, abstract objects, abstract relations, concrete/abstract objects, and concrete/abstract relations. (See figure 3.2 in Results Overview.)

In 50% of the case study children's speech events in the museum, the children spoke about concrete objects.² In this conversation, two children focused their speech on concrete objects almost exclusively (figure 4.26). The turn-taking structure carried along the discourse with recurrent themes of naming and describing concrete objects, while maintaining joint attention. In the cognitive accomplishment of negotiating joint attention, the transcript above shows how pointing gestures index objects of attention and direct gaze, and prosody expresses and modulates arousal. As the children looked at the fossil shells, with confidence and fluency they named and described aspects of diversity—a core idea in this gallery about ecology. The children did not overtly express any ideas about ecology, rather they experienced a diversity of shells. The concrete objects held their attention, and nothing compelled movement away from the perceptual features of the objects themselves. Indeed, in their perceptual engagement the children expressed intrinsic motivation and skill, using attention, speech, and gesture to differentiate among a series of museum specimens.

A very big whale

The two children, after looking at a variety of fossil shells ranging from tiny to big, discovered some fossils on a different scale of big. To emphasize the most salient feature, and perhaps provide aural contrast with verbal descriptions of the other specimens, the children extended vowel sounds, for example with the word “big” making the word “bigger.”

In this case, naming the objects (“they are fossils”) came in response to the question “this used to live?” The label *fossil*, by definition, entails the traces or remains of past life. The statement “they are fossils” indirectly answers the question and may assert an organizing principle for the natural history museum exhibition: all these things are fossils and therefore, all these things used to live. “They are fossils” provides maximum informativeness with an economy of speech, if the interlocutor understands what is a fossil.

Transcript: Girl (M) and Boy (R) walk toward and look at whale fossils

(17.15 seconds) Bold text highlights how the children used speech to **name and describe the objects**. Underlining indicates directing attention with speech and/or gesture. Italics indicate *what is it* questions. Text in parentheses indicates (actions). Text in brackets indicates translations of Spanish speech into [English].

R: Nos vamos aquí (R turns toward M and pushes M’s arm, spins her 180° and points, both walk toward whale fossils, touching each other’s arms)

R: Oh daaang (extended twangy vowel)

Other child: See one of these? (offers conversational bid holding up fossil shell identification card for R and M to see, figure 4.27)



Figure 4.27. A child offers a card with labeled pictures of fossil shells to M and R.



Figure 4.28. M and R walk toward a fossil whale skeleton.

(Bid rejected, children continue walking toward whale fossils, figure 4.31)

M: **Cooooool** (emphasis on oooo sound, consonants very soft) (pause)

R: Dang

M: They're so **biiiiig** (extended vowel)

R: This, *this used to live?* (pause)

M: I know, that's why they are **fossils** (palm up gesture toward whale fossils, figure 4.29)



Figure 4.29. M gestures toward whale fossils, "...that's why they are fossils."

R: *this used to live?* ... Aquí dice [Here it says] (point to text panel) aquí dice

M: I know they're **fossils**, I know that **fossils**

R: (inaudible speech) Mira, mira, mira [Look, look, look]

(R points over M's right shoulder, touches her left arm and they turn 100° to the right)

Four and a half minutes later—after seeing a giant model shark, a fossil walrus, a video about San Diego’s ancient bay ecosystem, touching a baby sea cow model, and reading a few sentences in English and Spanish about this ancient ecosystem—the children returned to a different specimen in the large display case, a fossil whale skull. To define the identity of the object, the child used the specimen label and directed the others’ attention to the source of her information. She named the specimen (“It’s an extinct fin whale”), and her friend provided a partial definition of the descriptor extinct (“it *lived*,” in the past tense). After a few tries, they converged on the correct English pronunciation for the word skull (which is very unlike *craneo*, the word in Spanish).



Figure 4.30. M reads and points to the whale fossil label.

M: It’s an **extinct fin whale** (reads text and points to specimen label, figure 4.30)

R: It’s an **extinct** becau...

M: And it’s a (points to specimen label)

R: **They lived** i...

M: and the **skol** (long o pronunciation) and the skull, skull (adjusts pronunciation each time, points to specimen label for the duration of utterance)

R: **Skull**, you know you're (inaudible speech)

M: Oh my God, I can't say it

Children classify objects

When children name and describe objects, they exercise flexibility in how they apply categorization schemes. Sometimes they apply classification schemes. To clarify the distinction between categorization and classification, categorization involves grouping based on perceived similarities; groups may have graded structure and fuzzy boundaries; membership may be flexible and context-dependent (Jacob, 2004). Classification depends on analysis of necessary and sufficient characteristics; fixed boundaries that define mutually-exclusive and non-overlapping classes; no members are more typical than others, they are equally representative (Ibid).

In the natural history museum, when the case study children used concrete speech focused on museum objects (n=149, five children), they infrequently applied a classification scheme (n=13). Among those instances, children talked about objects' authenticity most commonly. The children classified objects in these ways: real or fake (6/13), differentiating rock types, sedimentary, igneous, metamorphic (4/13), dead or alive (2/13), male and female (1/13). Children initiated most classification events (9/13). However, adults initiated all classification of rocks as either sedimentary, igneous, or metamorphic (4/13).

Appropriate to the museum setting, children ask a compelling question—*is it real? Is it real?* expresses a specific variant of *what is it?*, and highlights an aspect of museum design—*when is an object a representation?* Among the case studies, the children targeted a variety of

objects with *is it real?* —including models (a life-sized giant Pleistocene lion, a rattlesnake in a rock cave, a model nest of dinosaur eggs) and authentic specimens (a fossilized sabertooth cat skeleton, a gibbon skeleton, an igneous rock). The next chapter further explores *when* is a representation (Hutchins, 2012).

A fake sea cow



Figures 4.31 a, b. A touchable sea cow sculpture attracts several children, who touch and talk about the object. Child's perspective on left, child (with head-mounted camera) in physical / social context on right.



Figure 4.32. Patting the sea cow model reinforced her statement, "This is just fake, see?"

In one case, a child declared the “fake” status of an object on display. Her classmates streamed into the ancient bay gallery. Many confronted the life-sized model of a baby sea cow; they looked, touched, and talked about it (“Yay! He has little tiny eyes” figure 4.31a–b).

She made her way around the tail of the sea cow, watched a few children touch the model, then said to a classmate (who didn’t respond), “This is just fake, see?” She patted on the hollow fiberglass body of the sea cow baby to substantiate her claim (figure 4.32).

California Condor, dead and real

Taxidermy specimens present the opportunity to differentiate between the categories of dead-or-alive and fake-or-real. Fake things are not, and never were, alive. But *not* all dead things are fake. One child tried to express this distinction (using English, his second language) to classify a mounted California Condor—it was alive, is now dead, and is also real. Other interesting things happened in this one-minute encounter (joint reading, observing, and describing the condor’s small ears) between introducing the concept of “alive” at the very beginning, then returning to the theme with “real” and “they killed it” at the end.

Transcript: Girl (M) and Boy (R) look at and talk about a taxidermied condor

(1 minute 2 seconds)

R: This was supposed to be alive, and that’s the, it’s alive, but now it’s *primer cosas* [*sic*, first



Figure 4.33. R talks about a taxidermied condor.

things, figure 4.33]

Classmate: It's alive?

M: I know

(M starts to read aloud)

M: "A bigger bird bites the dust..." (figure 4.34)



Figure 4.34. M reads exhibit text.

She read aloud tracing the text with her finger, then he joined in reading, five sentences all together, until they stumbled on "predator," stumbled again on "teratornis'" in the last sentence, and stopped reading with three words to go.³

R: Though they think it's better, Oh my God, no these are better (in response to text "did humans hunt these giant predators to extinction...?")

Girl: I can see his ears figure 4.35)

M: Oh my God, they're so little



Figure 4.35. M leans on the panel and looks closely at the condor mount.

R: Because, um, **they're real**, but now they put stuff in it. (emphasis added)

M: Hm-hmm

R: That means they killed it. (figure 4.36)

M: Oh (staccato syllable)



Figure 4.36. R looks at M while talking about the condor.

In contrast, when M first encountered the condor two minutes earlier, she said “ooooohh.”

R turned 90° to the left and walked toward a partial fossilized horse skeleton. M turned and followed him, but a question from a friend caused M to turn her head fully around, even while her feet continued in the original direction (figure 4.37). Her friend’s question must have been some variant of *what is it?*, based on M’s response. If we could discern the specific wording of the original question from the audio recording, we might better understand the response that followed.



Figure 4.37. While walking away, a friend catches M and spins her around to look at the condor.

M: Es un pajaro [It's a bird]

Friend: ¿Viejo? [Old?]

M: No, es muerto [No, it's dead]⁴

Here, the children offer three orthogonal category labels: bird, old, and dead. M encountered the word “bird” in the text that she read; perhaps that influenced her response. “Old,” in a natural history museum, could mean several things: Is the specimen old? Is the bird ancient? What does “old” mean for the children in this exchange? “Dead,” a theme hit hard by R in their encounter with the bird moments earlier, propagated to M’s schema for the Condor. In this exchange, “it’s dead” seemed a suitable response to “old?”

The two friends completed their bird talk and followed the movement and gesture of a classmate to the next display (figure 4.38).

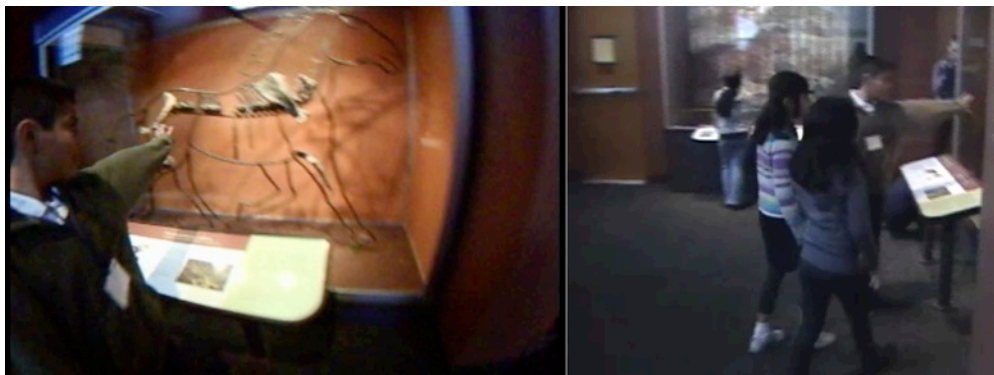


Figure 4.38. R gestures toward horse fossils mounted on a horse-shaped armature.

A horse fossil: male or female?

M: *What's that?* It's a horse? (all looking at partial horse fossil)

Friend: (inaudible) ¿no ves? [Don't you see?]

R: Sí, la mataron [Yes, they killed it]

M: Oh

Friend: La mataron, la mataron, la mataron [they killed it, they killed it, they killed it]

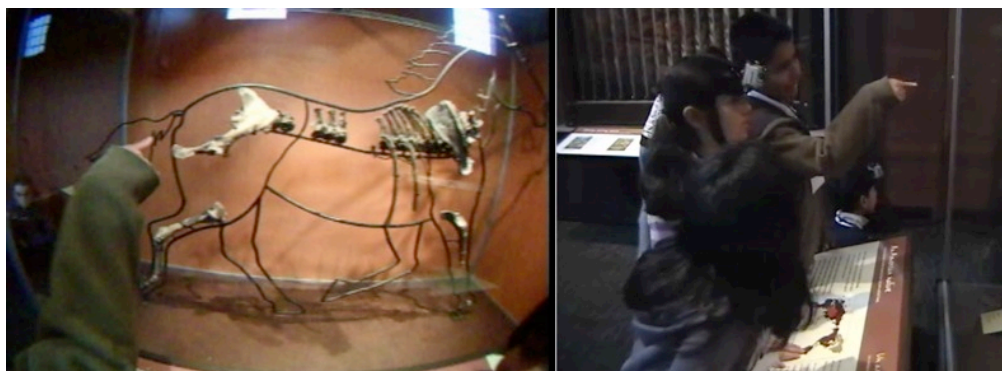


Figure 4.39. R points to the horse display while the children talk.

M: LO mataron (emphasis on pronoun lo) [They killed IT/masculine] (R points at fossils, figure 4.39)

Friend: (leaning toward R) LO mataron (emphasis on pronoun LO) [They killed IT]

M: (under her breath) You don't know how to talk in Spanish

Friend: Si un mujer, la mataron, pero si fuera [If it is a woman, then they killed it (feminine pronoun), but if it was]

M: Ni si quieres ... es hombre o mujer [It doesn't matter if it was a man or woman]

The children's extended "they killed it" exchange contains more information in Spanish than English. In the clause *La mataron* (transliterated *It they killed*), *la* refers to the horse, *caballo* in Spanish. However, here lies a grammatical inconsistency: the feminine gender of *la* does not match the masculine gender of *caballo*. M asserts the appropriate construction, emphasizing the masculine pronoun "LO mataron." The pronoun establishes the gender of the horse. The mere outline of a horse—a line drawing in metal that supports the armature and the horse's incomplete fossil remains—establishes the essential basic-level identity: horse.⁵

Although her friend tried to extend the conversational theme, perhaps as a form of conversational repair, M responded saying it doesn't matter if the horse is male or female.

Enculturation in museum practices

A lesson on how to read the museum: real or fake



Figure 4.40. A museum educator explained the concept of taxidermy to a group of fourth-graders.

Back at the Condor, on another day, a museum educator spoke to a group of children gathered around looking at the old bird specimen (figure 4.40).

Museum educator: If you guys want to know if something is real or not, you can always read the labels. (points to label) So it says this is a California Condor, and it says it's a taxidermy mount, which means that it was an animal that used to be alive that died, and, somebody preserved the body and stuffed it, so they cleaned out all the stuff that would rot away, and they cleaned it out so that we could preserve it so we can learn from it.

Fourth-grader: So it's actually real?

Museum educator: So it's real, I'm not sure about the face part, but definitely...

Our audio record ends here. The child listened to this point, then moved on, followed by the researcher with the video camera.

Real dinosaur eggs?!



Figures 4.41 a–c. A child (D) approached a modeled dinosaur nest with eggs. He asked “Are those real eggs?”, turned the wheel-shaped interface, then pointed at the egg that moved.

One case study child, D, seldom spoke about the exhibits, and this display—a model lambeosaur with a nest full of eggs—made his short list of talked-about items.⁶ (Approaching a group of children huddled near a cluster of spherical objects, figure 4.41a–c)

D: Are those real eggs? (figure 4.41b)

No one answered. The boy watched the eggs and the children's activity. He figured out that the eggs moved in response to the action of turning a wheel mounted to a panel. D spoke many more times with this one exhibit. This quiet child negotiated a place in line, waited to take a turn, watched how the eggs changed, and pointed out which ones moved (4.47). He discovered, without anyone explaining, that the eggs weren't real. Albeit in model form, he experienced that dinosaurs hatch from eggs.

A clash of classification schemes

From across the gallery, a child saw a chunk of granitic rock and said aloud to himself an extended version of "awesome." Based on his enthusiastic reaction, this rock falls in the category of interesting unusual objects. A teacher came up behind him, asked what he found, then asked him to classify the rock. A conversation ensued, with the teacher using a standard classroom discourse form called IRE, in which the teacher initiates with a known-answer question, the student responds, and the teacher evaluates the response (Mehan, 1979). The teacher sought specific responses from the child. He played the conversational game, making eye contact and responding to her questions, although he did not have the answers that the teacher seemed to want. During one question-answer pair, when the teacher asked if the igneous rock was intrusive or extrusive, he hedged his bets by responding "entrusive."

At one point during the conversation, the teacher brought the child's attention back to the specimen itself, "What can you see on the rock?" Together, they noticed the shiny minerals. She tried to make the critical link between pattern (visible crystals) and process (molten rock cooled slowly inside the Earth so the crystals had time to form). Yet, the child's body language—looking away, fidgety stance, arms folded over his chest—suggests his discomfort with the conversation. His agenda to look at and touch an awesome rock got hijacked by a teacher quizzing him on how to classify the rock.

Transcript: Child (L) and a teacher at touchable igneous rock display

(1 minute, 9 seconds)

L: What's here? (walks around exhibit, sees rock, walks toward)

L: Ahahawesome (figure 4.42)

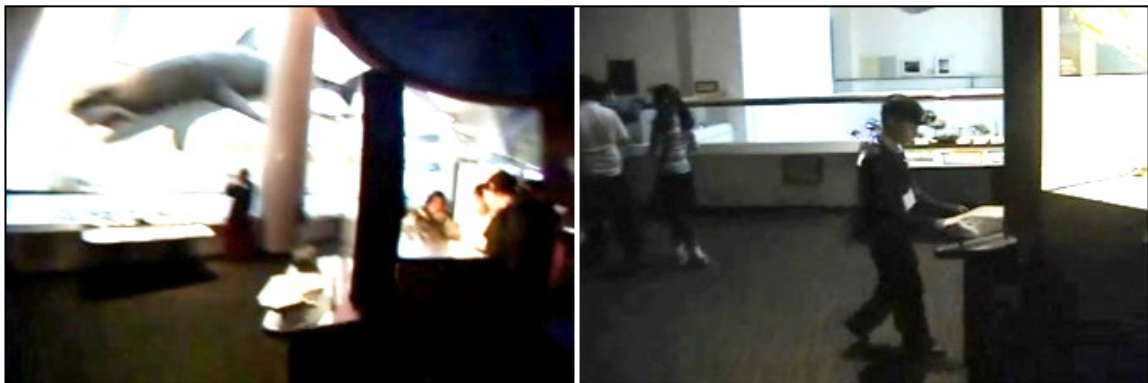


Figure 4.42. A child approaches a touchable rock. Child's perspective on left; research assistant's perspective on right.

Teacher: So let's look for rocks. (L touches rock)

What did you find L?

L: This rock (teacher walks over, looks at L; L looks from rock to teacher)

Teacher: What kind of rock is it?

L: It's uhhhhh

(looks at rock and label)

Teacher: Do you know?

Do you remember your three types of rocks?

L: (looks at label, points) Yea it's an ennnchuh (in-breath)

Teacher: Igneous

L: Yea an igneoussss (looks at teacher, looks away, looks at rock)

Teacher: Do you know what helps you identify the igneous?

What can you see on the rock? (points at rock, figure 4.43)

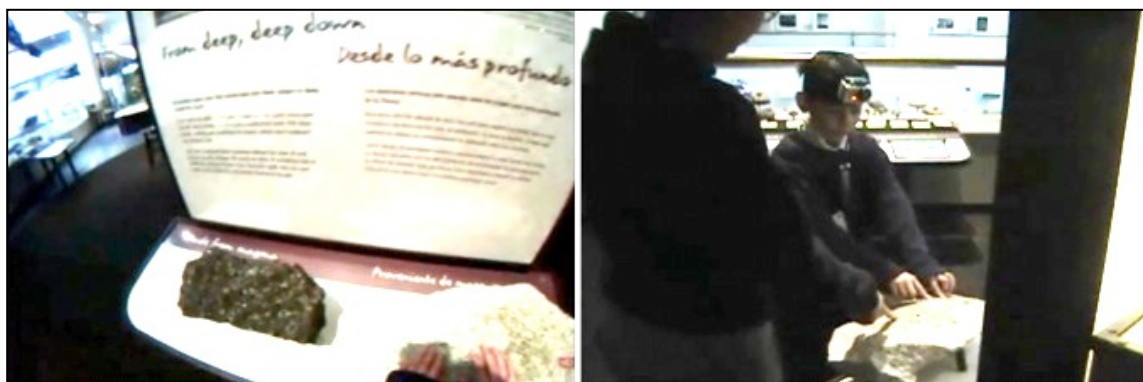


Figure 4.43. The teacher and child look at, touch, and talk about the rock.

L: (touches rock, looks at label) Heat pressure (looks at teacher)

Teacher: No—that's metamorphic (L looks back at rock)

Do you see something shiny? (unpinch gesture over rock, point/tap three times)

L: (looks at rock) Rocks? Minerals (looks at teacher, back at rock, touches rock)

Teacher: Yes, you really see them in igneous. What kind of igneous rock though helps you see the minerals? There's two: intrusive and extrusive. Think about it...

L: (looks away, shrugs shoulders, looks at teacher, figure 4.44)



Figure 4.44. The teacher asks a question and the child reluctantly offers an answer. Child's perspective on left; research assistant's perspective on right.

Entrusive

Teacher: Which one?

L: Entrusive? (looks away, looks at teacher, puts hand on hip)

Teacher: Intrusive? (leans ear toward students' mouth)

Is that what you just said?

L: (looks briefly at teacher, small amplitude but rapid head nod two times)

Teacher: Cuz why? It, the rock

L: Breaks?

Teacher: Holds— (gesture, open-cupped hands move toward each other)

L: And breaks? (hands move apart)

Teacher: No it cu...intrusive rock is when it cools slowly inside the Earth

L: (looks at graphic panel, looks at teacher) Ohhh

Teacher: So that's why the crista...uhh the minerals inside will form bigger minerals (hands move apart)

L: (crosses arms, figure 4.45) Yea



Figure 4.45. The teacher explains to the child, his gaze on her, his arms and legs crossed.

Teacher: Have you ever seen them?

L: (looks away, looks at teacher)

Yea (single nod, turns and leaves)

Children evaluate museum objects



Figure 4.46. Shot from a child's point of view, this video still shows how the expanse of the dinosaur gallery opened up before the child. This child (D) hardly spoke about the content of the exhibition. But when he reached this gallery, he spoke about the exhibits much more than previously, including a loud "whooooooa" when he saw the armored dinosaur standing on the floor (lower right).

All the case study children made audible exclamatory emotion-rich evaluative judgments about the museum exhibits throughout *Fossil Mysteries*. Their peers did the same. These expressions took a variety of forms—oh, ooooooh, aaaaww, cool, awesome, whoa, wow (e.g. figure 4.46). Because these utterances referred to present and perceivable exhibit content, they received the code "Concrete." Exclamations of 'cool' and 'awesome' describe a quality of

the objects as perceived and experienced by the children. The function of these expressions is to evaluate. This qualitative feeling occupies a dimension of experiencing objects, hence the discussion in this chapter.

The number of evaluative utterances varies among the case-study children. For one child, evaluative judgments comprise 10% of her exhibit-related speech. One child makes many evaluative judgments to himself; another child makes these statements much less often, but smiles very often, a different outward expression of evaluation.

Children utter evaluative judgments in the company of others and when by themselves. Children will watch others manipulate an interactive exhibit for several minutes, often in silence, and when they finally get their turn, they express the sounds of delight, satisfaction of expectations, or release of anticipatory inhibition. These often-effusive expressions signal surprise or satisfaction and, generally, positive affect. They sometimes direct the attention of others, and may reinforce the focus of attention for the individual.



Figure 4.47 a–d. Children engage with a touchable dinosaur model. Figure 4.47 a. The child approached an armored dinosaur model (child’s point of view). 4.54. Figure 4.47 b. The armored dinosaur seen from the researcher’s perspective. Figures 4.47 c, d. A classmate caresses, hugs, and talks to the armored dinosaur model (child’s point of view).

Positive affect in the museum

One boy (D) didn’t speak much overall. He talked most about video recording the other children with the camera on his head. After engaging with 28 different exhibits, 23 minutes 40 seconds into the gallery visit, he spoke for the first time about the exhibits. Eleven minutes after that, he entered the dinosaur gallery and saw this life-sized dinosaur with protuberant knobs, plates, and spikes (figures 4.41a–d). He let out the most forceful sound recorded in his forty-minute gallery visit, “whooooooa,” (figure 4.41a). His friend laughed, hugged the dinosaur

model, and said “He’s my dad now,” (figure 4.41d). The quiet boy responded, “I’m recording what you said.” His friend said, “No, no, you know what, I’m just playing.”

The child’s forceful whoooo powerfully expressed positive affect, perhaps elicited by getting face-to-face with an armored dinosaur, and feeling the size and shape of his body against the size and shape of a dinosaur body. Although video recording of peers continued to be a thread woven through this participant’s museum experience, when he arrived in the last gallery, video recording faded back, and wove together with other threads—touching more, talking more, and expressing interest and delight.

Evaluation, enjoyment, imagination

From across the room, a child (L) traversed the same path he took five minutes earlier, but this time he followed a higher line of sight and saw something else (figure 4.48).

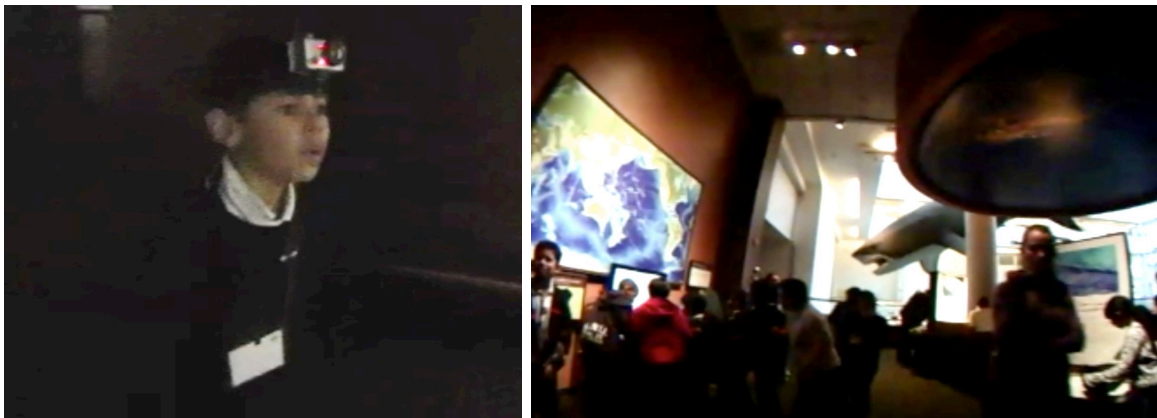


Figure 4.48. A child spotted the giant *Carchodon megalodon* shark from across the gallery, and exclaimed “Whooooa....awesss.” Child’s perspective shot from head-mounted camera on right.

“Whooooa....awesss”

His eyes widened, his pace quickened. He strode across the gallery and grasped the railing looking out to the atrium. Turning his head and gazing upward, he said slowly, in a low voice, “Hello, Sharky,” (figure 4.49).



Figure 4.49. Looking up into the face of the giant shark model, the child said “Hello, Sharky.” Child’s perspective on right.

Through engagement with these museum objects, children experience moments of enjoyment, play, and imagination. Although the moments are brief, they are profoundly unique, with uncommon objects in unusual spaces. Children move quickly from one exhibit to another, and a lot happens in a short amount of time. As they look, touch, talk and gesture, they integrate information from multiple modalities to make sense of their experience and to create new meanings, sometimes with positive emotional associations, here in a museum where they can freely explore the nature of objects.

Consequences of observation

When we look closely at what children actually do in the museum, we discover that they engage with concrete objects in interesting and important ways. They ask questions, name, describe, classify, and evaluate. Woven throughout their experiences are acts of imagination,

filling gaps that they perceive and create as they experience concrete objects. (See more about imagination in chapter 6). Children employ cultural practices as they explore objects and express their perceptions, opinions, ideas, and questions. They integrate information from the perceptions and actions of themselves and others to make sense of their museum experience.

The great abundance of children's talk about concrete objects using concrete speech reflects several relationships: the museum has a plentiful supply of concrete objects, and the children's cognitive and linguistic development makes concrete speech a comfortable medium for expression. In most cases, concrete speech provides the means to a satisfactory response to the driving question *What is it?*

Concrete speech, the most abundant observed speech form, serves many functions for children in the museum. Some functions, such as naming, questions related to identity, description and evaluation, are abundant and widely distributed across many types of exhibits. When children identify objects, they tend to use basic-level categories based on their experiential repertoire. They express evaluative judgments of museum objects, almost always with a positive emotional valence. Children offer simple descriptions of features, but rarely describe relations among objects using concrete speech. They classify objects infrequently. When they do, the most common classifications relate to objects being either real or fake.

Traditionally, information transmission has provided the dominant model for engagement and learning in museums. Based on observation in one natural history museum, we see that children don't perform as passive receivers of information. Rather, they actively probe the museum environment and the objects within. Using multiple modalities, they engage in embodied exploration and inquiry about the concrete nature of museum objects. Using language, they exercise cognitive skills as they ask questions, name, describe, classify, and

evaluate. With knowledge and respect for what children actually do, educators, designers, and researchers can explore ways to expand opportunities for children to explore and develop valuable skills of thought and action. Furthermore, through observation, we may expand what we find valuable in children's use of museums.



Figure 4.50. Entering the dinosaur gallery, one child's point of view (from a head-mounted camera) appears very similar to another's on a different day (figure 4.47), but the path each took diverged greatly from there.

Appendix 4A: Coding Talk

Parse speech by utterance (not word-by-word). An utterance comprises a thought, and may contain a subject and a predicate. Subjects and predicates may be explicit or implicit.

A = Abstract — When the content of the speech refers to abstract ideas related to exhibit content that include things or events that aren't physically present (earthquakes, evolution), that relate to generalizable principles (how things work in the abstract, such as processes/phenomena in time or space), and what abstract notions exhibit objects appear to represent ("go back to the future"). To count as abstract talk, the utterance must refer to the abstract conceptual content of the exhibit. Otherwise, code it as social or other.

C = Concrete — When the content of the speech refers to perceivable aspects of tangible concrete objects that are physically present in the exhibits. Concrete talk includes questions and comments related to the identity of an object (what's that?), to label its name or category (it's a fossil), an object's features (big, dark, smooth), an object's behavior (that thing moves slowly), or the ways that people's bodies can engage with concrete objects.

A/C = Abstract / Concrete — If a single utterance contains both abstract and concrete content in referent to the exhibit, we will code it as Abstract / Concrete.

S = Social — All speech, at some level, performs a social function. For this project, we will code it as social when the speech does not seem to overtly refer to abstract, concrete or both abstract and concrete exhibit-related content, but relates more directly to coordinating social activity ("let's go over there").

Sp = Spanish — This code will flag words that are spoken in Spanish. Fluent Spanish-speakers will code the content of this speech.

O = Other — Talk that doesn't clearly fit into one of the above categories and does not overtly refer to exhibit content.

RA = Read Aloud — The participant reads text on the panel out loud. Gaze direction and use of hands provide information to help discern if the participant is reading.

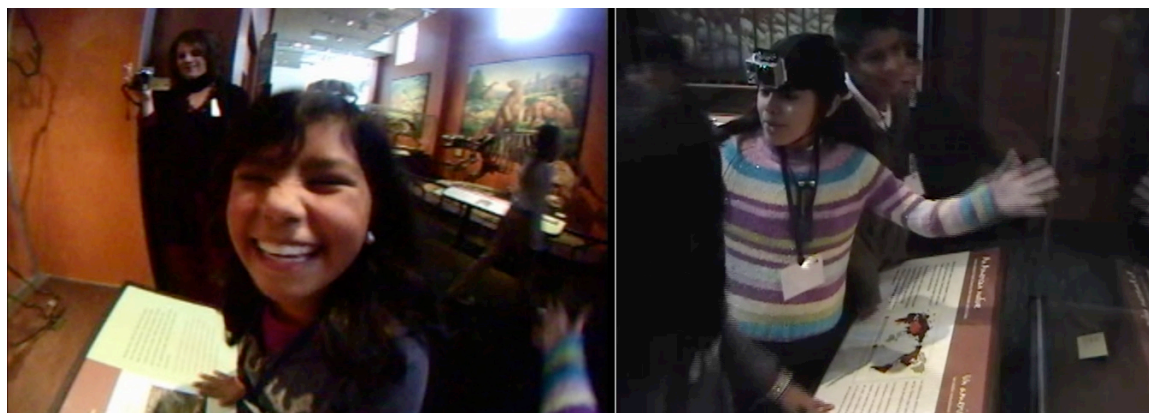
¹ When adding the percentages of these three categories of museum objects (specimens, casts of specimens, and models) the total exceeds 100. In some cases, the museum visitor can manipulate an object directly, such as moving a model of a bone, and in other cases one can manipulate the object indirectly through the use of an interface, such as a knob or a lever. This distinction highlights the differences among visual information, tactile information, and visual-tactile contingencies.

² This percentage of children's speech events excludes when children read exhibit text out loud.

³ At one time, a bronze *Teratornis* skull from a giant predatory bird related to the Condor accompanied the text, "A bigger bird bites the dust." Someone stole the skull. The text, with a beautiful drawing, remains as a vestige.

⁴ A note about language use: These friends always speak together in Spanish. Other classmates speak to M in English and M's friend in Spanish.

⁵ In the interaction that immediately followed the exchange about *what is it* (a horse) and classification (male or female): M turned away and began to read the horse text aloud. Her friend tugged M's arm and said, "¿A ver, a que preguntaré?" ("What would you like to ask it?") with a sweeping gesture toward the horse. M responds emphatically, with two-handed palm up beat gestures, speaking in English, "(friend's name), Let me read!" The two girls proceed to read the text panel side-by-side, M reading in English and her friend reading in Spanish.



⁶ One case study child, D, spoke seldom about the exhibits, yet his speech often referred to the camera equipment. In a gallery that kids call the "jungle room," dim light filters through the rainforest canopy, primates chirp, and animals hide in the trees and underbrush. In the jungle room, D started talking about the exhibits (pictured below, from the child's perspective, "A goose? Look, the... Look."). He spoke much less of the recording equipment. This pattern continued into the sixth gallery with the dinosaurs, in which D became totally engaged, much more vocal and active with his hands.



References

- Heath, S.B. (2007). *Diverse learning and learner diversity in “informal” science learning environments*. Board on Science Education.
- Hutchins, E. (2012). *When is a representation*. Personal communication.
- Jacob, E.K. (2004). Classification and categorization: a difference that makes a difference. *Library Trends*, Vol. 52, No. 3, 515-540.
- Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Cambridge, MA: Harvard University Press.
- Rosch, E. (1978). *Principles of categorization*, in Rosch, Eleanor and Lloyd, Barbara B. (eds.), *Cognition and categorization*, 27-48. Hillsdale, NJ: Lawrence Erlbaum.

5 Taking action in the museum

Children find and create opportunities to take action in the museum (figures 5.1 a, b). As they probe the physical aspects of the natural history museum, they discover the exhibits' affordances, i.e. how their bodies fit with objects and how they can act upon objects (Gibson, 1979). In addition to touching and manipulating exhibits as the designers planned, the children exploit affordances not intended by the design team. Where the exhibits do not allow for physical interaction (e.g. look-only exhibits), the children often take action in the social domain, using speech and gesture to direct attention. Through their actions, the children explore options and express answers to the question *What can I do?*

This chapter focuses on how children use speech, gesture, and various forms of manual action in the museum. Children employ language and hand actions to perform mostly different functions, they distribute the cognitive labor of their engagements across modalities. When they coordinate their activity with other children, the distribution of cognitive labor extends across multiple individuals. With the engagement of multiple modalities, of one or several people, the potential for cognitive complexity increases. In these cases, new functions emerge through interaction among the functions of each modality. These emergent functions include demonstration, interpretation, and exploring cause-and-effect relations. In this research using Distributed Cognition as the theoretical framework (Hutchins, 1995), the cognitive system relevant for analysis changes size and shape depending on the cognitive task under investigation and who participates in that task.



Figures 5.1 a, b. One child used his hand to move the jaw of a sabertooth cat skillfully coordinated with his mouth movements, while others point to and read exhibit text (in English and Spanish), and watch the action. (Video stills from a child's perspective.)

In the museum ecosystem, each type of action has a form and a function. Close examination of children's engagements reveals patterns in how they use the exhibits, based on how they use their hands and how they use language. The following analysis examines how multimodal actions co-occur, where actions co-occur in relation to the museum's resources, and the consequences of coordinated multimodal action in the exploration of objects and the expression of ideas.

Based on analysis of six case-study fourth-grade children's engagements with an exhibition about paleontology and geology, a description of the museum ecosystem emerges that includes the diversity (in form and function), abundance, and distribution of hand actions and action-oriented speech. Through this research, we see the primacy of attention and some means for its management, the pervasiveness of social influences, and children's multimodal manner of exploring sensorimotor contingencies (Noë, 2004). The data for analysis comes in two forms: (1) video data of children using the museum exhibits and interacting with each other, recorded from first-person perspective using head-mounted cameras and third-person perspective using hand-held cameras, (2) codes assigned to the video data that serve to highlight events and events in sequence that involve multiple modalities: visual attention, hand actions (touch, manipulate, gesture), and speech. (The methods chapter provides details about coding schemes related to the forms and functions of modal engagements.) This inquiry focuses on multimodal events that include action-oriented speech that refers to concrete observable exhibit elements. Excluded from this study are various interesting events that reside primarily in the social domain with the exhibits in the background, such as flirting, goofing off, and teasing.

Using hands for exploration: Forms and functions of touch and manipulate

All children in the museum use their hands to make contact with the exhibits. They engage in a variety of manual actions, which depend directly on the types of resources the museum makes available. Different forms of manual action (how children use their hands) serve different functions (what they accomplish by using their hands).

Interpretation of the functions of manual actions stems from examination of (1) hand actions in context with language use, (2) how hand actions fit in larger activity structures, (3) the actions and responses of other social participants, (4) how attention and action across multiple modalities index or represent information. Discourse structures, activity structures, participation frameworks, and information structures (Greeno, 2006) determine the consequences of hand actions. Interpreting function derives directly from observing the consequences of action.

Documenting correspondences among forms and function of action and the design of museum exhibits has theoretical and practical implications. Children's actions reveal what they perceive as affordances in the museum, thus contributing to theory about the organization of children's cognitive activity in a designed environment. Children's actions also reveal the consequences of design, which can guide reverse engineering from actions with cognitive benefits to designs that afford and promote those actions.

Children come into physical contact with museum exhibits most often by touching and manipulating. Along with manual gesture (discussed in this chapter), touch and manipulate comprise the basic forms of hand actions analyzed in this research. With interaction as a primary unit of analysis, the targets of touch and manipulate matter. In the museum, children can touch

a wide variety of things, including other people. This research focuses on three primary forms of touch that involve museum exhibit resources: (1) touch exhibit (involving graphic panels, exhibit casework, and interactive interfaces), (2) touch object (i.e. specimens such as rocks or fossils, casts of specimens, and models), and (3) manipulate interactive (taking action with an exhibit such that the exhibit responds in some perceivable way).

Forms of hand actions

The forms of hand actions define the codes used for annotating the video data. The coded video enables quantifying the occurrence of different kinds of touch events and analyzing their relationships with other modalities, in coordination and in sequence. With our current focus on forms of hand actions, a recapitulation of that coding scheme appears below. The methods chapter contains additional details.

Exhibit touch: When the participant touches some part of the exhibit that is a graphic panel, flip book (laminated pages hinged to the panel), graphic holder, vitrine (glass or plastic case around specimens), or interactive interface (such as a button or a knob), but not an actual specimen (rock, fossil, or cast), or a model or sculpture (figure 5.2). The surfaces of these exhibit elements are smooth; they have minimal textural variation. Touching a bench, stool, or wall does not count as exhibit touch and falls outside the scope of this research.

Object touch: When the participant touches an object unique to the museum, such as actual specimen (rock, fossil, or cast), or a model (static or dynamic) (figure 5.3), not part of the exhibit that is a graphic panel, graphic holder, or vitrine. These objects serve as the focal point of the exhibits. They vary in size, shape, and composition; their surfaces and edges vary in texture. Some are natural objects; others are human-made.



Figure 5.2. Some museum objects afford looking only (video still from child's perspective).



Figure 5.3. Some museum objects afford touching (video still from child's perspective).



Figure 5.4. Some museum objects afford manipulating (video still from child's perspective).

Manipulate interactive: The participant manipulates an exhibit such that the action effects a visible change in the exhibit (figure 5.4). In museum discourse, exhibits that are manipulable are called *interactive*. Interactive exhibits entail reciprocity; when the user takes action with an interactive exhibit, the exhibit responds in some contingent way to act upon the user, usually changing visual and tactile feedback (McLean, 1993). Interactive exhibits can be digital or analog. Every instance of manipulation involves touch, and receives a code for both manipulate and touch. At times, the child may rest her/his hand on the interactive interface without manipulating it; this action receives a code of touch only. Touch and manipulate are not mutually exclusive categories. In most cases, exhibit touch accompanies manipulate (not object touch), because the interface for the manipulable exhibit is separate from the specimen or model that moves, often a necessity of design.

This coding scheme makes visible how and when children use their hands. It also differentiates among the types of sensory information that children derive from their engagement with museum objects.

Due to design (usually to protect unique specimens) some exhibits only afford looking at museum objects (figure 5.2). People can often look at the objects from different angles.

By design, some objects occupy the same physical space as people. If placed at an appropriate height, people of various sizes, standing or seated, can touch these objects (figure 5.3). In these cases, the person experiences visual-tactile contingencies. The object does not change, but for the person looking and touching, the sensory information from two modalities becomes bound together—an object that looks like *this* feels like *that*. Moving the hands over an object drives tactile stimulation.

When people can manipulate objects (specimens, casts, models, digital media), relationships among visual and tactile information bind and integrate within the individual *and* the object changes in some perceivable way (figure 5.4). The change may be visual only (e.g. when pressing a button results in a delayed visual change) or both visual and tactile (e.g. when turning a knob, feeling mechanical resistance, and seeing the synchronous visual change).

In addition to performing these actions, children watch others. Theories of action observation and motor resonance contend that when one observes an action performed by another, the observer mentally simulates the action to varying degrees (influenced by prior experience) the feeling of performing that action (Calvo-Merino, Glaser, Grezes, Passingham, Haggard, 2005; Gallese, Fadiga, Fogassi, Rizzolatti, Giacomo, 1996). Given the social nature of museums, people frequently watch others touch and manipulate, so they may derive some benefits from motor simulation of others' actions—particularly if they have prior experience to draw from. These informational differences, constituted in deployment of multiple sensory and motor modalities, have cognitive consequences in processes of making meaning from museum experiences. Based on observation of the children's overt behavior such as speech, gesture, facial expression, and subsequent action, the most obvious observable cognitive consequences accompany one's own action, rather than watching others.

Museums serve multiple purposes, including to amass and preserve collections and to share those collections with people. Few would argue that all museum objects should be available for touching and manipulating. Curators and designers decide together when the multisensory benefits to museum visitors don't threaten the safety of collections. As affordances for multisensory engagement increase, the museum must invest additional resources, in design, fabrication, and maintenance. As this research shows, significant cognitive

consequences can result when a museum makes objects available for touching and manipulating.

Given the multimodal resources that the museum makes available, one could hypothesize several behavioral outcomes. Children might distribute their attention evenly across these three types of exhibits: look only, touch object, or manipulate. Or, relative to what is available, they might spend differentially more time (or a greater percentage of their exhibit engagement events) with exhibits where they can look only, touch, or manipulate objects.

With the case study children, visiting this museum exhibition with their classmates, a greater percentage of exhibit engagement events involve looking (without touching museum objects or manipulating interactives) than the percentage of look-only exhibits in the exhibition (figures 5.5a,b). This result reveals some consequences of crowding (figure 5.6). Among the three classes observed, each with 2530 students and 5 adults, the classes moved from gallery to gallery en masse. At any moment in time, the children distribute themselves throughout one 1000–1500-square-foot gallery. When necessary, they wait in line to touch and manipulate objects. With some exhibits, they watch others touch or manipulate objects without getting a turn, because they tire of waiting or the class moves to the next gallery. Opportunities to touch and manipulate objects can be quantified as percentages relative to all exhibits (figure 5.5a). An exhibition floorplan shows how the content and distribution of touchable and manipulable objects varies from gallery to gallery (figure 5.8).

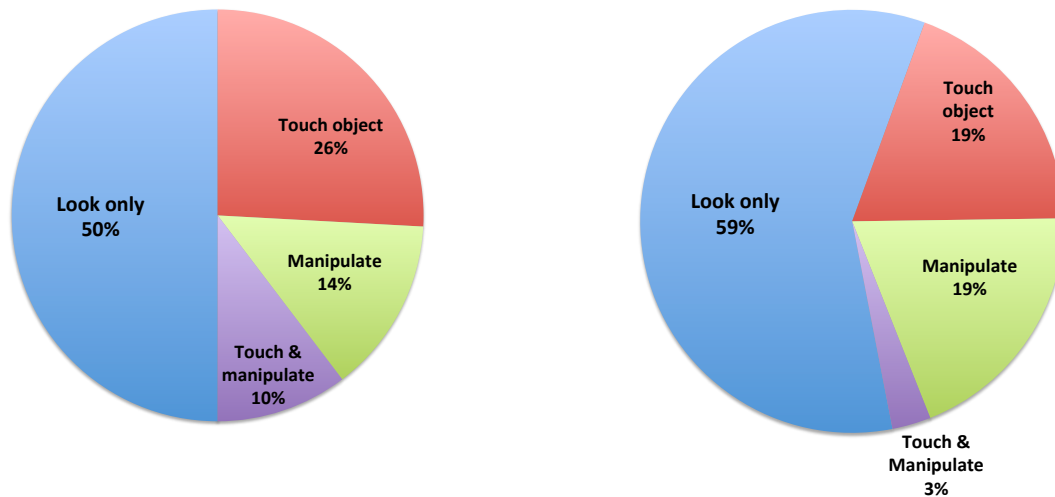


Figure 5.5 a, b. Comparing what exhibits offer and what children do. Figure 5.5 a. Looking at exhibits' affordances by percentage of relative abundance (n=58 exhibits), half the exhibits afford looking only; the other half also afford various modes of manual engagement, touch and/or manipulate. Figure 5.5 b Children use various modalities with each exhibit (n=204 exhibit events, 6 children). Children engage with exhibits using only their visual modality more frequently than look-only exhibits occur in the exhibition by 17%. Crowding likely explains this result.

The exhibit team's decision to include touchable and manipulable objects represented a simple hypothesis: that providing resources to touch and manipulate would increase attention, positive affect, engagement, and learning. This research examines that wide-ranging, under-defined hypothesis by documenting consequences of the design decision to provide the hands with access to sensory and causally contingent information.

The exhibit team made every decision bound by multiple constraints, variously construed, as educational goals, values related to visitor experiences, caring for museum collections, the museum's mission, investment of human energy and social capital, as well as more objective constraints, such as financial budgets, schedules, and physical space. Many people touched each decision at multiple times during implementation, including and not limited to exhibit developers, exhibit designers, the curator, project managers, collections

managers, preparators, fabricators, and administrators. Every decision required negotiation of various people and constraints. Touchable and manipulable objects require more resources to design, fabricate, install, and maintain, so decisions to include them often required more complex negotiations.



Figure 5.6. Children crowded around an interactive touchable map, such that the focal participant (white shirt, red sleeves) could not get close enough to touch or manipulate the exhibit.



Figure 5.7. Later, a space opened up and the focal participant had access to see and touch the interactive map, while another child manipulated the map by pushing a panel that represents a tectonic plate.

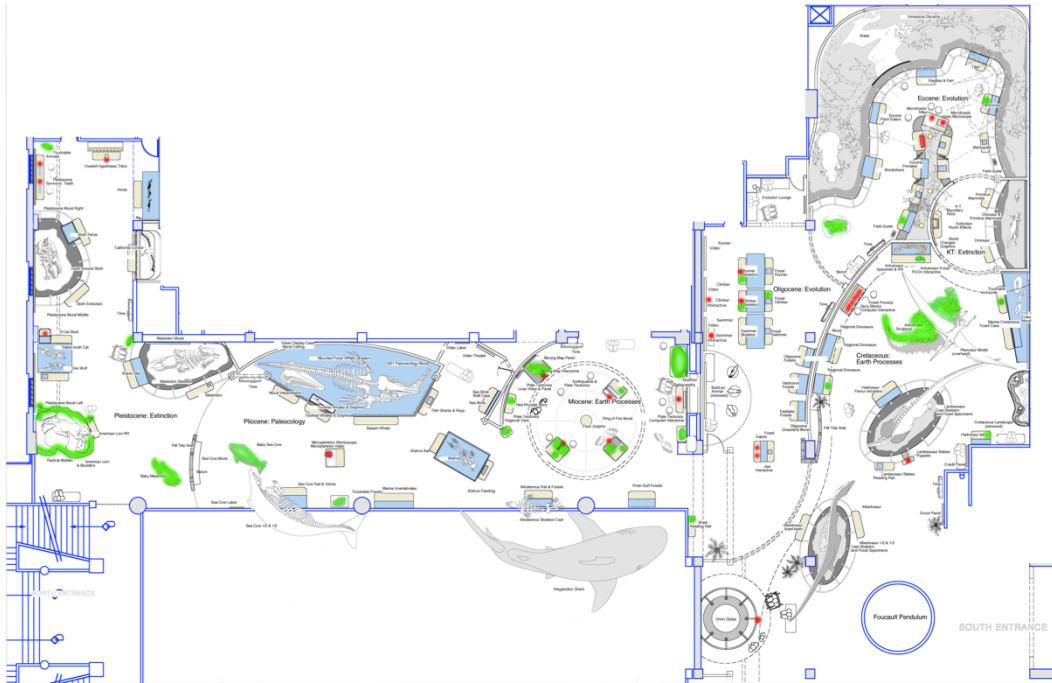


Figure 5.8. Fossil Mysteries floorplan, indicating opportunities to **touch objects** (green) and **manipulate exhibits** (red) in the four galleries that comprise the focus of the quantitative analyses in this research.

Exhibit cases and graphic panels surround museum objects that can't be touched.

Children often touch these smooth encasing exhibit elements. The angled exhibits and graphic panels (with rounded corners at waist-height) afford comfortable touching. Indeed, the opportunities for touching graphic panels and exhibit cases far surpasses opportunities to touch and manipulate objects unique to the museum environment. As noted above, crowding further reduces the opportunities to touch museum objects. Among the coded exhibit engagement events ($n=204$, 6 children), 79% involve the hands making contact—touching exhibit casework and graphic panels, touching museum objects, or manipulating interactives. Parsed another way—based on each instance of children's hands making contact with exhibits, rather than each exhibit engagement event—the relative frequency of different forms of touch and manipulate become apparent (figure 5.9). Touching exhibits (graphic panels and exhibit cases) occurs twice

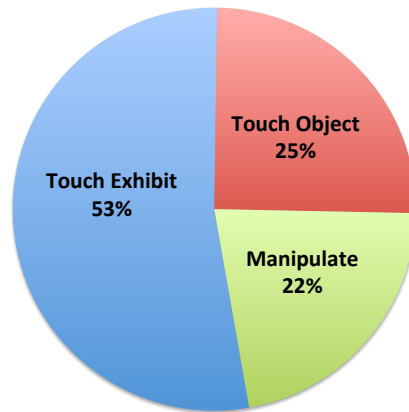


Figure 5.9. **Occurrence of touch and manipulate** (n=384 manual events, six children). Children most frequently touch the most abundant resource (exhibit cases and graphic panels). When available and physically accessible, children touch objects and manipulate interactives, multiple times with a single exhibit.

as frequently as touching objects or manipulating interactives. These different forms of engaging the hands serve various functions, depending on affordances of the museum resources, access to information, and the children's activity, discourse, and social arrangements.

Functions of touch and manipulate

Interaction between the child's hands and the target (e.g. exhibit graphic panel or specimen) define the forms of touch and manipulate, as exhibit targets constrain the possible functions of the hands' actions. For example, a child cannot manipulate a rock specimen; a child can only manipulate an interactive exhibit that can move. When children's hands make contact with the museum exhibits, they exploit relationships between the body and physical space with pragmatic and epistemic consequences. Among the case study children observed in the museum, use of the hands performs the following functions with varying frequency: physical anchoring, occupying physical space to claim social space, driving tactile stimulation, experiencing visual-tactile contingencies, directing attention of self and others, and enacting representation of meaning (figure 5.10).

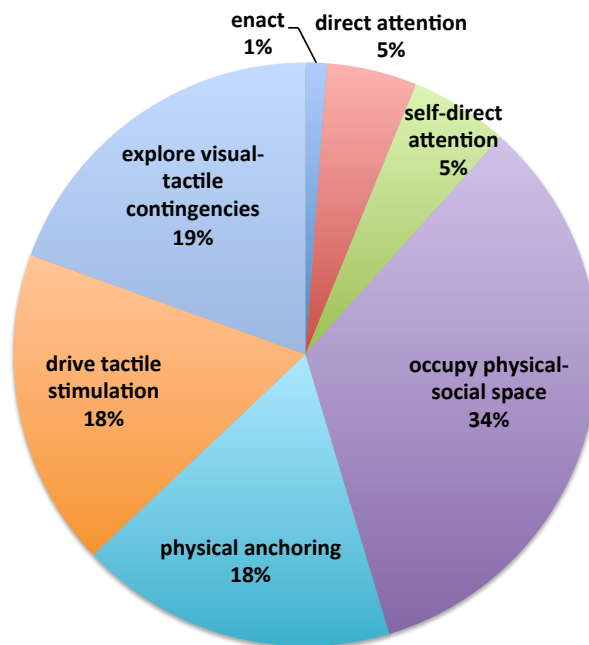


Figure 5.10. **Functions of touch** (n=421 touch events, six children).

Defining these categories of functions derive from the observed consequences of action. Analysis of action in the context of activity, discourse, and participation structures (Greeno, 2006) supports interpretation and description of the functions of touch and manipulate.

When children touch an exhibit (most often a graphic panel), they use their hands for physical support or to simultaneously occupy physical and social space. Almost 40% of touch events act as probes for sensory information—tactile or visual-tactile contingencies—depending on the affordances of the object. Ten percent of touch events involve directing attention of self and others, often in the form of an indexical gesture and coordinated with speech. Children touch objects as part of their iconic representational gestures as enactments of meaning very rarely, just 1% of all observed touch events. (Iconic representational gestures are much less common than indexical gestures overall.) Definitions and examples follow.

Physical anchoring (figure 5.11) Children rest their hands on exhibit surfaces. This usually happens with graphic panels whose surfaces are smooth and provide minimal tactile information. The children often put physical weight on their hands and lean on graphic panels to



Figure 5.11. Form: touch exhibit; function: physical anchoring.

get a closer view of the objects on display. The presence of other people adds a social dimension to physical anchoring, even if all the nuances of the social action are indiscernible to the researcher. Therefore, the code of physical anchoring is reserved for when the children's hands are at rest on an exhibit or object in the absence of other people.

Occupying physical and social space (figure 5.12) Children put their hands on exhibits when other children and/or adults stand in close proximity. As mentioned above, this action may serve the function of physical anchoring, but when other people are present, occupying the physical space has social consequences. Putting hands on the exhibit can establish a social place in a conversation, and/or assert a claim on the exhibit, for viewing, or taking a turn to touch a specimen or manipulate an interactive. Children sometimes make their claim overt by verbalizing a request ("Can I try?") or suggesting that the current user "hurry up."

In the exhibition under study, the physical design of the graphic panels, specifically height



Figure 5.12. Form: touch exhibit; function: occupy physical and social space. First-person children's perspective on left; third-person researcher's perspective on right.

and angle, provides a comfortable surface for touching and leaning. Children effortlessly find that their bodies fit with this physical design. Physical anchoring and occupying physical and social space happens often and almost exclusively with graphic panels, likely because graphic panels occupy so much more museum real estate than the limited resources of touchable

objects and manipulable interactives. Their design affords touching, leaning, and anchoring. In contrast, children use their hands for information gathering through movement when they engage touchable objects and manipulable interactives.

Driving tactile stimulation (figure 5.13) Children use their hands to probe for sensory information. Moving the hands over a surface changes the input to sensors in the skin. Movement provides the sensation of texture, exemplifying the active nature of perception (Noë, 2004). Children use their fingertips or whole hands, tapping, rubbing, or sweeping over surfaces. Through movement, they experience the tactile qualities of objects with variable textures (specimens, models, casts).

Through movement, they also feel the invariant textures of smooth graphic panels, although this happens much less frequently than moving their hands over complexly textured objects such as specimens and models.



Figure 5.13. This child looked at, read, and manipulated an exhibit that represents the San Andreas Fault. Then, she threw her hands on the textured surface and swept them over the modeled landscape.

Multimodal analysis includes the children's targets of visual attention. As they sweep their hands over surfaces, do they look at that surface or something else? The purpose of driving tactile stimulation may be to get more information about the object, coupling somatosensory and visual information (with variably textured specimens and models). Sweeping the hands over a smooth graphic panel while looking at another object may be a form of sensory stimulation with minimal tactile information, performing a function similar to fidgeting.

In the spirit of speculation, some movements that serve no immediately apparent purpose may allow a child to embody a different kind of understanding. For example, on two separate occasions, children made wide horizontal sweeps on a smooth graphic panel in front of a taxidermied mounted condor with wings outstretched (figures 5.14–16). The smooth texture of the panel provides minimal tactile information. Rather, the children's arm movements, symmetrically extending outward, then toward the body, out and back several times, could serve the purpose of "feeling," from inside one's body, the bird's wings. Design experiments could explore the following conjecture: an exhibit that evokes gestures—which map the child's body to features or relations among museum objects —compels engagement and enhances certain kinds of learning. To know with the body. How do such processes unfold? How does embodied knowledge get used, and for what?

Experiments can probe the consequences of design with different visual (2D) and tactile (3D) elements on the graphic panel. When looking at a real California Condor, what would compel a child to stretch out his/her arms? A) Text and images (the current design); B) a 2D-silhouette of the condor with wings outstretched; C) a 3D-silhouette in the form of a flat cut-out



Figure 5.14. When does movement have *meaning*? What kind of meaning? Movement can serve pragmatic, epistemic, and representational functions. Within context, eye gaze and manual actions may support interpretation of action as pragmatic or epistemic. But in this case, the forms of look and touch are not sufficient to deem the sweeping gesture representational. To warrant interpretation of actions as representational, speech and other vocalizations (by oneself or others) provides a triangulating data point. Chapter 6 focuses on unambiguous *acts of representation*.



Figure 5.15. A series of video frames shows a child's sequence of action: while looking at the mounted condor, he swept his hands horizontally over the panel, outward then inward four times. Does this motion of the hands have meaningful content vis-à-vis the condor?

condor. Suppose we confirm a hypothesis that the 3D cut-out evokes the most arm movement among all the design options, so what? What value derives from moving the body? Researchers in multiple domains—dance (Kirsh), mathematics (Marghetis; Nemirovsky, Nuñez), technoscience (Alac & Hutchins, 2004), chemistry (Weddle; Myers, 2009), and no doubt many others—have demonstrated how people use their bodies as instruments of thought. Human

bodies—used as measuring devices, vehicles for conceptual metaphor, tools for complex forms of exploration and expression—give form to humanly embodied minds of extraordinary cognitive flexibility.



Figure 5.16. On another day with a different class, another child listened to a museum educator speak, looked at the mounted condor, and swept his hands horizontally over the panel's smooth surface. Physical and social space contained and constrained his right arm and hand, so his hands' outward-inward motion was asymmetrical before transforming into a circular counterclockwise motion.

Experiencing visual-tactile contingencies through application of force (figure 5.17)

With some exhibits, children can touch and make things move. They focus their visual attention where the movement happens, and they often repeat the action, exploring the contingent relationship between what they do with their hands and visible changes in the exhibit. Children explore visual-tactile contingencies (O'Regan & Noë) with manipulable interactive exhibits (analog and digital) and flip panels (laminated pages hinged to graphic panels). Children can learn about mechanical aspects of force dynamics with interactive exhibits. And, depending on the exhibit content, they may also experience representations of event sequences or other types of cause-effect relationships with interactive exhibits (figure 5.17).



Figure 5.17. Turning a knob causes the gibbon skeleton's forearm to rotate. The design intent is to illustrate biomechanical relationships between anatomical form and function.

Children do not necessarily nor immediately understand the contingent relationship between their manual actions and visible changes in the exhibit. When manipulable objects occur in close proximity, children express the expectation that the objects have a contingent relationship, even when they don't. They move exhibits multiple times and watch to see what happens. The experience of visual-tactile contingencies plays a critical role in children's exploration of cause-and-effect relations, an emergent function that involves multimodal interaction, often distributed across multiple individuals. A mini-case study illustrates the relationship between exploring visual-tactile contingencies and testing cause and effect, at the end of this chapter.

Directing attention of others (figure 5.18) In addition to using speech and gesture to guide others' attention, children touch the specific part of an exhibit that is the object of attention, using a canonical indexical gesture, not necessarily with the index finger (figure 5.18)

or another configuration of the hand, such as a whole-hand touch. In this form of environmentally-coupled gesture (Goodwin, 1994; Hutchins & Palen, 1996), physical touch leaves no room for ambiguity about the attentional target.

Regarding the putative function of touching objects, directing attention happens less frequently other functions of touch. Children routinely use other modalities (eye gaze, body orientation, speech, non-touching gesture) to direct attention. Using touch to index objects and direct attention may serve as a strong form of disambiguating the target of attention, or it may simply reflect interactional opportunism based on spatial relationships between bodies and objects, free of obstructions. When children touch exhibit panels (not specimens or models) to guide attention, this occurs most often during individual or joint reading, tracing an index finger under the lines of text (figure 5.19).



Figure 5.18. This child touched a museum object, a chunk of igneous rock (granodiorite), and said to the research assistant/videographer, “Is this a real one?”



Figure 5.19. This child touched the text panel and moved her index finger while reading aloud; her tracing each line of text coordinated joint reading. A museum educator strongly mediated this interaction, with a complex geological story and a lot of text and maps. Even without adult intervention, the focal participant (wearing the head-mounted camera) read exhibit text frequently.

For this focal participant, in her first episode of reading exhibit text, she read silently, in the absence of others, without using her index finger. In all other instances of reading, she read aloud, in the presence of others, while using her index finger. In three of those eight cases, a classmate joined her in reading aloud. In one case, her reading partner (shown in figure 5.19) left to look at another exhibit. She continued reading the English text, while another friend read aloud in Spanish in parallel, while tracing her finger under each line of text (figure 5.20). See the endnotes in the previous chapter (Objects) for a lively display of the girls' friendship.

Directing attention of self (figures 5.20–22) When a child points to and touches an exhibit, and the direction of the child's gaze intersects with the point of contact, and the child does not use words to direct another's attention, and no one else is looking where the child is pointing, the function of touch is unambiguously to direct one's own attention.

Children use touch to direct their own attention when reading independently, as a



Figure 5.20. Two fourth-grade friends point to exhibit text and read aloud side-by-side, one in English (top right) the other in Spanish (lower left).



Figure 5.21. In the absence of others, one child pointed to a video image of a gibbon brachiating through the trees (child's perspective) and said, "Oh look."

spontaneous response to identifying an object (figure 5.21), and to hold a location during a shift in the activity of directing one's own attention to directing the attention of others (figure 5.22).



Figure 5.22 a–e. After observing an exchange between a classmate (gesturing saberteeth, far left) and a teacher, a focal participant used her index finger to “hold a place” in an illustration of a sabertooth cat plunging its giant canines into the neck of its prey, while her classmate enacted a representation of the cat’s saberteeth (5.24a). She then turned away to try and “grab” her classmate’s attention, saying “Look.” He looked, then said, “I know. You didn’t know that?” then turned and left. Her index finger remained fixed on the illustration as she navigated social and content dimensions.

Enacting representations of meaning (figure 5.23) Touch alone is insufficient to enact a meaningful representation. Touch may be part of gesture that uses iconicity of hand shapes to represent an object or idea. In this unique form of environmentally-coupled gesture, touch serves the purpose of anchoring the representation to the physical object, with a non-arbitrary



Figures 5.23 a, b. A child placed the tip of his finger at the “mouth of the volcano,” then rapidly shot his hand up in the air while making the sound, “Psshhhhhhh”—literally and symbolically a release of gas.

placement of touch.

Touch used in enacting meaning (Hutchins, 2010)—the rarest form of touch observed—reflects the rarity of children’s interpretation and expression of representational content in the museum. Concrete/abstract speech or sonification often accompanies these enactments of meaning and articulates the representational domain or content of the touch and gesture. In this exhibition with these case study children, the most common representational environmentally coupled gestures that use touch involve an exhibit that depicts the subduction of a tectonic plate and resulting volcanism. Children touch the opening of the “volcano” and enact a volcanic explosion (figures 5.25-26) or oozing of lava over the landscape, often accompanied by a sound. The triangulation of data points—non-arbitrary touch to an object (which has agreed upon representational content), coordinated with a dynamic gesture and a sound—supports interpretation of the children’s actions as representational. The next chapter, with its focus on processes of representation, will address these rare events in greater detail, with and without touch.

Children have busy hands as they make sense and make meaning from experience in the museum. Some children’s hands are busier than others, but all the children touch and manipulate the exhibits when given the opportunity. What they can accomplish by using their hands depends directly on the resources that the museum makes available.

Using hands for expression and exploration:

Forms and functions of gesture

Children use their hands to gesture for purposes of expression. Many examples of gesture involving touch appear above. Looking at the full set of the case study children’s observed manual gestures, we see that they often complement speech, offering a uniquely

visual-spatial expression of language and thought. Not all gesture serves a communicative purpose. A common and conventional medium, gesture serves two primary observable functions by children in the museum: to index objects with pointing gestures that guide attention, often accompanied by speech, and to explore and express ideas through iconic sensorimotor means (Alac & Hutchins, 2004). Children enact representations of objects, actions, and relations. In the process of experience, they *explore what it feels like* to be giant like a seacow, spreading like lava, or exploding like a volcano. The next chapter delves more deeply into these creative acts of *seeing* the exhibits as representations and *making* representations through expressive use of the body. Here, we see the relative abundance of different forms of gesture (figure 5.24) and functions of gesture.

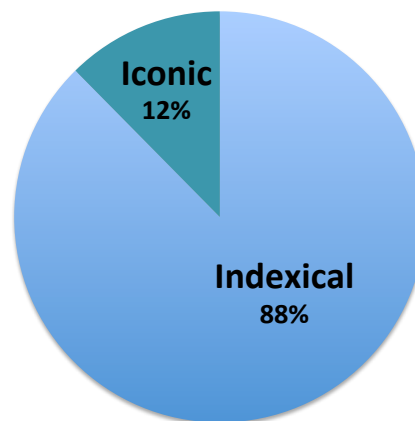


Figure 5.24. Manual gestures, proportions of indexical and iconic. (Six children, n=113 gesture events.)

Children frequently use indexical (pointing) gestures in a variety of social configurations and with all kinds of exhibits. Indexical gestures outnumber iconic gestures seven to one among the case-study children during the observation period. The children consistently use the index finger to gesture toward objects of interest, typically accompanied by concrete speech, most often following the other modalities of look, touch, and previous talk. Children point to models

and, using concrete/abstract speech, provide verbal labels for what those models represent.

Children use indexical gestures to direct the attention of others, to channel their own attention, to itemize objects while identifying them, and to show linkages among semiotic resources within a perceptual field (figures 5.25b, 5.26).



Figure 5.25 a–c. Children touch, manipulate, talk and gesture with a plate tectonics exhibit. 5.25 a. Using her hands, a focal participant enacted magma emerging from the sea floor. Figure 5.25 b. “That’s lava inside it. (pointing) That’s the lava.” Figure 5.25 c. “When it gets out, it’s magma.” Despite the child’s error in her use of lava and magma, she made a distinction between pre- and post-eruption states with speech, and with gesture, she indexed the “magma/lava” and embodied the bilateral spread of molten rock.

Iconic gestures used to physically represent objects, both concrete and metaphorical (figures 5.23, 5.25a), occur infrequently and with very few exceptions, occur with concrete-abstract speech at interactive exhibits. Iconic gestures will be discussed in greater detail in the next chapter. This analysis focuses on manual gestures, although the children also use other body parts to gesture (head nods, shoulder shrugs), observed in this setting to occur even less frequently than iconic gestures.



Figure 5.26. Children use their hands to index objects and link semiotic resources in their shared perceptual field. Using their hands in combination with speech, a child shows and tells his classmates that the fossil fragment they now touch was the tip of a giant mastodon tusk. (This image was recorded with a head-mounted camera from a child's perspective.)

Using the voice for action: forms and functions

When engaging with exhibits, children use language to perform actions. Action-oriented speech may occur independent of, or in combination with, actions of the hands. Most of the children's action-oriented speech takes a concrete form, which is the subject of this analysis. Some action-oriented speech blends concrete with abstract, to be discussed in the next chapter.

Forms of action-oriented speech

Forms of action-oriented speech include verbs and prepositions. For this analysis, the coding scheme uses verbs, in part, to distinguish between *object*-oriented speech from *action*-oriented speech. Object-oriented speech pivots on the objects in the museum, and as such, emphasizes nouns and adjectives. With object-oriented speech, children use the verb "to be" with nouns to name parts and wholes, to classify, to create perceptual and conceptual links. They use the verb "to be" with adjectives to describe objects. Analysis of object-oriented speech is included in the previous chapter. For the children in the museum, action-oriented speech uses verbs that emphasize current or immediately future action, to express or direct actions by oneself or others. Below are functional definitions of action-oriented speech. Examples will follow that illustrate examples of action-oriented speech in finer-grained detail.

Functions of action-oriented speech

Children use language to structure activity in a variety of ways (figure 5.27). They direct speech toward others and toward themselves. This list represents an effort to characterize the range of functions of children's action-oriented utterances observed in the museum. All examples below record the children's verbatim speech.

Direct attention (look) Imperative action-oriented verbs channel the direction of activity and focus attention. Verbally directing attention comprises the most abundant action-oriented speech function. In the museum, an environment rich in visual stimuli, children most often say “Look,” and “Look at the (without saying a name),” often accompanied by an indexical pointing gesture.

Self-directed speech Similar to directing the attention of others, self-directed speech articulates an imperative for the current action, as if to buttress and maintain the current train of thought, as in “Rocks, rocks, where are the rocks?”

Tell what to do Children tell each other what to do, and they (show and) tell each other how to engage in museum activities, particularly with interactive exhibits. Examples include “Touch it,” “Press it,” and speech coupled with action, “Do it this way.”

Test cause and effect

Can’t do Children verbally express the attempted activity at which they did not succeed, “I can’t do it,” or “I didn’t get to see it.” In these few instances, children noted that they couldn’t see a desired target (in two individual cases, this involved not being able to see tiny fossils through a microscope).

Take a turn To gain physical access to exhibits, children must negotiate for social access. They assert, “Let me see,” or ask, “Can I try it?” These statements satisfy the requirement of exhibit-related speech by an overt reference or by implying the exhibit as the object of attention. For the purpose of an unambiguous coding scheme for speech, exhibit-related speech must have a clear verbal, gestural, or action-based reference to the exhibit. When children use speech to manage the line while waiting for a turn with phrases such as “Get it line,” without any explicit reference to the exhibits, this speech was coded as “social.”

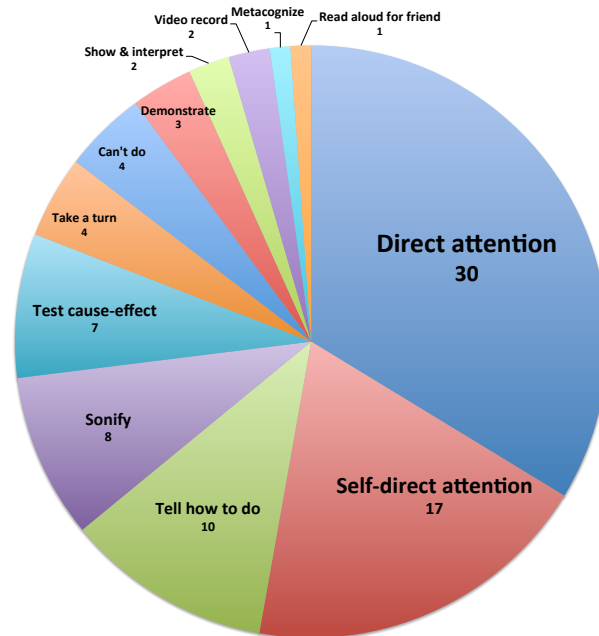


Figure 5.27. Functions of action-oriented speech (six children, n=89 multimodal speech events).

Video record Children wearing head cameras make overt references to recording the museum exhibits. For example, referring to a model of a male giant Ice Age lion, one child said “I recorded the balls.” References to the recording equipment, or video recording other people, with no mention of the exhibits, is coded as social speech and excluded from this analysis.

Metacognize Children comment on their own thought in relation to the exhibit content. This function was observed on one occasion when a child was trying to read the exhibit text and said, “Oh, I don’t know that word.”

Read aloud for friend This type of speech refers to when a child says s/he is reading out loud for a friend, as when a child said of video subtitles, “I’m reading the Spanish for Marilyn.” Reading the text aloud is coded as “read aloud.”

Sonify Children make sounds to accompany their activity. In contrast to directing or describing an action, this use of the voice performs the action, as when a child moves a plate tectonics display and in synchronized rhythm says “boodyumpbaa, boodyumpbaa, boodyumpbaa, boodyumpbaa,” or operates the moving jaw on a deer skull and says “la la la la la la la la la.” As these examples illustrate, some sonification does not obviously signify anything related to the representational content of the exhibit. In some cases, children make sounds that express representational content (figures 5.23a, b) accompanying an environmentally coupled iconic gesture. The next chapter, focused on processes of representation, addresses representational sonifications in more depth.

Exploiting resources, coordinating modalities, emergent functions

In the museum, children take action. They explore and express *what they can do* through coordinated action of their hands and speech with resources in the museum. Their actions perform multiple functions. They manage the attention of themselves and others as they probe the material aspects of the museum environment, negotiate social interactions, and discover and give form to ideas. Multiple perceptual-motor modalities participate in a distribution of cognitive labor. With their hands, the children achieve accomplishments different

than with their speech, and vice versa. And when manual actions and speech combine, the complexity of the accomplishments increases. When engaged in joint activity, multiple individuals share the physical and cognitive load of taking action and making meaning from experience. The children occupy physical, social, and conceptual spaces simultaneously; the meanings of objects and actions are multi-layered. The children's modes of exploration and expression do not distribute evenly throughout the museum galleries. Each exhibit permits particular forms of engagement—some permit touching of unusual objects; some allow manipulation; some compel sharing of ideas. Among the six case study children, their individual differences show a range of possible engagements. And common themes transcend individual variation.

When the museum makes specimens and models available for touching, children touch them. If an exhibit can be manipulated, children interact with it. Indeed, they will wait for several minutes to get their turn. Touchable objects and manipulable interactive exhibits have a kind of magnetic attraction. When children enter a gallery, they quickly search the space, looking for things to do. Touchable and manipulable exhibits are scarcer resources than objects behind glass, two-dimensional images, and text. So children negotiate the limited availability of these high-value exhibits. Whether waiting in line or taking their turn, children stay longer at touchable and interactive exhibits than other types of displays. The design principle is quite simple: Give the hands something to do and children will engage.

Children touch, children talk, and sometimes children touch and talk at the same time. Across the six case study children, among all the instances when the children touched exhibits, they simultaneously talked about the exhibits about half the time (53%). Among all the instances when they talked about the exhibits, children also touched exhibits 70% of the time.

This suggests that the children were more likely to touch without talking than they were likely to talk without touching.

The children's touch can take many forms and perform various functions. They touch exhibit panels and cases, which are not very informative in a tactile sense. They touch museum specimens and models, which provide rich variable tactile information in form and texture. They manipulate interactive exhibits (mechanical and digital)—when they make physical contact with the exhibit and can make things move, they change the content that is available for visual perception.

The affordances of different kinds of exhibits (i.e. what the children can *do* with them), determines the range of possible functions of touch. By touching exhibits, children can physically anchor themselves (they lean on exhibits which support their weight), simultaneously occupy physical and social space (e.g. to claim a place in line or in the conversation), drive tactile stimulation (picking up information about shapes and surfaces), experience visual-tactile contingencies (their manual actions cause visual changes and they see the effects), direct the attention of themselves and others, and produce representational gestures coupled with objects.

Whereas most touch supports functions of holding physical and social space, and probing for sensory information, action-oriented speech and gesture add layers of meaning with greater specificity. Speech and gesture act to manage and direct attention in particular ways. Language provides the specific imperative, the relevant object label and target for attention, and gesture, sometimes combined with physical contact with the exhibit, provides the spatial location: "Look at the heads," "Look at the ribs," "Look at the great shark tooth." When the museum does not provide opportunities for physical interaction, children create alternative

ways to take action, finding objects of interest and directing the attention of their peers.

Children also direct others' attention when exhibits do allow them to touch specimens and manipulate interactives. But the attention-directing function becomes embedded in other actions and woven into speech—telling or demonstrating how to operate the exhibit, imagining a scenario, or interpreting and expressing meanings. The hands engage in operating the interactive, showing others how movement changes visual perception. Action and movement attract and focus attention. As the affordances for engagement expand, cognitive complexity increases. Children use their hands and language to perform different and complementary actions in a cognitive division of labor.

Emergence of function

Children engage in sequences of multimodal action that add up to cognitive achievements of complex emergent functions. As observed in the museum, these functions include demonstrating, interpreting, and testing cause and effect. Compared to all the other multimodal speech events, these emergent functions are uncommon. Three of the six case study children engaged in these types of actions, mostly at the same three exhibits about plate tectonics and two exhibits about biomechanics. All these exhibits allow for physical interaction.



Figure 5.28. Two children spun a wheel that drives the movement of a skeletal deer leg. While turning the wheel one said, “Do it this way.” His speech made the demonstration explicit.

Children demonstrate

Children use concrete speech combined with action to show and tell how one could or should use an exhibit. By synchronizing action with speech that tells others what to do, children create a multimodal audio-visual demonstration. Demonstrations are difficult to quantify precisely, because in social situations, many actions can serve an implicit function of demonstration. Strong evidence for demonstration comes with the use of explicit speech combined with manual action, for example when a child said “Do it this way” (figure 5.28). This function only occurred overtly with interactive exhibits; looking at and touching static objects did not elicit explicit demonstrations.



Figure 5.29. An exhibit, designed to represent biomechanics emphasizing form and function, includes a mounted deer skeleton with a mechanical foreleg, a stylized mechanical model of deer foot bones and channelized joint, and a graphic panel with text and illustrations comparing anatomical features and running functions of humans and deer.

This child approached the display of a deer skeleton, immediately put his hands on the drive wheel, and started to turn it slowly counter-clockwise. Another child put his hands on the

wheel, rocked the wheel back-and-forth two times, then started pulling it in a clockwise direction. The two children continued turning the wheel together for four seconds, all the while looking at the skeleton to see the effects of their actions. The first boy continued turning the wheel in a clockwise direction for almost 40 seconds, then said to his classmates, “Do it this way,” while he kept turning the wheel for another 25 seconds. Throughout this process, these two children, plus four others, also manipulated a mechanical model of deer foot bones on the right side of the graphic panel, while focusing their visual attention on the skeleton for most of the time (figure 5.29). The boy’s demonstration of how to operate the exhibit was embedded in a multimodal multiparty exploration of cause and effect. Another interaction with the same display (described below on pages 197–198) illustrates more clearly the distribution of cognitive labor in another emergent function: testing cause-and-effect relations.

Children show and interpret

Adding to a demonstration, children interpret the content of exhibits, usually by describing how the elements relate to each other. The children use gesture and concrete speech, often deictic in nature (“this” or “that”), to show what is relevant in the exhibit. Words, in combination with action and gesture, highlight elements, relations, or both. Concrete speech and gesture anchors the child’s interpretation of the exhibit’s meaning to the object. Concrete speech and gesture links the object to the abstract imagined reality. Children were observed to show and interpret only with interactive exhibits.



Figure 5.30. A child slid the plate tectonic model, read text through a small cut-away window, traced his fingers along the surface, and commented on what he saw with only the researcher to hear, no eye contact made.

This child watched a classmate move and talk about an interactive exhibit that illustrates how one tectonic plate slides past another along a segment of the San Andreas Fault. He asked “Can I, can I?” Then, with permission, he grabbed the knob, began to slide the knob in its track, and sat on the stool. He read the single word through the cut-away window. “The present, right now I think. Let’s seeee.” Then he slid the knob again to the left, aligned the text to be visible in



Figure 5.31. One child moved the exhibit showing tectonic plates, while another walked his fingers over the surface.

the window, and read, "Future." He traced his fingers along the sculpted arroyos in the exhibit's surface. "Together, mmmm, yea," while tracing his fingers along another arroyo (figure 5.30) . He said something in an inaudible tone. He slid the knob all the way back to the right, "Past," he paused, leaned forward, nodded his head, "yea, it's better in the past than the future." He slid the plate back and forth two times.

The teachers called everyone's attention, he turned toward them and one teacher



Figure 5.32. While pointing to the aligned arroyos where they cross the faultline, the child said "The past is better."

asked, “Did anybody find any rocks in here?” He turned back toward the exhibit and said to no one in particular, “Yea.” After this brief interlude, two classmates joined the boy at the exhibit, and he proceeded to show them how movement changes the display, giving brief commentary between each move. He slid the knob, pointed to the text through the window, laid his hand flat on the exhibit surface and slid the tectonic plate back and forth underneath his hand. A classmate said, “That’s how it used to be,” and pointed to an arroyo twice on the moving faultline between the plates. The other classmate walked his fingers over the miniature landscape (figure 5.31), the first boy waved his hand away, slid the plate back to the right and pointing to an arroyo where it joined the faultline he said, “The past is better, and the past” (figure 5.32). He moved the plate again, pointed to the same spot then extended his hand flat, “And the present, it’s not together like it used to be.” He swept his hand over the surface, “And the future’s gonna be kinda like (head nod) better.” His classmate nodded, and they both turned and walked away.

All within 70 seconds, this boy gained access to the exhibit, interpreted for himself what he saw as he slid the miniature tectonic plate, and read the changing text: present, future, past. He then demonstrated the function and interpreted the exhibit for his classmates, an action that, whether intended or not, served as an effective way to maintain temporary ownership of the exhibit. His interpretation linked the concrete object with abstract meaning, a key feature of representation, treated in depth in the next chapter.

On a different day, another child followed a very similar action pattern. He made a verbal bid, in Spanish, to take over the exhibit. Then, as he manipulated the exhibit, he coordinated his hand motion with visual feedback to align single words in the cut-away window, which he read aloud for himself one-by-one during pauses in his motion, “past—present—

future.” His hand swept over the textured surface of this representation of the San Andreas Fault, he looked at the graphic panel then back to the surface, and moved the knob back and forth. After another child arrived and asked, “What is this?”, the first child returned the knob to reset position and read “past,” as he pointed to the word then traced an arc over the sculpted landscape (figure 5.33). He moved the knob again, read “present,” underlined the word with his finger and briefly pointed at the landscape. He moved the knob a final time, read “future,” took a brief look at the graphic, then ceded possession of the interactive to his classmate.



Figure 5.33. A focal participant showed and interpreted a plate tectonics exhibit for his classmate. Child's perspective (left), research assistant's perspective (right).



Figure 5.34. Adult user's view of San Andreas Fault plate tectonics interactive exhibit.

In 24 seconds of activity, this child negotiated two social interactions in two languages, coordinated visual and haptic attention to guide sensory-motor exploration; he read text to

establish context and make some sense of the object, then he used interaction with the object combined with gesture and speech to demonstrate the object's function and interpret its meaning, in response to a peer's question "What is this?". The timing and sequence of movement, speech, and gesture enabled the child to establish relevant semiotic resources and link them together.

The children negotiate physical, social, and conceptual spaces simultaneously and continuously. Often supported by physical interaction with exhibits, physical, social, and conceptual spaces knit together in mutually supportive ways.

Children test cause and effect

Throughout the museum exhibition, indeed throughout life, children experience and explore sensorimotor contingencies (Noë, 2004). Through engagement in various forms of activity, children learn about kinematic, mechanical, and social causality. Sometimes the children encounter a violation of their expectations, so they test cause and effect by repeating an action and observing the consequences. The observed examples of testing cause and effect often involved more than one person, with action, observation, and interpretation of events distributed across multiple individuals.



Figure 5.35. A child grabbed and turned the knob attached to the gibbon skeleton's hand while looking at the skeleton. Child's perspective (left), research assistant's perspective (right).



Figure 5.36. A mounted gibbon skeleton has a mechanical rotating arm attached to a turnable knob. The accompanying graphic panel has illustrations of the skeleton, one with a stylized 3-D humerus that rotates.

A child approached a mounted gibbon skeleton and grabbed the knob on the outside of the case (figure 5.35). The gibbon hand bones attach to a knob on the inside of the case (figure 5.36). When someone turns the knob, it causes the gibbon's forearm to twist. From the appropriate angle, one can see how the gibbon's radius and wrist cross over the ulna when the skeleton hand turns with the knob. After gaining access to the exhibit, the child turned the knob two times. He moved his hands from the knob to the small stylized model of a humerus with ball-and-socket shoulder joint mounted on the graphic panel and asked, "What is this for?" (The humerus model has no mechanical connection to the skeleton.) He moved it back and forth a few times *while looking at the gibbon skeleton*, then put his hands back on the knob and started turning it again. Another child arrived and began to move the humerus model. He quickly glanced at the panel and said, "Keep on doing that." He continued looking at the skeleton and turning the knob, and said, "No, no, no, no. That's all." He kept turning the knob while looking at the skeleton, then declared, "No hace nada" [It doesn't do anything]. His assessment that the

exhibit doesn't do anything contains some ambiguity. Does he refer to the action of turning the knob or moving the humerus model that has no effect?

In either case, the physical design of the exhibit doesn't make the critical information perceptually available. The child's expectation that the humerus model should have an effect on the skeleton logically extends from the Gestalt Law of Proximity, especially given the context of the mechanical interactive exhibits in this museum gallery. One expects that objects in close proximity should have a relationship. Turning the knob moves the skeletal arm; the child expresses an expectation that moving the humerus model will also move the skeleton. The child



Figure 5.37. At his height relative to the height of the exhibit, the child cannot see the critical elements in the skeleton arm that rotate when he turns the knob.

expects a mechanical causal relationship where there is a perceptual/conceptual relationship of part to whole. The two-dimensional skeleton illustration that provides context for the humerus model, accompanied by interpretive text, do not sufficiently express their physical separation from the mechanical aspects of the skeleton, while maintaining their conceptual connection.

If the child meant that turning the knob had no effect on the skeleton, a clue to his interpretation can be found in viewing the sequence of images from his head-mounted camera.

At his height, from his perspective, the apparatus for moving the arm bones blocks his view of the critical biomechanics (figure 5.37). For design to support making meaning, the exhibit elements need conceptual coherence and mechanical functionality. They must attract and manage the attention of the user and make critical elements available for perception for users of all sizes.

After spending 20 seconds with the gibbon skeleton, conducting an empirical investigation of cause and effect, the boy turned and walked to the exhibit on his left. There, a similar pattern of collaborative exploration played out.

The boy reached immediately for the model of a deer foot (phalanges or “finger” bones) on the graphic panel and started moving it back and forth while looking at the deer skeleton (see figure 5.29 above). Another child turned a wheel attached to a drive shaft that caused the



Figure 5.38. One child moved a model of a deer foot on the graphic panel, while another child turned a wheel to drive movement of the skeleton's foreleg. Both children trained their visual attention on the skeleton. Child's perspective (left), research assistant's perspective (right).

deer's front leg to move slowly in a running motion (figure 5.38). Unlike the drive wheel that moves the deer's front leg, the deer foot model on the panel has no mechanical connection to the skeleton.

After almost fifteen seconds of moving the deer foot model, a classmate reached across the graphic panel toward the model (figure 5.39). The boy said emphatically “Wait.” She replied, “I wanna... Do it faster.” He responded by moving the model faster, back and forth. At this point, three children looked at the moving parts on the panel and looked at the skeleton. The boy varied the speed of movement for 11 seconds, and the girl declared, “No mueve nada” [It doesn’t move at all]. Still looking at the deer skeleton, he stopped moving the model (figure 5.40), and without saying a word, he turned and walked away.



Figure 5.39. A classmate reached for the model of the deer foot on the graphic panel. Child’s perspective (left), research assistant’s perspective (right).

Children integrate action and perception to test cause and effect relations in the physical world. By moving and not moving the deer foot model while watching the skeleton, the



Figure 5.40. The child looked at the deer skeleton while moving the deer foot model on the graphic panel (with no mechanical connection to the model). Child’s perspective (left), research assistant’s perspective (right).

child's pattern of action calibrates the expectation for a contingent perceivable reaction.

Allocation of visual attention suggests the target of the expectation. When perceptions do not match expectations, children repeat the action as a test of contingency. Sometimes they mark the violated expectation with speech, "No hace nada" [It doesn't do anything], "No mueve nada" [It doesn't move at all].

The deer skeleton and the gibbon skeleton share many design features and elicited similar responses from the children. The design affords participation by a social group, and groups of children negotiate access to the action-oriented parts of the exhibit. In their social coordination, they share the load of making the exhibit move, observing the effects of their actions, and interpreting those effects. However, at the intersection where fourth-grade children meet with these particular museum resources, the potential for cognitive complexity leads to confusion.

Following the pattern established by other exhibit components, the children expect the moving models to act as interfaces that move the main attraction—the skeleton. Words and images on the graphic panel do not channel the children's attention to the deer foot model on the panel. Action, movement, mechanical causation, dramatic specimens, and spatial proximity attract and direct their attention to focus on the moving skeleton. The children missed the point of the deer foot model because the design compelled them to direct their attention elsewhere. To ask the question, "did the kids 'get it'?" is only the beginning. Successful or unsuccessful transmission and reception of information does not provide an adequate model of engagement and learning in the museum. Children probe the environment for interesting, engaging, relevant resources. They collect information. They test cause-and-effect relations. They find *the*

differences that make a difference by exploring the world with their bodies, through action and perception (Bateson, 1979). They create meaning from experience.

Children find and create many ways to take action in the museum. The most flexible human tool—hands—can be put to good use in the museum. Indeed, children have active hands. They will use their hands with whatever resources the museum makes available. In the natural history museum, the most abundant touchable resource—graphic panels—offers the least tactile information. The least abundant resource—interactive exhibits—offers the most multisensory information; tactile engagement changes somatosensory experience while changing the visual field. Touching and manipulating objects compels the allocation of individual and joint attention and influences what and how children see. Touching and manipulating objects changes the form and function of children’s speech and gesture. When the children experienced cause and effect, they talked more about relations between objects, not just the features of objects themselves. With particular interactive exhibits, children spoke and gestured about the representational content of the exhibits, i.e. they mapped abstract concepts to concrete objects.

Exhibits that engage the hands encourage embodied exploration and acquisition of integrated multisensory information. Children combine the multiple functions of multiple modalities, and they coordinate their actions with others. This opportunistic distribution of cognitive labor, made possible in part through deliberate design, offers great potential for cognitive complexity and richness of meaning-making.



Figures 5.41 a, b. Children moved a sliding lens and looked at microfossils under magnification. They pointed at and read text, in English and Spanish, and talked about the specimens. Children exercise a rich repertoire of action in the museum.

References

- Alac, M., Hutchins, E. (2004). I see what you are saying: Action as cognition in fMRI brain mapping practice. *Journal of Cognition and Culture*, 4.3.
- Calvo-Merino, B., Glaser, D. E., Grezes, J., Passingham, R. E., Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex* 15(8), 1243-1249doi:10.1093/cercor/bhi007.
- Gallese, V., Fadiga, L., Fogassi, L., Rizzolatti, Giacomo. (1996). Action recognition in the premotor cortex. *Brain* 119 (2): 593–609.doi:10.1093/brain/119.2.593.
- Greeno, J. (2006). Learning in activity. In K. Sawyer (Ed.) *The Cambridge Handbook of the Learning Sciences* (79–96). New York: Cambridge University Press.
- Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.
- Hutchins, E. (1995). *Cognition in the Wild*. Cambridge, MA: The MIT Press.
- Hutchins, E. (2005). Material anchors for conceptual blends. *Journal of Pragmatics*, 37: 1555–1577.
- Hutchins, E. (2010). Enaction, imagination, and insight. *Enaction: Toward a new paradigm for cognitive science*. Cambridge, MA: The MIT Press
- Kirsh, D. (2009). Projection, Problem Space and Anchoring. In N. A. Taatgen & H. van Rijn (Eds.), *Proceedings of the 31st Annual Conference of the Cognitive Science Society* (2310-2315). Austin, TX: Cognitive Science Society.
- McLean, K. (1993). *Planning for People in Museum Exhibitions*. Washington DC: Association of Science & Technology Centers.
- Schulz, L., Gopnik, A. 2004. Causal learning across domains. *Developmental Psychology*, 40, 2, 162-176.

6 Processes of representation and making meanings with things



Figures 6.1 a, b. At an interactive model designed to represent subduction, volcanism, and continental uplift, children enact more representational gestures than with any other exhibit in this exhibition. The exhibit does not represent volcanic eruption or explosion at Earth's surface. Children often fill that gap with representational iconic gestures.

How do children talk about the meaning of things in a natural history museum? Children use words and gestures to express ideas in the museum (figures 6.1a, b). When the case-study children spoke about museum exhibits (figure 6.2), most commonly they used language to refer to concrete objects, which they could perceive. Rarely, they articulated imperceivable abstract ideas. The children only used abstract speech in response to adult's questions. At times, they explicitly connected concrete perceivable objects with imperceivable abstract ideas. This last type of speech, which links concrete and abstract, speaks to the representational affordances of museum exhibits. Analysis of the fourth-graders blended concrete/abstract references suggests that the occurrence and distribution of this form of speech relates to physical design.

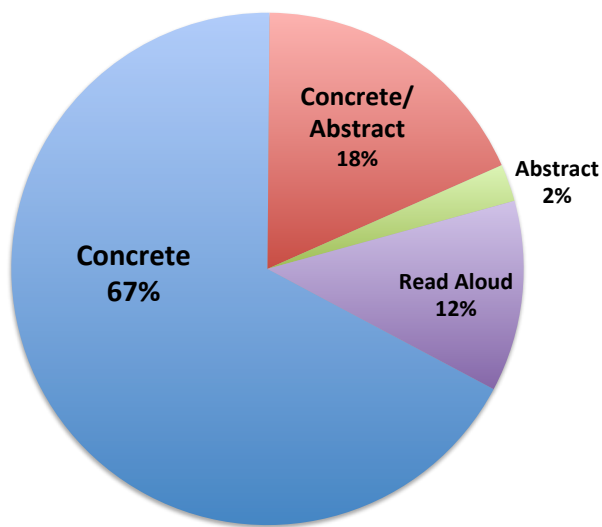


Figure 6.2. Exhibit-related speech forms (six children, n=343 speech events). Children most often spoke about concrete perceivable objects. Sometimes, in speech and gesture, they combined concrete and abstract references—the focus of this chapter.



Figures 6.3 a, b. Working with an exhibit that represents subduction (6.3a), one child (6.3b right) manipulates the exhibit by pushing the lever down; two other children walk their fingers across the miniature landscape.

This chapter will focus on how, when, where, and with what consequences the children used concrete/abstract speech, in combination with gesture and other actions, to explore and express representational content as they engaged with museum exhibits. When the children create representations in speech and gesture, they express not *What does this exhibit mean*, but *What does it mean for me?* (figures 6.1a, b; 6.3b).

Functions of concrete/abstract speech

Children use the concrete/abstract speech form for a variety of functions.

Concrete/abstract speech events are less abundant than concrete speech events, their functions vary in type, and they differ in frequency. When aggregating all the observed concrete/abstract speech events, two thirds of the speech events are object-oriented, one third is action-oriented (figure 6.4). Four of the six case-study children used the concrete-abstract speech form.

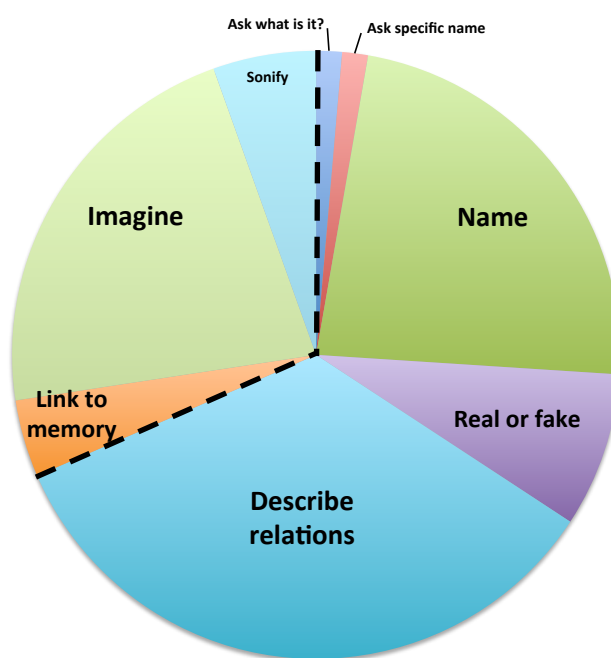


Figure 6.4. Frequency of functions of concrete/abstract speech form (four children, n=73 multimodal speech events). Object-oriented speech (right) occurred almost twice as frequently as action-oriented speech (left).

When using *concrete/abstract object-oriented* speech, children name objects as representations with approximately the same frequency as they name concrete objects. When using concrete/abstract speech, they describe relations much more frequently than when using concrete speech. The co-occurrence of certain design features may elicit concrete/abstract

speech and compel children to describe relations among elements in the exhibits. With models, children will sometimes name what a model is designed to represent. If they can manipulate the model such that the model moves, they sometimes describe relations within the model.

Using concrete/abstract object-oriented speech, they infrequently ask what things are. An example in this concrete/abstract form is “Tectonic plates, what are those?” in response to a teacher touching an exhibit and saying, “Here are the tectonic plates.”

By linking what is present with what isn’t present, *concrete/abstract action-oriented* speech serves different functions than concrete action-oriented speech focused on the here-and-now. These functions include using the imagination, linking with memory by invoking past events, and making sounds with representational content to accompany actions (sonification). Detailed descriptions follow.

Children name objects as representations

The children sometimes assign names to models in the museum, similar to, but different from, their talk about other concrete objects. They use concrete/abstract speech including nouns to say what an object represents, rather than labeling the actual object itself (e.g. a model made of plastic and wood). For example, when a child saw glowing red in a geologic cross-section model of Earth and said, “That’s lava,” the artifice of the museum became transparent. She was able to look upon the model and see it as a chunk of Earth, despite the discrepancies in size and material (Goodwin & Goodwin, 1998). Children clearly expressed that they understand the difference between real lava (or magma) and a model, for example, by pretending that the “lava” was hot enough to burn the fingertips, making sounds “tssss, tssss”



Figure 6.5. A child's fingertips dance atop the "volcanoes" as he makes the sound "tssss, tssss." Child's perspective (left), research assistant's perspective (right).

like burning flesh with each touch (figure 6.5). Sometimes they use speech to explicitly mark the real-fake dichotomy.

Our cultural habits involve labeling objects, and our cultural habitat is stuffed with representations. So when a classmate asked about the subduction geologic model (pictured above) saying, "What's this supposed to be?," his question simultaneously spoke to the common behavior of verbal labeling and the role of the model as representing something other than itself.

When looking at models, children also ask the generic question "what is it?," which they ask more often of museum specimens. With natural object specimens—such as rocks, fossils, skeletons, taxidermy mounts—a concrete label satisfies the *what is it* question, even when these objects are intended to serve a representational function in the museum setting. For example, the design intent may be to use a sabertooth cat skeleton to represent the concept of extinction. But such a representational relationship entails a vast conceptual distance (Hutchins, Hollan, Norman, 1986) and lacks clear analogical structure (Gentner, 2010). To bridge the gap and make the mapping between the object as symbol (sabertooth cat skeleton) and an abstract

concept (extinction) often requires reading text and linking multiple concepts. The conceptual links may be transparent to designers and curators, but inaccessible to those who don't read the text or have background knowledge to link the concrete object with the abstract concept.

Models in the museum give form to certain features abstracted from an object, process, or concept that designers intend to represent. The children have been enculturated such that they understand that models in museums serve a representational function. Yet the function can only be achieved when a child engages in an *act of representation*. We cannot observe a child's every act of representation, we can only observe how, when, where, with what and with whom children create external representations in action through movement, speech and gesture.

Children often use models in the museum (in the form of physical exhibits) when they create representations with their actions. Children tap relevant prior knowledge and use speech and gesture to express correspondences between what they see and what a model might stand for. The degree of structural alignment (Ibid.) between the concrete object (in the museum) and the object, process, or concept represented likely has a strong influence on children's acts of representation. When what the child perceives in a model has sufficient structural alignment with some previous experience, and the perceived structure preserves critical features, the child may express a representational relationship.

People sometimes ask, when do the children "get it," that is, when do they understand the intended message of the museum exhibits? The phrase "get it" might entail the Information Transmission model of education—do the children get what the exhibit designers and curators intended to convey? The premise: Exhibits contain and transmit messages, and children receive

those messages, or they don't. When children don't "get it," we presume a failure of either the child or the exhibit.

An alternative construal of children "getting it" involves structural alignment (Ibid) and the Principle of Ecological Assembly (A. Clark, 2011), a view compatible with Distributed Cognition theory (Hutchins, 1995, 2010) and Constructivism in education. The Principle of Ecology Assembly proposes that cognizing agents coordinate a combination of internal and external resources to accomplish the cognitive task at hand.

When Andy Clark says internal resources, "embodied resources" provides a better description. The body—the sensing, acting, cognizing organism, with a personal history embedded in cultural history, rooted in evolutionary history—carries an extraordinary, dynamically changing set of resources. Clark's *internal* cognitive resources may stop at the skin, yet they are not just internal mental representations construed as patterns of neural activity. Perception, action, and other forms of cognition involve the whole body.

Clark's *external* cognitive resources include artifacts, tools, physical environments, cultural practices—all the stuff outside the body. But the stuff outside the body shapes what is inside the body. Cultural practices organize much (or most) activity throughout life, and how one becomes enculturated organizes many aspects of brain connectivity, classically considered an internal resource (Hutchins, 2013). Thinking deeply about the organization of distributed cognitive systems, brains—shaped by culture—can't be considered as the center from which cognition extends outward through the body and into the world (Ibid). Brain, body, physical and cultural worlds all provide resources, constraints, and organizing structures and processes, available for dynamic assembly for the purposes of action, perception, and meaning-making.

When children “get it,” the children and designers have achieved mutual understanding. Through a chain of mapping from one modality to another, alignment of perceptual/conceptual structures supports the creative act of representation. This progressive alignment (Gentner & Namy, 2006) links embodied motor-sensory modalities and cultural modes of expression, with multi-directional dynamic relationships. Like representation, we come to see multimodality, not as a thing, but as a process.

The children and designers use a visual-spatial language. For language to have meaning requires coordination and complementarity. Herb Clark describes use of language as joint action, likening meaningful conversation to a pair of dancers who must perceive and respond to the moves of the other (H. Clark, 1996). Whether the language is verbal (Clark’s focus) or visual-spatial, shared understanding depends on common ground (Ibid). That common ground may be perceptual and conceptual; the cognitive resources may be embodied and external.¹ To achieve mutual understanding requires structural alignment across all these fuzzy permeable boundaries, among perceptual and conceptual, embodied and external—within and between child, designer, and exhibit.

Designers face multiple challenges in understanding and exploiting the common ground they share with exhibit users. Face-to-face conversation allows exploration and rapid feedback to establish what is common ground. Designers often work in isolation from users, so they miss out on the feedback, dynamic adjustment, gap-filling, and repair that occurs in conversation. Front-end and formative evaluation can play a useful role in compensating for the lack of immediate and continuous feedback by probing, at decision points in the design process, what children (and adults) know and can perceive when presented with a design, and how they make sense of the experience.

For children in the museum, from their perspective, their task is to find interesting things to look at and do, and to make sense of their experience. They bring resources to the museum—skills related to perception, action, language use, and social interaction, their bank of prior experiences, their curiosity and motivation to engage. The museum offers resources—a variety of objects and images with various affordances for perceptual and conceptual engagement. Other people purvey resources, directing attention, labeling objects, linking semiotic resources with language and gesture. The children select from this smorgasbord of resources, they exploit what they know and explore what they don't know. When they express how they perceive and what meanings they construct, they add to the array of available resources.

Sometimes children construct meanings that align with the meanings expressed by the exhibit team, and an observer might say they “get it.” To follow one model, perhaps to an extreme, successful transmission of information requires paying attention at the right time and place, and passive, unobstructed reception. Emphasis falls on clarity of message and compelling children to act as good receivers.

To follow another model, the ecological assembly of resources entails that children will actively seek information, guided by rules of motivation and reward and enculturated patterns of interaction. Emphasis falls on interface and interaction, where resources—embodied, social, physical, conceptual—mix and mingle, and with sufficient coordination of multiple resources, children achieve various forms of perceptual and conceptual coherence.

Are museum objects real or fake?

Children encounter unfamiliar objects in the museum. In their efforts to make sense of experience, they sometimes ask about a museum object, *Is it real?* (figure 6.6). This question speaks to the dual nature of museum objects. Certainly all perceivable museum objects have a physical reality. But the objects in question may appear to be one thing (bones), when in fact they are something else (a plastic models, or fakes. When children ask, *Is it real?*, in a sense they ask if the object serves to represent something else. The case-study children inquired about the authenticity of models (a life-sized giant Pleistocene lion, a rattlesnake in a rock cave, a model nest of dinosaur eggs) and specimens (a sabertooth cat skeleton, a gibbon skeleton, an igneous rock). They tended not to elaborate on the question of authenticity, nor on the representational content of the object beyond the real/fake classification or the name of the object.



Figure 6.6. A child manipulated the arm of a gibbon skeleton cast and asked the research assistant, “Is it real?”

Children describe relations

When focused on the objects as representations, the children also described relations among elements. In some cases, the children gave voice to spatial and/or temporal relations, in coordination with gesture and interaction with exhibits. When children describe relations among exhibit elements, almost two thirds involved concrete/abstract speech (25/38). Describing relations is the most common cognitive function observed in the children's concrete/abstract speech events (25/66). In contrast, describing relations is very uncommon among instances of concrete speech (7/150).

Among the observed engagements, children use more concrete/abstract speech when engaged with interactive exhibits than non-interactive exhibits, and children describe relations more when using concrete/abstract speech than concrete speech. A constellation of design features likely plays a role. As a first-order prerequisite, opportunities for interaction compel attention. Interaction results in movement and change. Movement and change can highlight relations with perceptual and conceptual consequences. Clear correspondences between the designed object and abstract concepts ease the pattern-matching process when bringing together external (perceivable) and internal/embodied (memory-based) resources. Children express this cognitive achievement with representational speech and gesture.

Spatial relations With a display about a type of tectonic plate boundary (a subduction zone where one plate dives below another), a child used speech to name the focal elements, “Land and water” (figure 6.7). She used gesture synchronized with her speech to express the spatial location and side-by-side relationship—right hand for land, left hand for water. Full extension of the hands, laid flat on the surface, conveyed a sense of spatial extent. The cadence of her delivery, combined with exaggerated rising and falling intonation, emphasized the contrast between land and water, in location, elevation, and appearance. The durable plastic materials of the exhibit are not land and water; they represent land and water in a visual-spatial-physical language successfully decoded by the child.



Figure 6.7. Hands and speech identify the exhibit elements as the child makes public her act of representation, “Land and water.”

Dynamic spatial relations With the same subduction exhibit, a child first identified a focal element with an indexical gesture and the word “Lava.” He then traced his finger along the cross-section of the volcanic vent saying, “It goes up, it goes out to this” (figure 6.8). The environmentally coupled gesture specifically locates and highlights the element of interest. The gesture also provided direction and movement to his multimodal expression. His use of speech provided a label (“lava”) that identified the most salient feature (glowing red shapes), and perhaps the most relevant feature given his prior knowledge (molten rock, actually called magma by geologists when below the Earth’s surface). His speech provided some information redundant with the dynamic gesture (“goes up” and “goes out”), yet the redundancy served to draw attention to and reinforce the expression of important relationships.



Figure 6.8. After tracing the exhibit’s volcanic vent with his finger, the child said and gestured, “It goes up, it goes out to this.”

Temporal relations With an interactive moving map, when children push on a panel that represents the Pacific Plate, they see how plate tectonics reshaped the west coast of North America. After pushing the panel to its full extent and revealing the time read-out through a small cut-away window, a child established a temporal relationship, by reading two words of exhibit text and bringing the concept of “the present” into registration with his own experience with his words, “The present, oh right now” (figure 6.9).



Figure 6.9. The child manipulated a moveable map and using the exhibit text said, “The present, oh right now.”

Ecological relations Two children, each one moving the jaw on the skull of a predatory carnivore (mountain lion) and an herbivore (mule deer), spoke as if they were vocalizing for the animals (figure 6.10). They explored how hand motions made the jaw open and close, synchronized speech with the movement of the jaw, and took turns in conversation. Amid this sensorimotor complexity, one child said, “You must not eat me,” expressing a relationship



Figure 6.10. Children moved levers to operate the jaws of a mule deer (left) and a mountain lion (right). They coordinated speech with action to express relationships that they perceived among the objects.

between predator and prey, and the relationship between the skulls and the classes of animals that they represent. Using the specimens like puppets, they enacted their understanding that tooth morphology entails lifestyle (sharp teeth belong to meat eaters). Here, the spatial layout, with both skulls oriented in the same direction and the predator posterior to the prey, suggests pursuit, as reflected in the children's speech. "I could beat you." "Then why am I in front of you? Hah!" Through their activity, the children successfully established multiple correspondences, both sensorimotor and conceptual. They expressed conceptual relationships, not by reading the exhibit text (with the headline, "What's for dinner?"), but through perception and action, and bringing their relevant prior knowledge to bear.

As the children spoke back-and-forth, they created a dialogue between an imaginary predator and its prey. In their social, verbal, sensorimotor exploration, the children expressed a

fundamental idea underpinning the exhibit—the differences in the skulls correspond with the animals' different identities as meat-eater and plant-eater.

To describe how elements relate involves greater cognitive complexity than assigning a name or asking what something is. A relationship requires at least two things, and some way to link them. To express relationships of representation—bridging the concrete perceivable and the abstract imperceivable—is a uniquely human accomplishment. Practices of representation, ubiquitous and skills-based, provide the foundations of analogy, arguably the human cultural achievement that enables great feats of intelligent activity (Gentner, 2003). Museums, places where objects serve as touchstones for various forms of representation, offer opportunities to practice the skills of representational thought and communication.

Children link the present with memories, projecting back in time

The children connect what they see in the museum with their prior experiences. Sometimes they give verbal form to those links with memory. To verbally link their present experience in the museum with past experiences occurred rarely, only three times among 73 observed events involving concrete-abstract speech uttered by four of the six case-study children.



Figure 6.11. Watching a video of extant animals designed to represent the inhabitants of an ancient San Diego Bay (3.5 million years past), the children talked with a museum educator about their own experiences with these animals.

In one case, while a group of children and a teacher watched a video of various marine animals, the teacher elicited expressions of memory. She said, “That’s my favorite, the bat ray. Have you ever touched one before?” One child (a focal participant) responded, “Yea,” and a few seconds later he added, “I touched the biggest one,” at a nearby nature center (figure 6.11).

In another case, a child looked at a volcanic rock surrounded by her classmates and asked, “Was this one the one that we were looking at in the classroom?” (figure 6.12). When children name objects, talk and move through the museum, they use multiple forms of memory

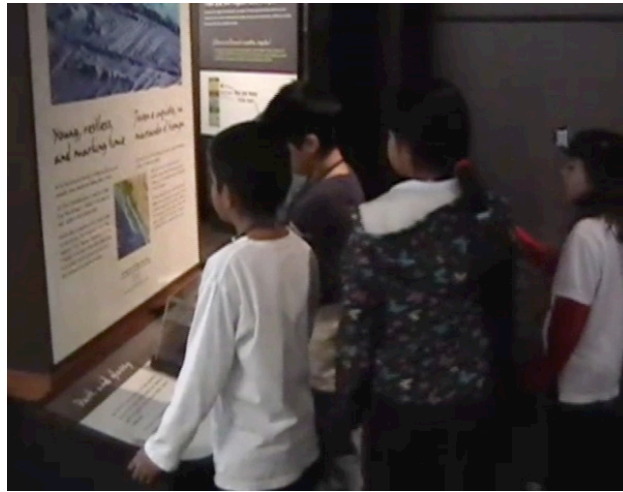


Figure 6.12. Children gather around a display about volcanic processes and products, including obsidian. A focal participant asked, “Was this one the one that we were looking at in the classroom?”

(sensorimotor, semantic, episodic) connecting with prior experiences, proximal and distal in time, at various scales.

What compels children to verbalize their memories? What are the consequences of children remembering prior events while engaged in new experiences? In what ways can museums use their unique resources to catalyze creation of new memories that connect with old memories? The current research evokes, but can’t answer, these questions.

Children use museum objects as springboards for imagination

Children use speech to give verbal form to actors, actions, events, and environments that don’t presently exist or have never existed. They imagine possibilities, using their present and previous experience to describe or create alternatives to the present or known reality. Inclusion in this analysis requires that the speech relate to the museum exhibits. So these

expressions of imagination in the museum make reference to a concrete exhibit object and also make reference to something not physically present, in a sense, abstract. Among the six case study children, four used concrete/abstract speech during the observation period, and two engaged in verbal acts of imagination. One of those two children (E), produced the majority of imaginative expressions (14/16), described below as creating an alternate reality. The other child (M), imagined possible futures. Children undoubtedly express imagination in museums in ways that were not observed. This research catalogs some ways children give voice to their imaginations.

Children imagine possible futures

After looking at several different fossil shells and other marine invertebrates, and touching fossil sanddollars in sandstone, 70 seconds into the exhibit engagement, M looked at, pointed toward some very small clam shells, and said to her friend, “I like these ones; they’re tiny, tinyeeee. I wanna find one of those once” (figure 6.13). Her last statement, following an evaluation and a description, imagines a future in which she might find some tiny tiny shells. (The previous chapter focused on objects includes a detailed description of this one minute 17 second exhibit engagement, a duration longer than average among these fourth-graders.)



Figure 6.13. While two friends looked closely at tiny clam shell fossils, one said “I wanna find one of those once.” Child’s perspective (left), researcher’s perspective (right).

After waiting for a long time to see the suspended giant shark, M walked deliberately to the shark’s head with rows of enormous teeth. She made multiple expressions that resembled fear combined with wonder, uttering sounds, covering her face, and finally saying while smiling, “Oh I can’t see it” (figures 6.14ad). She made more fearful sounds, walked around while looking at the shark, and said “I’m scared of him.” Her friend replied, “I think it’s fake.” “I know, but I’m scared of it I’m afraid that it that it falls.”

What is the cognitive and conversational function of this statement? Did she truly fear that the giant model would fall from its well-hidden supports? Did the child confabulate an explanation for her fearful behavior?

When a young girl met the giant extinct shark, *Carcharodon megalodon*, no clear line existed between real and pretend fear. Her words and movements expressed strong feelings of mind and body. Using the imagination resolved the cognitive/emotional tension. With the words "I'm afraid that it that it falls," she projected into the future, justified her fearful response (even if in play), and simultaneously brought the shark conversation to a satisfactory conclusion.



Figures 6.14 ad. A child walked toward a model of a giant extinct shark, gasping, shuddering, and making verbal expressions of fear. Researcher's perspective (left), child's perspective (right).

Children create alternate realities

As a form of play, exploring conceptual spaces not dictated by the museum, the teachers, or the curriculum, one child made several imaginative expressions that blended his engagement with concrete physical reality with an alternate imagined reality.

When all the children (from three classes on different days) first entered the exhibition, the adults gave them the task to find rocks. The adults reinforced this agenda item repeatedly, asking the children if they had found any rocks and what kind of rocks they found. In one observed instance, several children gathered around a large boulder of green glassy jade with a swirling texture (figure 6.15). Within a 52-second interaction with the rock and his peers, this child interleaved his speech with that of the other children. He moved between a language of play (“Hi baby, Hey, look at this baby”) to language of classification (“It’s a metamorphic rock”), social interaction and directing attention (“Feel it”), back to play (“Hi baby, don’t do that again”), and then description (“This thing is cold”). Shifts in body orientation, gaze, gesture, and action



Figure 6.15. A group of children leaned on, caressed, talked about, and talked to a giant jade boulder, pretending it was a baby.

conveyed to whom he spoke (multiple changing interlocutors), and of what he spoke (an imaginary baby, a metamorphic rock, a baby, a rock) moving fluidly among worlds of imagination and concrete experience.

Earlier in his gallery visit, the child looked at, touched, pulled on, and patted the baby sea cow model, walking from its head to its tail and back up to the middle body for a total of 15 seconds. The child turned to the model, took a symmetrical stance, put both hands on the model's back and said, "You need to eat less hamburgers" (figure 6.16). Then he turned 90° to his left, leaned on the sea cow model, and looked up at a 26-foot-long skeleton of an adult sea cow, now extinct, bones on one side, skin on the other.



Figure 6.16. In an act of imagination, a child said to a model of an extinct sea cow baby, "You need to eat less hamburgers."

A conceptual gap of geologic time exists between the living breathing human child and an extinct sea cow that lived 3.5 million years ago in an ancient San Diego Bay. But no physical gap existed between the child and the life-sized baby sea cow model in the museum. As they shared the physical space, the child created an alternate reality in which their bodies ate the same food and abided by the same rules of calorie calculations. The child moved effortlessly between imagined relations and concrete sensorimotor engagements; one moment the sea cow was something or someone to talk to, the next moment the model was something to lean on while looking at another museum object.

Using imagination presents opportunities to exercise critical cognitive skills. asserted, and others have agreed, that all creative activity—in the sciences, arts, technology, etc.—originates from imagination. From a developmental perspective, “creating an imaginary situation can be regarded as a means of developing abstract thought” (Vygotsky, 1978, p. 103). “Speech frees the child from the immediate impression of an object. It gives the child the power to represent and think about an object that he has not seen” (Vygotsky, 1986, p. 346). Historically, some (notably Freud and Piaget) have contended that imagination runs contrary to logical conceptual thinking. Vygotsky provides an alternate perspective, asserting that imagination, as a form of play, constitutes a valuable mode of exploring what is possible (Gajdamaschko, 2005). Some still consider imagination as a distraction and diversion to educational goals. From the perspective that imagination gets in the way of learning, educational systems and practices may coerce children into passive modes of reception, consequently attempting to contain or control children’s imaginations. When educators and designers consider imagination, like attention, as a resource, exhibits might serve as tools for the imagination, rather than as media for the transmission of information.

Children make meaning by making sounds

Children make sound effects for the actions they engage in. The children coordinate sounds with their actions—they sonify their activity (Kirsh, 2011). Their sonifications use vowel and consonant sounds heard in language, although they are not words. Sonifications carry prosodic profiles, with varying rhythm, pitch, and stress. For analysis purposes, coding, quantification, and interpretation of speech includes sonification, although these utterances are not formal speech. Sonifications don't follow the same conventions of syntax and grammar as speech. Sonifications express and convey many possible meanings in ways that speech can't.

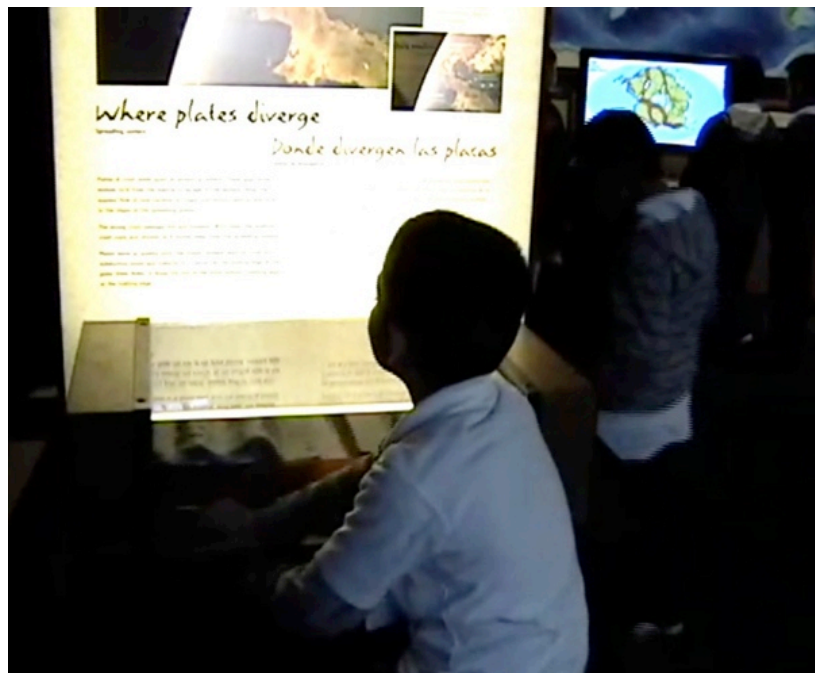


Figure 6.17. A child manipulated the plate tectonics spreading seafloor model and repeatedly said with each movement, “boodyumpbaa, boodyumpbaa.”

The examples here illustrate how children use their voices to sonify their own physical processes or to represent processes anchored to museum objects.

With an interactive plate tectonics exhibit showing seafloor spreading, a child pushed the plates apart and let them slide back to reset position several times, while making the sound

“boodyumpbaa, boodyumpbaa, boodyumpbaa, boodyumpbaa,” for a total of nine times (figure 6.17). The sing-song sound effects for the manual movement of the exhibit seemed to have no semantic connection to plate tectonic motion in the real world. Rather, he coordinated the timing and tonal inflection with the mechanical rhythmic motion of pushing the model plates apart and letting them slide back together. Grounded in the child’s sensorimotor coordination with the concrete mechanical object, this sonification adds a representational layer to the action rather than the museum object.

Interactions with another plate tectonics exhibit, which shows a prototypical subduction zone and resulting volcanism, showed a marked contrast. The child described above, and several other children, made sounds like a release of pressure, always synchronizing their sounds with



Figure 6.18. While demonstrating subduction and volcanism for a classmate, the child sonified the action with “brrrrrchh.”

gestures that start at the “volcanoes” on the exhibit’s surface and move rapidly upward (figure 6.1a). Explosive gestures accompanied explosion sound effects such as “Pssshh,” and “brrrrrchh” (figure 6.18). Some of the children’s verbal exchanges included the word volcano,

confirming that their representation matched the designer's representational intent. Mutual symbolic understanding—a significant collective cognitive accomplishment—attributable to our unique ability to give form to and understand visual analogies (Gentner; Goel, 2013).

One child's gestures seemed to illustrate the volcano's effects for an imaginary little person. His gesture started at the volcano's opening, with his hand standing on his index and middle fingers like two miniature legs. His hand shot up in the air, the child said, "Aaaaahhh." Reaching his hand and arm to full extension, his hand followed an arc until it landed on the other side of the display. In this big gesture, his hand seemed to represent a small body shooting through the air. He talked about the lava moving up through the volcanic vent. Then, his index and middle fingers became like two small legs again. He extended his fingertips to touch the glowing red volcano openings, with each touch saying, "Aaaah, aaaah, tssss, tssss, tssss, tssss," his hand like a small body, fingers like legs, fingertips like little burning feet (figures 6.19a, b). In these sequences of action, we see how a child creatively used his hand to represent a human body, establishing the critical representational correspondences by abstracting the features that matter (legs and torso) and compressing them to the size he can work with (fingers and hand), while using his voice to show the effects of stepping on the mouths of volcanoes. Actions of the hands gave meaning to his sounds, and his sounds gave meaning to the actions of his hands.

Analyzed in context of discourse and activity, these sonifications were anchored to the concrete object and made reference to a generalized abstract entity not physically present (i.e. volcanoes and the heat they generate). The children's sounds, coordinated with gestures coupled with the physical aspects and conceptual content of the display, contributed to the enactment of volcanic eruptions and related effects. In playful forms of sound and movement, the children created meanings with the subduction exhibit.



Figures 6.19 a, b. The child's gesture began with two fingers, standing like legs on a volcanic peak, then shot up into the air fingers extended, accompanied by the sound, "Aaaaahhh."

Using the hands and voice in acts of representation

When children engaged with museum exhibits, the majority of representational utterances blending concrete and abstract elements co-occurred with hand actions. Manipulation appears to be a critical factor. When children used the concrete/abstract speech form for any function—describing relations, linking with memory, imagining possibilities, and sonification—in more than 75% of the events, either the child speaking or another child manipulated an exhibit (figure 6.20).

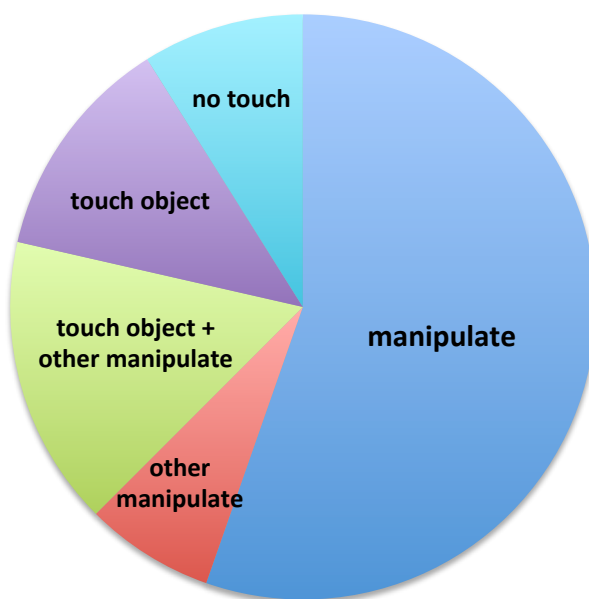


Figure 6.20. Concrete/Abstract Utterances Co-Occur with Hand Actions (4 children, 56 multimodal speech events). Children often used their voices in acts of representation associated with manipulation of exhibits, either by the speaker (31/56) or when observing another child (13/56). Children rarely used representational speech without involvement of the hands (5/56).

The four children who used concrete/abstract utterances varied in the number of times they used this form in combination with different hand actions. Despite individual variation, each child was more likely to use concrete/abstract speech when the exhibit was manipulated by themselves or someone else. They only very rarely used the concrete/abstract speech form

when no one touched an object or manipulated an exhibit. When looking at the profiles of multimodal engagement for each of four case-study children, individual variability becomes apparent. Still, exhibit manipulation (by the focal participant or another child) predominantly co-occurs with representational speech. Representational speech happens very infrequently in the absence of touching or manipulating exhibits (figure 6.21). The data suggest gender differences in these patterns, a hypothesis that could be tested with an experimental paradigm.

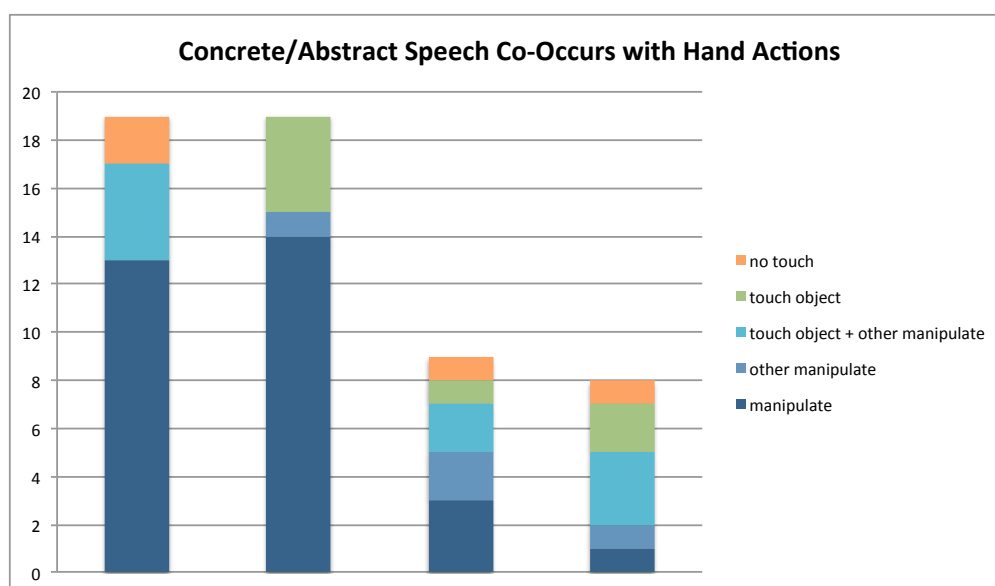


Figure 6.21. Interactional profiles of four children who used concrete/abstract speech. The two left bars represent data from two boys; the two right bars represent data from two girls. These data suggest potential gender differences, but with a small number of participants in uncontrolled conditions, the results are far from conclusive. Future research could explore gender differences related to manipulation of exhibits and the resulting cognitive consequences.

Many factors likely relate to concrete/abstract vocal expressions. Simply involving the hands is not sufficient to elicit concrete/abstract representational speech. Shifting the perspective to all the times that the children manipulated an exhibit, they used concrete/abstract speech during almost 70% of those events. In stark contrast, 5% of the times the children touched a museum object (specimen, cast, or model), they used concrete/abstract

speech. Within this museum ecosystem, concrete/abstract speech happens more frequently with involvement of the hands and is not independent of manipulation ($\chi^2 = 112.8$, $df=1$, $p<0.001$). Manipulation not only engages the hands. Manipulation changes the configuration of elements in the exhibits, and therefore changes what the child can perceive in the exhibits. Manipulation changes the degree to which the abstract concepts are made available for perception. As a consequence, interactivity expands the potential for using the exhibits as tools for representation.

Manipulation demands attention, in part because motor action requires eye-hand coordination. Action draws the attention of others too, as they watch to see what happens, and wait to take a turn. Exhibits that invite manipulation attract and hold attention, and therefore, interactive exhibits tend to win the competition for that limited resource of attention. Furthermore, increasing the quantity and quality of engagement enhances the likelihood that children speak.

Hands serve as tools for exploration and expression. When exhibits afford interaction, children can use their hands to change things and explore perceptual variations. When interactive exhibits function well as material anchors for conceptual representation, changing perceptual relationships expands the representational potential of an exhibit. In addition to visual representational exhibit media and verbal interpretations, children use their hands to express ideas with iconic representational gestures when using interactive exhibits more than in any other condition. Gesture serves as a creative, flexible, expressive medium for creating, linking, and layering representations.

Emergent properties of multimodal multiparty meaning-making

Acts of representation in the museum described here involve concrete/abstract speech, gesture, touch, and manipulation. Children deploy these forms of modal engagement for functional purposes—to name things, describe relations, remember the past, imagine possible futures or alternate realities, and to give meaningful sounds to action. When children engage with exhibits, they combine these various strategies to achieve accomplishments of cognitive complexity. As they make meaning with things in the museum—using the exhibits as tools in acts of representation—they improvise, play, and weave in multiple narratives anchored to the exhibits. They use the objects as representations of concepts, sometimes compressing vast scales of time and space. They identify relevant semiotic, or meaning-making, resources and link them together via speech, gesture, and actions with exhibits. They use their imaginations to fill what they perceive as gaps in the exhibits.

Layering of narratives

In the following example, children use a digital interactive exhibit that illustrates how the movement of Earth's plates over millions of years has dramatically shaped and reshaped continents and oceans (figure 6.22). One child rotates a wheel that drives the movement on a screen. Several children watch and comment. They express relations in time and space. They imagine and express alternate realities linked in critical ways to the exhibit. Their social negotiations to access the exhibit interleave their meaning-making activities. A multimodal transcript below identifies the functions of children's speech coordinated with their actions.

Transcript: Children use multiple modalities with “Moving Plates” digital interactive exhibit
(1 minute 27 seconds)



Figure 6.22. Plate tectonics digital interactive exhibit.

Plain Roman text indicates when a child directs attention and/or tells another child what to do. Gray text indicates social negotiation. Underlined text indicates when a child makes references to space; bold text indicates **references to time**. These spatial and temporal references involve either naming objects or describing relations. **Italic text highlights imagining alternative narratives**. The focal participant's speech is marked with an L; numbers designate other speakers, all of them children.

One child turned the wheel, while five other children watched and jockeyed for position to take their turn.

1: I'm after

L: Hey cutter (turns toward child 1 and moves body between him and exhibit)

1: I'm after you

2: Look, look (all children orient their bodies and gaze toward the display screen)

3: Oh look (point to red dot on screen) there we are, over there (figure 6.23)

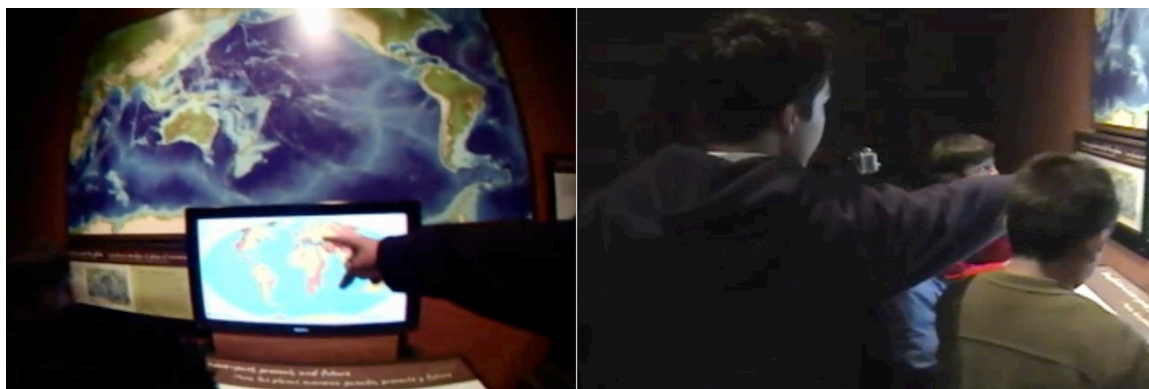


Figure 6.23. One child points to a red dot on the screen, “there we are, over there.”

3: *He's killing us* (San Diego, represented by a red spot, pushes toward the image margin)

1: L, what's that red spot?

3: That's us, it's San Diego

1: That's where we are?

3: That's San Diego, look, in the dot, down below (point), it says San Diego,

3: *He's killing us*

(Child who was spinning the wheel stops, turns on the stool, stands up, and walks away)

L: Yay (L takes the seat in front of the interactive exhibit, pushes another child's hands off the wheel and begins turning it)

1: After, I'm gonna be next

3: Ah, my neck

L: Press the button

1,2: Hey, hey, Jason, Jason (two children in unison)

2: Get in line

L: Wait

2: You're cutting Jason

4: I was

(A touches spin browser, pulls hand toward body, elbow flies back and touches classmate in the abdomen)

1: Oooh! (doubles over in mock pain, laughs)

L: Sorry (laughs) I was like, ah baah (repeats motion with spin browser) (all kids laugh)

(L presses button to change to earthquake and volcano visualization (figure 6.24))

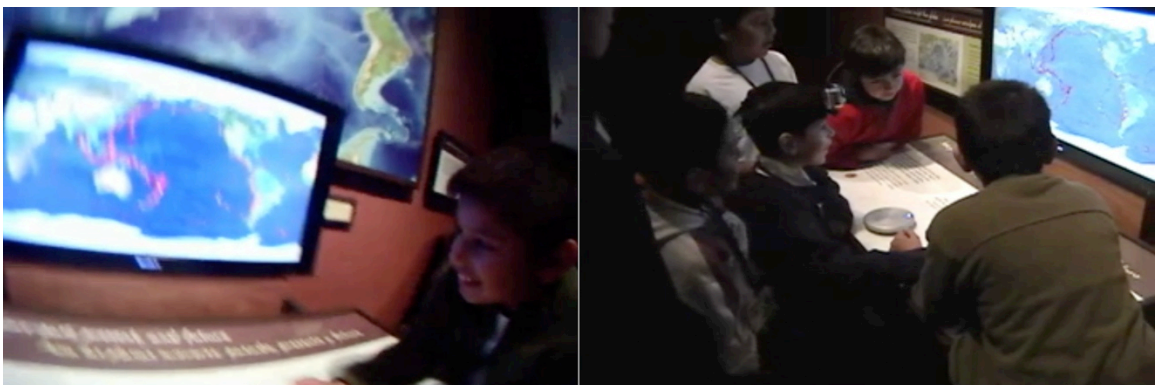


Figure 6.24. The child controlling the exhibit changes the display by pressing a button.

4: Oh five (points at screen)

(Other child presses button to change to plate movement animation)

L: Wait

L: That's where we are (eye gaze toward red dot)

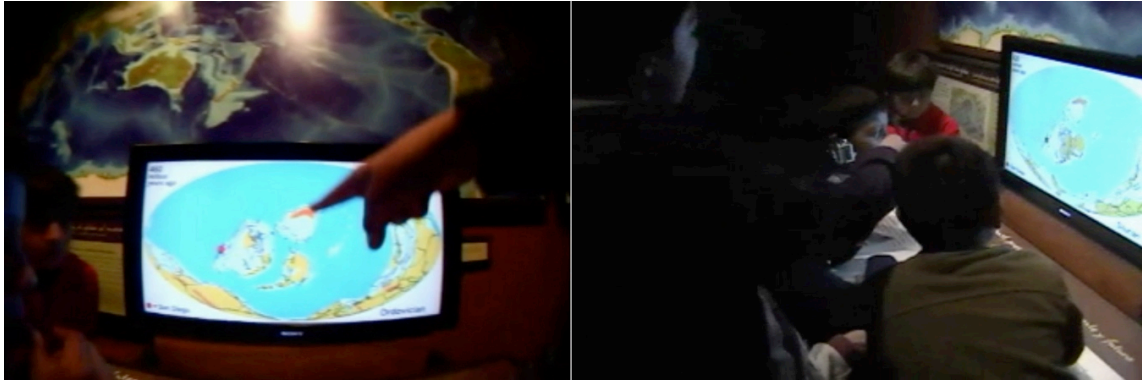


Figure 6.25. A child points to the red dot a second time, “Look, that’s where we are...”

- 4: I’m next
- 3: Look, that’s where we are, he’s connecting the, (points to screen, continents coming together (figure 6.25))
- 4: Get in line, Richard
- 3: he’s connecting us with the
- 2: I was here a long time ago



Figure 6.26. Manipulating the digital interactive changes the plate tectonic visualization, and the continents move close together.

- 3: He’s connecting (figure 6.26)
- 4: **That’s the future, go back to the future, that’s the future** (points to screen)
- L: Hey, who pressed the button?
- 3: **That’s, that’s a (inaudible) years ago**
- 1: *I control you (makes steering wheel gesture, as if the child operating the interactive is the steering wheel) (figure 6.27)*
- 3: **A billion years ago**
- 1: *I control every country (figure 6.28)*
- 3: *Alan, you’re killing us (the red dot of San Diego approaches the image margin)*



Figure 6.27. "I control you."

3: Ooo, you saw the future?

L: Oh yea?



Figure 6.28. Through manipulation of the exhibit, the continents move to a recognizable configuration. "I control every country."

2: *The world's coming to an end* (perhaps a reference to 2012, a theme in several observed conversations)

4: *That's not reeeall*

3: *Yes it is*

L: **There's the future**

4: *Why don't you come to it then? Why don't you come?*

L: **Future, future, future, future, future** (continuing to spin wheel)

4: **Jurathic, Jurathic, go to Jurathic** (point to screen)

L: **Oh there's future**, press it, press it (referring to the button)

These fourth-grade students engaged in complex, multi-layered discourse. They tracked the changing shapes as they moved on the screen and attended to the changing text. They used their prior knowledge in combination with the animation to establish correspondences with known space (San Diego), and known time (present, future, Jurassic) by naming representational objects. They interpreted the meaning of the exhibit ("That's where we are, he's connecting...") by describing relations. Managing social interaction didn't derail their meaning-making activity. They played with alternative story lines, tying their imagined scenarios to the activity on screen ("He's killing us," "I control every country," "The world's coming to an end"), demonstrating awareness of critical changes in the visual display and engaging in creative self-expression. Children waited for long periods of time, if necessary, to gain access to this particular interactive exhibit, which has a low barrier for engagement and a high threshold for boredom. Simple improvisations in meaning-making.

Giving form to imagination and filling a gap

Among the fourth-grade children, iconic representational gestures are rare and not evenly distributed throughout the exhibition. Rather, the majority of iconic gestures occur at a plate tectonics exhibit, previously discussed, designed to represent a subduction zone. The design of the exhibit strongly activates a representation of volcanoes among the children, yet the physical design leaves out a critical conceptual component—the eruption of lava from the Earth’s surface. With iconic gestures, the children give form to imagination and, with their hands, they fill a gap in the physical design by enacting eruptions and explosions (figure 6.29).



Figure 6.29. With an explosive upward gesture, accompanied by the sonification, “ppsshhhhh,” a child enacted a dramatic volcanic eruption at this exhibit.

In an exhibit representing a subduction zone, pushing down on a red knob at an oblique angle moves a horizontal slab of material to represent the oceanic plate diving beneath the continental plate (figure 6.30). On the vertical surface of the display, representing the Earth in cross-section, shapes light up red and orange, signifying how the leading edge of the subducting plate melts. The molten rock, more buoyant than the surrounding crust, appears to rise up as plumes of magma. Some magma reaches the surface through volcanic vents. Simultaneously, the top surface on the right, which represents a mountainous chunk of continent, lifts up.

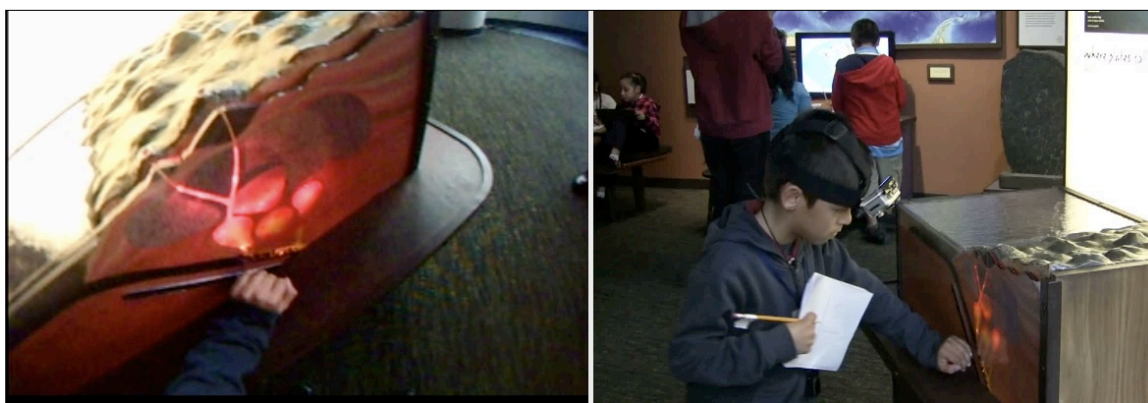


Figure 6.30. With this manipulable interactive exhibit, pushing down a handle drives an “oceanic plate” down into a “subduction zone” causing the “plate” to “melt”. “Plumes of magma” rise up. Some “magma” rises up into “volcanic vents.” Child’s perspective (left), researcher’s perspective (right).

Among the gestures at the subduction exhibit, the greatest percentage of iconic gestures represented volcanic eruption. The eruption gestures took two primary forms: rapid vertical movement with one or two hands (figures 6.1a, 6.1b, 6.8, 6.19a, 6.19b, 6.29, 6.31), or a spreading motion with one or several fingers (figure 6.32). These gestures achieve *motion-for-motion* mapping and *shape-for-shape* mapping (Taub, 2001) with varying degrees of specificity. Many gestures were accompanied or preceded by the word “volcano,” or produced synchronously with a sound like air rushing out of a tube. Explosive eruption gestures originated at or above one or both of the volcanoes at the exhibit’s surface, or followed the volcanic vents on the front side in an upward direction (figure 6.8). All these gestures representing volcanism

occurred in spatial and temporal coordination with the exhibit, demonstrating a particular form of environmental coupling (Goodwin, 2007). Oozing eruption gestures model a radial flow of lava from the volcano's mouth using all the fingers of one hand, or trace the path of a lava flow with a single finger. Children produced volcanic gestures alone or in the presence of others, suggesting that the gestures are not necessarily communicative, but a form of sensorimotor exploration.



Figure 6.31. A rapid upward gesture represents an explosive volcanic eruption with the subduction exhibit.



Figure 6.32. A radial spreading gesture on the surface represents a volcanic eruption of spreading lava with the subduction exhibit.

Conceptual blending theory provides a useful framework to interpret the children's actions (Fauconnier & Turner, 2002; Parrill & Sweetser, 2004; Coulson & Oakley, 2005). Conceptual blending entails a selective projection of features from input spaces that expresses correspondences in structure, which when blended, produces some novel emergent structure (Fauconnier & Turner, 2002, pp. 40–50). In the museum setting, objects can be seen as objects and as representations of other things (Duensing, 2002). A museum object can serve as an input space, and as such, they serve as material anchors for conceptual blends (Hutchins, 2005).

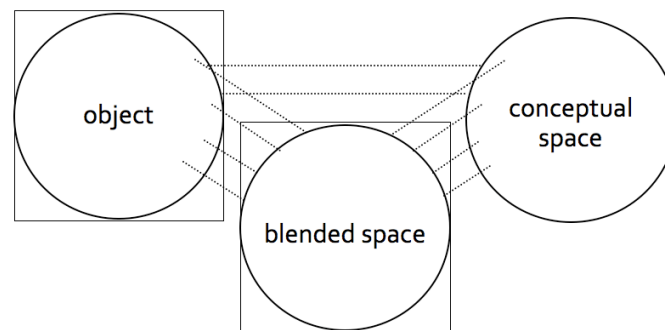


Figure 6.33. A generic model for conceptual blending shows two input spaces (one a concrete object, one a set of related concepts). In an act of representation, a person may selectively bring together corresponding elements from the two input spaces in the blended space. This graphical convention uses circles to represent different conceptual spaces; squares indicate spaces that are anchored to objects. Lines represent correspondences in content.

A blending model (above) without specific content shows input spaces: the object and conceptual space, and suggests a partial mapping between input spaces, indicated by dotted lines (figure 6.33). The conceptual blending diagrams here use conventions established by Gilles Fauconnier, Mark Turner, Edwin Hutchins, and Robert Williams. The squares drawn around the input and blended spaces represent conceptual spaces anchored to a physical object. The correspondences between input spaces support projection of a limited number of features to

the blended space, where the blend can be elaborated (Fauconnier & Turner, 2002, p. 48).

Correspondences between input spaces make conceptual blending not just possible, but comprehensible.

The diagram below illustrates how the subduction exhibit serves as a material anchor for a conceptual blend (figure 6.34). Isomorphic relationships exist between the exhibit's physical structures and the conceptual structure of what constitutes a volcano. Through these relationships, one can see the exhibit (made of plastic, metal, and wood) as a volcano. The correspondences are direct, due in large part, because volcanoes are a physical phenomenon well suited to the extraction of defining features and giving them physical form. The exhibit features express the deliberate intentions of the design team to create a stylized representation of a subduction zone with volcanoes.

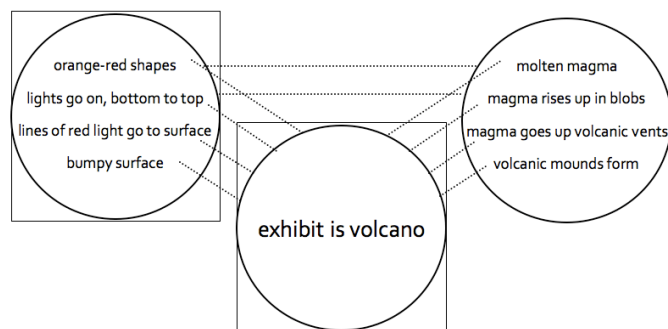


Figure 6.34. Perceivable features of the subduction exhibit (upper left) and generalized abstractions from a conceptual space related to volcanoes (upper right) provide inputs to a blended space in which exhibit elements can be seen as a volcano (center).

However, the input space for the exhibit object (figure 6.35, upper left) lacks a physical structure that corresponds with a critical element that defines the prototypical volcano, i.e. a volcanic eruption.

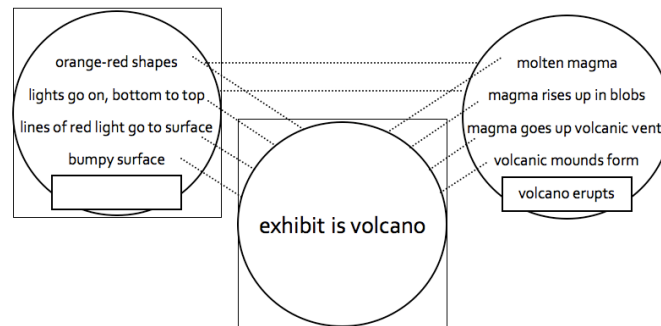


Figure 6.35. The input space of the physical exhibit (upper left) lacks a key feature—volcanic eruption—that corresponds with the conceptual space of volcanoes (upper right).

Some children fill this gap in physical structure by creating a gesture that expresses a rapid explosion upward or lava slowly spreading outward (figure 6.36). Here we see correspondences between the hand gestures described above, the conceptual space and the

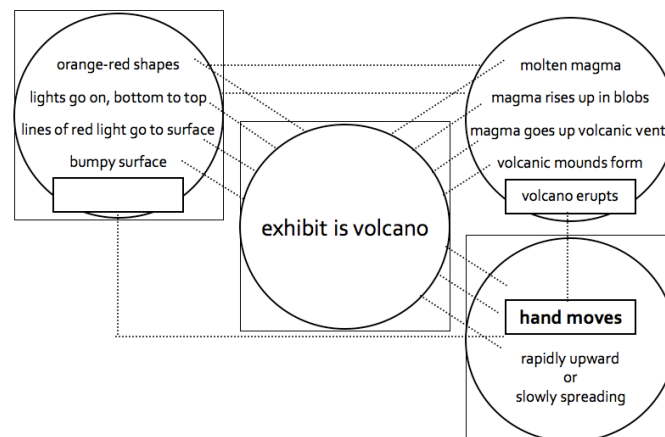


Figure 6.36. Bodily gestures involving movement of hands and arms provide an additional input space in the process of conceptual blending in which exhibit elements come to represent a volcano.

object. Through these correspondences or mappings, the gesture contributes to the blend.

When the children gesture to model an exploding volcano or oozing lava, they flexibly use their bodies—perfectly suited to the task—to complete the blend and provide the climax to a volcanic eruption narrative. In the design process, to create this convergence of elements in an exhibit with a clear and available role for the user is not convergence of elements in an exhibit with a clear and available role for the user is not an easy task.

Building on our original content-free model, we now add another material anchor for the conceptual blend—the body (figure 6.37). Bodies—and hands in particular—present representational resources of extraordinary flexibility (Alac & Hutchins, 2004). In this one example, the gestures of children capture structure with spatial and temporal dimensions, coupled strategically with the object in a manner that reflects prior knowledge of volcanoes. The children effortlessly map their body schema (in size, position, and dynamics) to an image schema or mental model of what volcanoes do.

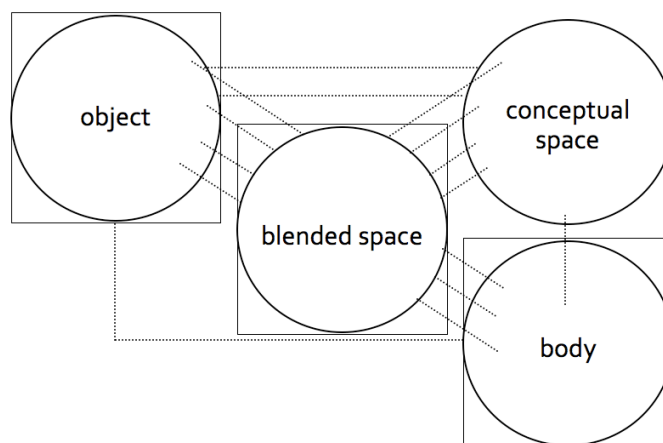


Figure 6.37. The body provides meaning-making resources, brought into coordination with objects and concepts, to create a conceptual blend and to experience the coupling of object and body as a representation.

In addition to representational gestures that convey volcanic eruptions, children produce gestures that convey uplift of the continental plate, but this was observed only twice among the focal participants' classmates when the children were free to explore the galleries. The observed rarity of the uplift gesture stands in contrast to the relative abundance of eruption gestures, amounting to fifteen total made by thirteen children recorded on video of the case-study children and their classmates. Conceptual blending theory may help in positing an explanation. As explained earlier, the exhibit serves as a material anchor for a conceptual blend. Regarding the phenomenon of uplift, different physical features stand out as relevant (figure 6.38). The children need not know about subduction zones or have a mental model for uplift. They can see the brown and gray mass that represents the continental crust pop up after pushing down the handle.



Figure 6.38. Seeing the model as a representation, the child forced a tectonic plate down into a subduction zone and touched the lava at the mouth of the volcano.

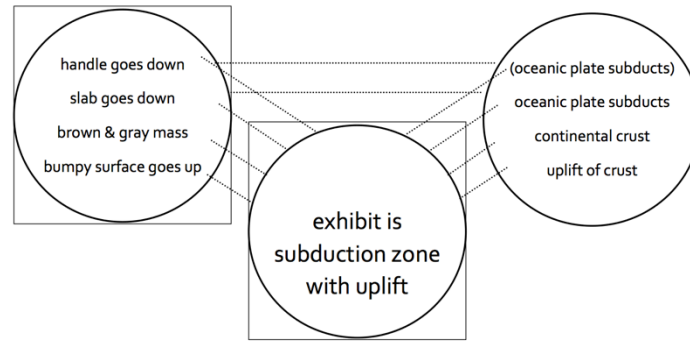


Figure 6.39. With a focus on different physical features, the subduction exhibit can support representation of continental uplift.

When children move their hands in an upward motion, using words or spatial location to convey uplift of the continental crust, their gesture highlights an existing feature of the physical object. Unlike the volcanic eruption gesture, the uplift gesture (figure 6.40) does not fill a gap in the material anchor's mapping to the conceptual space (figure 6.41). Rather, the gesture provides sensorimotor reinforcement of the uplift of continental crust. In addition to the representational redundancy of the movement, the exhibit feature of continental uplift is much less salient than glowing red blobs of magma and volcanic vents.

The alignment or similarity between the perceptual features of the object and ideational features of the concept determine the ease and transparency of the act of representation. Material anchors can stabilize thought and action. The ubiquity of using objects to represent ideas can render the function and consequences of material anchors invisible to us. Awareness of how people use objects for representational purposes can guide design and education.



Figure 6.40. A child and teacher gestured “uplift” at the subduction exhibit. Image shot from a child’s perspective with a head-mounted camera during a gallery lesson.

Features of the design of the subduction exhibit—the affordance of physical interactivity, alignment between concepts and objects to create an effective material anchor for a conceptual blend, and a salient conceptual gap in the physical representation—elicited representational gestures from the children. Their creative gesturing to complete the volcanic eruption—simultaneously exploratory and expressive—provides another illustration of the distribution of cognitive labor across different modalities in coordination with design media.

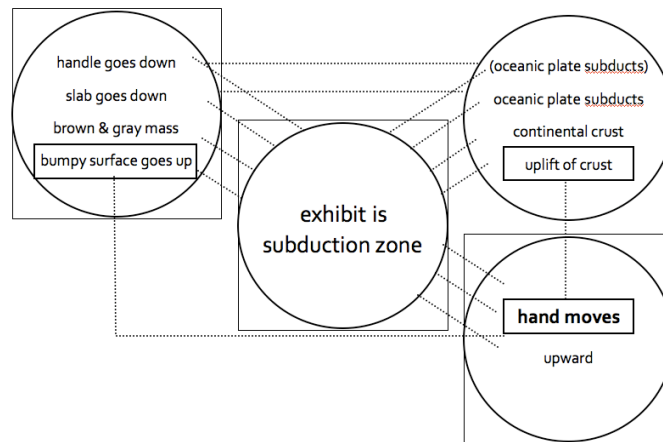


Figure 6.41. An uplift gesture corresponds with features in both the physical exhibit and the conceptual space of subduction zones. As a consequence, the gesture does not fill a gap in the input spaces required to complete the conceptual blend in which the exhibit represents a subduction zone with continental uplift.

Design, as a process of representation, can instantiate concepts in physical objects, making concepts available for perception. Representational objects—a class of *material anchors for conceptual blends*—can stabilize conceptual relations for the representational thinker (Hutchins, 2005). Conceptual content from a discipline’s *semiotic field* (the world of possible meanings in the Earth sciences, for example) can be given physical form to create a meaning-rich perceptual field (Goodwin, 2000). With direct correspondences between scientific concepts and physical representations in the museum exhibits, the children can perceptually grasp the conceptual objects and meaningful relations intended by designers. When an exhibit affords interaction, manipulation adds dynamics. When interactive elements maintain an isomorphism between the conceptual space and the exhibit as material anchor, deep geologic time and vast geographic space compress to human-scale time and space. Human-scale changes in time and space, accessible to the senses, can be conceptualized as Earth-scale changes in time and space.

Access to the display's conceptual content does not derive solely from the directness of mapping with the physical object. Although important, an object's accuracy of correspondence with an expert grasp of the content, seen as "transparency" (Meira, 1998) or "epistemic fidelity" (Roschelle, 1993), does not determine behavioral and cognitive outcomes. We may call the museum object a representation, but it serves as a representation only when a person perceives it as a representation, i.e. when the person experiences correspondences between the perceivable object and abstract concepts. Therefore, the relevant question is not *What* is a representation. Rather, the relevant question is *When* is a representation (Hutchins, 2012).

Potential confounds, or criteria to satisfy?

Many factors complicate interpretation of when, where, and why children make representational use of speech and gesture in this data set. From a reductionist perspective, these additional factors confound a singular causal interpretation. From an ecological perspective, these factors suggest a set of criteria that, when satisfied, enable children to engage in representational thought and action. Four of the six children used concrete/abstract speech, mostly with interactive plate tectonics exhibits. Involvement of the hands with manipulable exhibits likely plays a major role. In addition to the affordance of manipulation and its role in attention, the following factors likely affect when, where, and why children blend the concrete here-and-now with abstract objects or concepts that exist only in words and gesture.

—Children bring prior knowledge with them into the museum. For example, they have seen representations of volcanoes in various media. They know about earthquakes, oceans and continents, rocks and planets.

—Geology and plate tectonics is a fourth-grade science standard. The children may have previously encountered some of the exhibition's Earth science content, particularly in visual form that they could map to the media in the museum.

—Children expect the museum to be about something. Their museum literacy (a function of participation in a special museum immersion program for the case-study children) drives an expectation of representation.

—The plate tectonics gallery provides many instantiations of a set of fundamental concepts (i.e. processes and consequences of movement of Earth's crustal plates). In this exhibit area with many related ideas, children can use the same basic idea (e.g. lava or earthquake) as a point of entry to various idea networks.

—The degree to which abstract concepts are made available for perception in the representational technology of exhibits, the ease by which an object anchors thought, the alignment and distance in the mappings between the concrete object and the conceptual space, stems from the internal structure of relationships among visuo-spatial elements (in the exhibit) and conceptual elements (in the thing represented).

—The directness and complexity of the representation of ideas in exhibits influences how and if children propagate those ideas in speech and gesture.

Many things, animate and inanimate, compete for children's attention in the museum. As they navigate physical, social, and conceptual space, attractors pull their attention in

different directions or align attention among multiple modalities and across multiple dimensions. Perhaps that is the primary function and desired consequence of interactivity in design—to align attention in physical, social, and conceptual dimensions.

How children create and express meaning in the museum depends on a rich mix of the skills and knowledge they bring with them, and how they get to exercise those skills and play with their knowledge through engagement with exhibits. The physical and conceptual design of exhibits permits, invites, affords different forms of engagement. Different forms of engagement have profound consequences for motivation, affective response (e.g. frustration or enjoyment), social coordination, linking with memory, and learning. Opportunities to interact—to change what is perceptually available—can satisfy critical criteria related to motivation to engage, attention (individual and social), use of concepts to support new ways of perceiving, and use of perception to build new concepts.

The idea of meaning-making in museums isn't new. The main thrust of Constructivism—that people actively build knowledge from direct experience—has influenced museum practice for decades (Hein, 1998). This research builds on that foundation and catalogs various modes of meaning-making, the forms they take and the cognitive functions that result. In addition, this research explores the consequences of design on meaning-making activity. Alignment between concepts and physical design can make ideas available for perception and compel acts of representation. Children's embodied expressions of meaning—using gesture, speech, and other forms of action—provide meaning-making resources that others can draw on (figure 6.48).

Our cultural history confers a privileged position to abstract concepts, based on the notion that abstractions and general principles provide multi-purpose tools for use in various situations. The children in this study infrequently speak of abstract concepts that address the

question, *What does this mean?* Yet, through speech and gesture, they link the concrete and perceivable with abstract and imperceivable. In their acts of representation, the children show us the critical importance of embodied exploration in their expression of ideas.

Design can provide the means to satisfy the children's fundamental questions of *What is it?* and *What can I do?* The answer to *What can I do?* should be easy to discover, and the consequences for action can offer a multi-layered exploration of *What is it?*. Explorations can go beyond a name to include *What does it mean?* and extend to what are many possible meanings.

By paying attention to what children actually do in a museum—how they use their bodies, how they use exhibits, and how they interact with each other—we come to see their exploratory and expressive inclinations as invaluable resources for themselves and others.

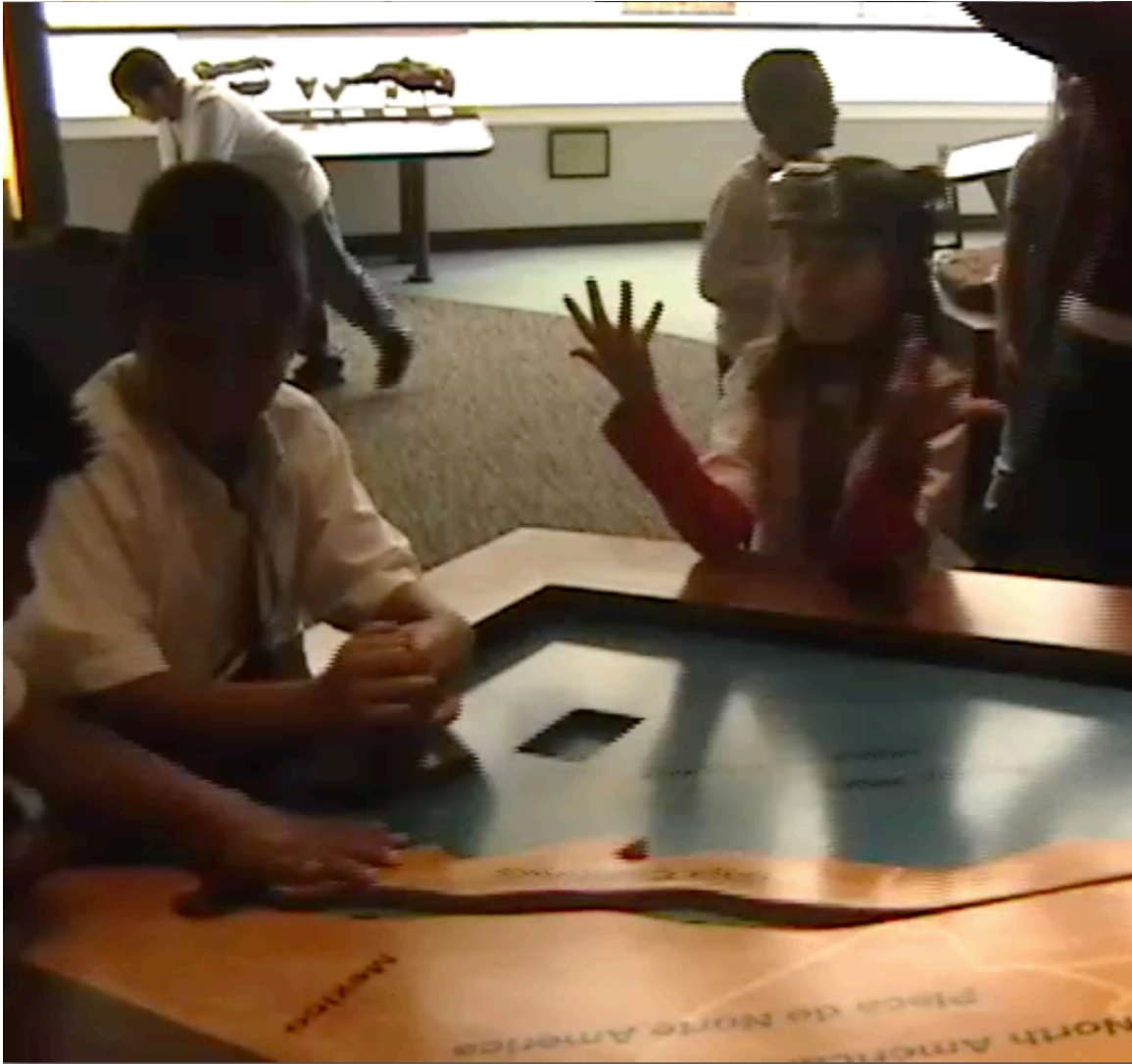


Figure 6.42. Children use gesture to represent objects and relations in the museum. This child pointed to the exhibit's ocean-floor rift and said, "That's the lava." With hands rising and palms up, then spreading out to the sides, she created dynamic forms to accompany her speech, "When it gets out it's magma." This enactment of meaning highlights relevant conceptual features and relations for the child, and provides potential meaning-making resources for use by others.

¹ "Common ground may be perceptual and conceptual; the cognitive resources may be embodied and external." My sentence, even in context on page 6, obscures the complexity of each adjective. Lacking punctuation inhibition, one might be inclined to use back slashes, m-dashes, or quotes to highlight the limitations of the words—perceptual, conceptual, embodied, external—in the linearity of text. In the sentence above, the words form coupled pairs, not intended as dichotomous.

References

- Alac, M., Hutchins, E. (2004). I see what you are saying: Action as cognition in fMRI brain mapping practice. *Journal of Cognition and Culture*, 4.3.
- Clark, A. (2011). *Supersizing the Mind: Embodiment, Action, and Cognitive Extension*. New York, NY: Oxford University Press.
- Clark, H. (1996). *Using Language*. Cambridge, UK: Cambridge University Press.
- Coulson, S. & Oakley, T. (2005). Blending and coded meaning: Literal and figurative meanings in cognitive semantics. *Journal of Pragmatics* 37: 1510-1536.
- Duensing, S. (2002). The object of experience, in (Ed. S. Paris) *Perspectives on Object-Centered Learning in Museums*. Mahwah, NJ: Lawrence Erlbaum Associated Publications.
- Fauconnier, G. Turner, M. (2002). *The way we think: Conceptual blending and the mind's hidden complexities*. New York: Basic Books.
- Gajdamaschko, N. (2005). Vygotsky on imagination: Why an understanding of the imagination is an important issue for schoolteachers. *Teaching Education* 16 (1), 13-22.
- Gentner, D. (2003). Why we're so smart. In D. Gentner and S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and cognition* (pp. 195-236). Cambridge, MA: MIT Press.
- Genter, D. (2010). Bootstrapping the mind: Analogical processes and symbol systems. *Cognitive Science*, 34, 752-775.
- Goodwin, C. (2000). Action and embodiment within situated human interaction. *Journal of Pragmatics*, 32, 1489-1522.
- Goodwin, C. (2007). Environmentally Coupled Gestures. In *Gesture and the Dynamic Dimensions of Language*, edited by Susan Duncan, Justine Cassell, and Elena Levy. Amsterdam/Philadelphia: John Benjamins. pp. 195-212.
- Goodwin, C., Goodwin, M.H. (1998). Seeing as situated activity: Formulating planes. In Engeström and Middleton (Eds.) *Cognition and communication at work*. Cambridge, U.K.: Cambridge University Press.
- Hein, G. (1998). *Learning in the Museum*. New York, NY: Routledge.
- Hutchins, E. (1995). *Cognition in the wild*. Cambridge: MIT Press.
- Hutchins, E. (2005). Material anchors for conceptual blends. *Journal of Pragmatics*, 37: 1555-1577.
- Hutchins, E. (2012). *When is a representation*. Personal communication.

Hutchins, E. (In press). Human Cognition: Culturally Pervasive, Not Extended.

Hutchins, E., Hollan, J., Norman, D. (1986). Direct manipulation interfaces. In D. Norman and S. Draper (Eds.), *User-centered system design*. Lawrence Erlbaum Associates, Inc.

Kirsh, D. (2011). Creative Cognition in Choreography. *Proceedings of 2nd International Conference on Computational Creativity*.

Meira, L. (1998). Making sense of instructional devices: The emergence of transparency in mathematical activity. *The Journal of Research in Mathematics Education*, Vol 29, No. 2, 121–142.

Parrill, F. & Sweetser, E. (2004). What we mean by meaning: Conceptual integration in gesture analysis and transcription. *Gesture 4*, 197-219.

Roschelle, J. (1993). *Designing for cognitive communication: Epistemic fidelity or mediating collaborative inquiry?* SRI International.

Taub, S. (2001). *Language from the Body: Iconicity and Metaphor in American Sign Language*. Cambridge, UK: Cambridge University Press.

Vygotsky, L.S. (1978). M. Cole, V. John-Steiner, S. Scribner & E. Souberman, eds., *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

Vygotsky, L.S. (1986). A. Kozulin (translator) *Thought and Language*. Cambridge, MA: MIT Press.

7 Conclusion: Implications for Practice, Education, and Design

How do children use museum exhibits in a natural history museum? Children's patterns of use inform inferences about the consequences of design for physical, social, and conceptual engagement. Video-based observational studies support detailed analysis of children's multimodal engagements with exhibits and with each other. In this investigation of behavior and cognitive activity *in the wild*, we discover interesting cognitive phenomena and their patterns of organization.

This research does not probe what experiences will leave a lasting memory trace. Future research could explore questions of memory, drawing on the larger video corpus. This research documents how environmental structure constrains and affords children's cognitive behavioral activity in a museum. Consequently, the results raise implications for designing environments for exploration, expression of meaning, and learning.

Six fourth-grade children explored a natural history exhibition with specimens, models, interactive exhibits, immersive environments, murals, graphic panels, video and sound. The research results focus on the children's multimodal engagement with exhibits (looking, touching, talking, gesturing). In this effort to describe a complex cognitive ecosystem, the research describes broad organizing structures for the children's activity in the museum, the *forms* of engagement with exhibits (what perceptual and expressive modalities are used) and the cognitive *functions* of engagement (the cognitive work that is accomplished).

Exploring the museum driven by questions

When children move through a museum, their behavior is not random. As the children observed in this research navigated physical, social, and conceptual spaces, they devoted considerable attention to the museum exhibits. From the researcher's point of view and using educational parlance, the children spent a lot of "time on task."

When the children focused attention on museum exhibits, their actions expressed, and sometimes answered, a set of questions: *What is it? What can I do? What does it mean?* Oftentimes the children's speech made these questions explicit, as when children said, "What's this?" or "What's that?" Their frequent naming and describing of museum objects speaks to the question *What is it?* Their iterative and exploratory actions of touching, stroking, pushing, pulling, and turning implicitly address *What can I do?* At times, children verbally articulated the question, "How does it work?" implying *What can I do?* Children inquire about the meaning of museum objects and their potential for representation, as expressed in the question, "What's this supposed to be?" Making use of museum exhibits, they express meanings using speech and gestural enactments to represent objects and ideas.

To know the nature of things drives exploration. These questions—*What is it? What can I do? What does it mean?*—are interrelated and non-exclusive, with *What is it?* acting as an overarching question. Can the object be named, described, acted upon, or interpreted? If the object affords action, what kind of action is possible? Children pursue the question *What is it?* If a concrete label, descriptor, or discovery of affordances cannot satisfy the question *What is it?* and its action-oriented variant *What can I do with it?*, then the child may pursue *What does it mean?*, i.e. what is the object's potential for representation? The children spoke of objects as

representations with models that differed significantly from their representational subjects in scale. They tend to label natural objects (fossil, rock, bone, and taxidermy specimens) and not speak of the representational potential.

Children explore and express the nature of objects: *What is it?*

In the natural history museum under study, static objects comprise the most abundant type of display. These include specimens (fossils, modern bones, taxidermy mounts, rocks) and static models (environmental dioramas, life-sized animals). Among the children, the most abundant form of speech related to concrete objects. With this concrete speech form, the children name objects, describe objects, classify objects in exclusive categories, and ask questions about objects. The children's concrete object-oriented speech exceeded non-exhibit related social speech in frequency.

Busy hands: *What can I do?*

Children use their hands whenever and wherever possible. Among six children's engagements with individual exhibits, the vast majority (79%) involved touching. Graphic panels comprise the most abundant touchable element, and children touch graphic panels more often than anything else. Touchable specimens and models, although less abundant, have a strong power of attraction. If children have physical access to these touchable objects, they almost always touch them.

Touching the variable sizes, shapes, and textures of specimens and models provides tactile information to accompany other sensory modalities—vision, audition, and the often unmentioned proprioceptive and vestibular sensory systems that relate to the body’s configuration and position relative to motion and gravity. We don’t know the significance of informational coding in the proprioceptive and vestibular systems relative to learning in a museum. Yet we do know that the body and brain continuously integrate information from multiple modalities, computing statistical regularities and forming predictions based on past experience (Jacobs & Shams, 2009). Looking at and touching a variety of objects adds to that bank of experience; the neural networks involved in sensorimotor activity also serve as the substrate for memory (Fuster, 1999). When we examine the nature of learning at the individual level, multimodal engagement complexifies the experience and associated nervous system processes, integrating many channels of information. Touching presents risks to objects, hence adults sometimes say to children “touch with your eyes.” But physical touching confers many benefits, a claim supported by theory and empirical evidence.

Multimodal sequence, coordination, and function

When engaging with exhibits, children’s talking and touching do not function independently. Transcending individual variability, deployment of perceptual-motor modalities showed strong sequential patterns. While engaged with an exhibit, the children tended to look first, then they touched some part of the exhibit. If they had physical access to a high-value scarce resource, such as a specimen, model, or interactive interface, they would touch that more than touching an object with little sensory information, such as a graphic panel. When

children spoke while engaging with an exhibit, they tended to touch something before talking. The function of touch depended on what they touched and if anyone else was present. Gesture, most often in the form of a pointing gesture to direct another's attention and almost always coupled with speech, tended to follow previous talk about the same exhibit.

Analyzing each instance of touch and talk reveals another pattern. When children touched exhibits, they simultaneously talked about half the time. When they talked about exhibits, they simultaneously touched 70% of the time. In other words, children tended to touch exhibits more without talking (47%) than they talked about exhibits without touching (30%).

Whereas in the past, adults may have preferred that children be seen and not heard, various lines of research assert that language use can bootstrap cognitive development (Spaepen, Coppola, Spelke, Carey, Goldin-Meadow, 2011; Balcomb, Newcombe, Ferrara, 2011; Carey, 2011). At multiple levels, whether behavioral associations or purported neural connections, talking about experience can form and strengthen linkages between percepts and concepts (Gentner & Boroditsky, 2001; Ayoub & Fischer, 2006).

Different forms of touch and talk serve different cognitive functions. In their integrated action, children's hands and speech participate in a distribution of cognitive labor. As outlined in earlier chapters, children use touch to physically anchor their bodies while engaging with exhibits, sometimes providing greater perceptual access. When touching exhibits, children sometimes occupy physical space and, as a consequence, change the shape of social space. They move their hands across surfaces, most often specimens and models, to drive tactile stimulation. They manipulate exhibits, and in the interaction, they experience contingent relationships between the actions of their hands and changes in their visual field. Speech that accompanies these forms of touch relate to the current activity, but serves a different function.

When children talk about exhibits, they accomplish certain kinds of cognitive work. Children most often talk about concrete objects, by naming, describing, classifying, and asking questions. Children talk about action, and they take action with their voices. Overt management of attention comprises 75% of the action-oriented utterances. They talk to themselves and point for themselves, channeling their own attention toward specific targets, “Rocks, rocks, where are the rocks?” “Oh, here’s a rock.” They coerce the attention of others, most often saying “Look” or “look at that,” very often accompanied by indexical pointing gestures. The voice grabs attention, and the hand gesture directs attention to a particular location. The children tell each other what to do, and how to do it. Through their actions and interactions with exhibits, they demonstrate and interpret. On occasion, the children make sound effects when they interact with exhibits—they give sound to, or sonify, their actions. These sounds constitute sonic play, sometimes a sensorimotor accompaniment to the mechanical function of an interactive, and sometimes reflecting the representational content of an exhibit. Also within their action-speech repertoire, children read exhibit text aloud, alone and with others. Not every child reads; many read something; some read much more than others.

In the museum, the children bias certain kinds of knowledge in their speech. Whereas children commonly use concrete speech related to objects on display and actions (67% of exhibit-related speech), they talk about the abstract representational content of exhibits much less frequently (18% of exhibit-related speech). When the children talk about what is present and perceivable AND what is physically absent in the same utterance, they blend concrete and abstract speech. Children use this form of concrete/abstract speech for various functions. At the surface, some functions appear the same as concrete speech, such as naming, “Earthquake!” “Lava.” However, the processes of naming an object and naming that which an object

represents have different properties in important ways. Although both involve perception, recognition, and mental linkage with a verbal label, naming a representation involves *seeing as* (Goodwin & Goodwin, 1996; Alac & Hutchins, 2004). In each case, naming an object and naming a representation putatively involve multiple processes: selecting relevant features, matching features to an exemplar for comparison, satisfying weighted criteria, activating some labels while inhibiting others, and determining a “winner” label (Rosch, 1978; Tyler & Moss, 2001; Barsalou, 2008; Goldstone & Day, 2013).

In the museum setting, designers intervene in this object-naming process. Obvious linguistic interventions include identification labels and interpretive text. Visual-spatial strategies come into play when museums present models as representations. Designers select what features to include, presumably based on relationships to a specific example or generalized exemplar, and designers choose how to weight various features. When designers create a representation, they play a significant yet not determining role in others’ processes of using an object to represent something other than itself.

Children also use exhibits as points of departure for their own acts of imagination. They talk about possible futures or imagine alternative realities. This may involve creating a narrative, or taking a role. When children engage in acts of representation, the imagination comes into play in various ways. The exhibits serve as tools, anchors (Hutchins, 2005), or pivots for the imagination (Vygotsky, 1938). Museum objects hold some content stable while allowing for freedom of movement around a set of ideas in physical form. The imagination links what is present with what is not present and creates representational relationships. When children use concrete/abstract speech and iconic gesture as vehicles of expression, they make these representational relationships available for observation, for themselves and others.

Consequences of interactivity and *What does it mean?*

When the children engaged with interactive exhibits, they were much more likely to use concrete/abstract speech. In addition to naming conceptual elements associated with perceivable objects, they described conceptual *relations* among those elements. The children described relations when using concrete/abstract speech with much greater frequency than when they used concrete speech. To elaborate, children tended to focus on perceivable objects and features (using nouns and adjectives) with static non-interactive exhibits and more frequently spoke of relations among objects (using verbs and prepositions) with manipulable interactive exhibits.

Some concepts are better suited than others to material representation. In this museum setting, the majority of concrete/abstract speech events occurred with exhibits about the geology of plate tectonics, specifically the effects of movement of crustal plates. In these exhibits, the critical conceptual elements of geographic space, geologic time, and movement correspond with logical analogs: space, time, and movement on a human scale. With these exhibits, the children used very short label text (e.g. “Pastpresent–future,” “The present, El presente”) to help them assign meaning to exhibit elements. The children also deployed prior knowledge (e.g. about lava and earthquakes) to interpret the exhibits’ visual-spatial language and represent the exhibits’ ideas with words and gestures. Like their concrete/abstract speech, almost all the representational iconic gestures occurred with the plate tectonics exhibits. In gesture, movement of the hands offers an especially effective instrument for expressing spatial location, direction of movement, and dynamics.

Children's use of concrete/abstract representational speech tended to occur with mechanical and digital interactive exhibits. The manipulable interactive exhibits that elicited concrete/abstract speech have many features that could contribute to this result. Action and interaction with exhibits attract and hold attention, of both actors and spectators. Children stayed longer at interactive exhibits than non-interactive exhibits, extending the opportunity for speech associated with that exhibit. But time is not the only determining factor. With interactive exhibits, a child's actions create contingent movement in the display, which serves to highlight both the important objects and their relations with one another. Interactive exhibits present opportunities to make objects, relations, *and concepts* available for perception. In addition, children likely talk more about representational meanings of exhibits when they have more prior knowledge to draw on and weave into the current experience.

Consequences of multimodal exploration

The cognitive accomplishment of making representational expressions in concrete/abstract speech and iconic gesture emanate from multimodal exploration. Children's representational speech and gesture come after looking, touching, and manipulating the exhibits, in almost all situations. These exploratory and expressive forms serve different functions, determined by context.

Involving multiple perceptual-motor modalities permits a distribution of cognitive labor—as the hands manipulate an object, the visual field changes, speech can label the objects and express how they relate, and gesture can locate those objects in space and express dynamics of the phenomenon in concrete and/or abstract terms. With engagement of multiple

modalities comes the potential for greater cognitive complexity, predicated on the integration of distributed cognitive labor.

As the affordances of the exhibit increase, so does the range of possible answers to critical questions—*What is it? What can I do? What does it mean?* Whereas the traditional approach to learning (in museums and elsewhere) involved moving children from perceptual experience to conceptual understanding, this research suggests not unidirectional movement, but multidirectional linkage. A predominant focus on achievement of conceptual understanding pervades both pedagogy and research. Some exceptions focus on the development of perceptual skill (Goldstone, 1998), perceptual expertise (Palmieri & Tarr, 2008; Tanaka, Curran, & Sheinberg, 2005), the disciplining of perception (Stevens & Hall, 1998; Goodwin, 1994), and various forms of media literacy (Lemke, 1998).

Perceptual experience supports integration with and expansion of associations with concepts, including acts of naming, describing features and relations, classifying, and making sounds to accompany actions and representations. The complement can also be true. Conceptual knowledge can support and permit children to make sense of their multisensory experience. Conceptual knowledge can help them to differentiate and unify objects, and in concrete terms, to distinguish a horse from a walrus from a sabertooth cat.

Distribution of cognitive labor and cognitive complexity

The distribution of cognitive labor creates the potential for cognitive complexity. Coordination of multimodal action and the cognitive achievements that result can involve one or more people. Sequences and synchronies of multimodal actions allow for the emergence of

functions that differ from the individual functions of each modality. As described earlier, children often used speech in the museum to name objects, describe, classify, evaluate, ask questions, direct attention of self and others, and tell others what to do as they interact with exhibits. They also use their voices to sonify, or make sound effects for, their actions. They use touch to physically anchor themselves, to simultaneously occupy physical and social space, to drive tactile stimulation, and to explore tactile-visual contingencies when they manipulate exhibits. Children use their hands for expressive purposes, to direct and guide the attention of others and themselves with indexical (usually pointing) gestures. They also give form to ideas with iconic representational gestures. By combining and coordinating these functions, they engage in more complex cognitive activities: they explore and test cause-and-effect relations, they demonstrate how to use exhibits, and they interpret the meaning of things in the museum. With the six fourth-grade children observed, these complex emergent functions occurred when they engaged with interactive exhibits.

Exhibits that afford interaction support achievements of greater cognitive complexity—in sensorimotor exploration, expression of ideas, and acts of imagination and representation. To interact with an exhibit, i.e. to act upon an exhibit and the exhibit responds in some way, expands opportunities for action, perception, and interpretation of present experience and related experiences. When expanding opportunities for multimodal and multiparty engagement expands the potential for cognitive complexity, coherence or confusion could result. What determines the outcome?

An experience makes sense when what is perceived can be understood in light of past experience; enough perceptual pieces fit together into a coherent whole. We make meaning by relating present experience to other ideas. In many learning or meaning-making situations, the

expert or teacher can assess the learner's prior knowledge and adapt to the learner's needs. In traditional museum settings, the museum holds content expertise, but cannot respond in the moment to the learner's current understanding and potential for learning within the learner's zone of proximal development (Vygotsky, 1978). To compensate for this limitation, museum professionals assess multiple learners' levels of understanding (through evaluation and prototype testing) and aggregate that assessment to create an integrated framework of ideas designed for learners at various levels to navigate.

Museum designers engage in a distribution of cognitive labor, on different scales of time and space than the users of exhibits. The intelligence invested in museum exhibits modifies the users' task of sense-making and meaning-making. Museums, as object-based technologies for exploration of ideas, can use material means to make concepts available for perception and to use concepts to enhance perception.

To increase the probability of perceptual-conceptual coherence and reduce the probability of confusion, the results of this research suggest implications for design. By applying a design-based research approach, the field could collectively explore the consequences of implementing these recommendations.

Using observation to inform design

Design can support intelligent, exploratory, emotionally rewarding activity. Engagement in museums has multiple dimensions—related to individuals, social interaction, cultural practices, affordances of objects and environments, and institutional histories, each one abundantly complex. What follows are not guidelines or prescriptions for design. Rather,

reflections and questions, inspired by observation, provoke consideration of the physical and social uses of exhibits and the cognitive consequences of those uses. When in the museum, children (and adults) simultaneously navigate physical, social, and conceptual spaces. These spaces interrelate and interpenetrate; the following questions speak to these entwining relations.

Children approach the museum with tacit questions related to *What is it?* and *What can I do?* When they find clues or answers to those questions, perhaps revealed through multi-layered experience, they can explore and pursue a path to perceptual/conceptual coherence. To answer the question *What does it mean?* presents a greater challenge. Meaning can involve greater complexity than an identity label or finding affordances for action.

Museums serve as modern multimedia technologies for representation. Central in their panoply of media, museums collect, organize, and display objects based on their conceptual content, i.e. museums use objects to represent concepts. When museum practitioners attend to fundamental questions about relationships among the perceptual and conceptual, they can enhance the potential for museum users to engage in acts of representation and make meaning from their experience.

Museum practitioners might ask: In what ways can a physical perceivable object represent a concept that generalizes beyond the immediate circumstance? Is the concept amenable to concrete modes of representation? What features of the concept are considered essential for coherence? Which conceptual elements, features, and relations are instantiated in physical form? How do elements, features, and relations of the object(s) correspond with elements, features, and relations of the concept(s)? Are these readily perceivable? What should receive emphasis, and what methods will highlight those elements? Does the object instantiate

an isomorphic mapping with the concept? In other words, is there structural alignment? (Gentner, 2010). Or are multiple mappings, or multiple conceptual steps, required to achieve correspondence between the object and concept? If multiple steps are required, what kinds of intellectual scaffolding will support making those steps? Does the exhibit follow consistent rules for abstraction, simplification, and representation? If not, why not?

To expand exploration with the questions above, practitioners share prototypes with people who have no prior experience with the exhibits in development. Fundamental questions during prototype testing may address: What are the primary perceptual elements of the exhibits? How do the perceptual elements relate to each other? What interferes with a coherent perceptual experience? What is perceptually available for users of different heights and with various sensory abilities? Observing interactions with prototypes can provide information that question-answer conversations cannot. Additional questions follow.

How do the physical aspects of the exhibit guide or channel attention? What features are most pronounced? With interactive displays, does movement play a role of highlighting specific features? If children want to name, describe, or classify objects or elements in the display, what resources can they use? How can their activities of naming and describing serve as scaffolding for subsequent engagement? How many ways might a child answer *What is it?* What ways interest, engage, and delight? What affective responses does the exhibit elicit? How can people engage with *what objects are*, not just as an end goal, but as the means to deeper engagement?

What actions does the physical design afford? What can children see and do? Can they touch and manipulate objects? How do actions of the hands change what is available for

perception? What cause-and-effect relationships (mechanical and/or representational) does the exhibit embody?

Interactivity recruits attention, in part because interactivity enables multimodal engagement. Manipulation and other forms of movement provide a changing stream of perceptual information, including the senses of sight, hearing, touch, and body orientation relative to the self (proprioception) and the world (vestibular perception). When an exhibit does not afford physical interaction, what opportunities exist for sensorimotor and social interaction?

Interactivity supports distribution of cognitive labor across multiple modalities, and potentially across multiple parties. Interactivity can enhance children's use of concrete/abstract representational speech and increase cognitive complexity. How does activity relate to the exhibit's conceptual content? How are activities, and the ideas that imbue the activities, organized in space and time such that multiple people can collaborate productively? How do exhibits present opportunities for people to explore objects and ideas? How might this model of "exhibit as a mini-world for exploration" differ from "exhibit as medium for transmitting information"?

What are the opportunities for physical engagement among social groups? Does the design allow for multiple users to simultaneously engage (Borun, Dritsas, Johnson, Peter, Wagner, Fadigan, Jangaard, Stroup, Wenger, 1998)? Can children work together to operate the exhibit? Do multiple users create interference or opportunities for collaboration (Allen & Gutwill, 2003)? Can multiple users see each other's actions and the consequences of their actions, and to what end? Does the exhibit offer users opportunities to demonstrate and interpret? What resources support demonstration and interpretation?

How does the exhibit serve as a tool for the imagination? Do children have opportunities to create alternative meanings?

Educators and designers often define target learning outcomes. If learners don't hit the target, educators and designers determine that something is wrong with the learner or the learning technology. On the other hand, strong Constructivists sometimes eschew target outcomes, taking the position that every learner will make her/his own meaning, which should not be predetermined by others. A middle path may articulate target learning outcomes to support clear thinking about design of intentional physical, social, and conceptual affordances (i.e. what the learning technology makes possible). A middle path may also embrace that each learner uniquely perceives every situation, bringing individual prior knowledge, skills, interests, expectations, and motivations. As a consequence, unexpected outcomes will emerge from the uniqueness of each interaction. Paying attention to learner-driven emergent outcomes can expand educators' and designers' notions about what kinds of learning are possible and valuable. As an example, this research shows how often children engage with museum objects to name, describe, classify, and imagine. Investing design effort to explicitly support these activities satisfies learners' needs and could lead to other unanticipated forms of productive engagement. With this orientation, exhibits can serve as resources for exploration and expression of ideas.

To redefine the purpose of target outcomes may also expand our notions of valuable learning products and processes. Conceptual knowledge, powerful in its presumed generalizability, often holds a hegemonic grip on target learning outcomes. Many formal and informal learning environments (e.g. schools and museums) direct learning experiences toward the acquisition of concepts, invoking a metaphor for learning of filling the mind like an empty

vessel. Sometimes museums miss opportunities to enhance perceptual-motor engagement with the physical world, and the inherent potential to exercise perceptual skills, for sensory, aesthetic, and creative enjoyment.

Perceptual-motor engagement may support “bottom-up” abstraction of principles that serve as building blocks for concepts. “Top-down” conceptual knowledge can guide and organize perceptual-motor experience. In this perceptual-conceptual interplay, concrete experiences allow perception of similarities and differences, to differentiate between the features that matter and those that don’t depending on the task, to apprehend individual parts and unified wholes, to know in what category to place an object or action, to take appropriate action to gain relevant information. All these critical skills rely on perceptual-motor engagement, with the structuring guidance of conceptual knowledge.

In some traditional models of learning, physical interactions between body and world are overlooked or explicitly devalued. Formal schools’ elimination of science labs, wood shops, physical education, and arts programs in favor of book learning and lecture formats illustrates a sometimes exclusionary emphasis on conceptual knowledge and a fundamental misunderstanding of how deep learning emanates from interaction. Many schools embrace the value of multimodal interaction with project-based “hands-on” learning, collaborative learning, interdisciplinary studies, community service, field work, etc. Similarly, museums express a range of educational philosophies, even under one roof, from a narrow emphasis on promoting conceptual knowledge to supporting learning in a broad sense, including perceptual-motor, social, affective, and conceptual learning.

This observational research bears directly on educational practice and supports an expanded nuanced view of learning processes that engage whole human bodies embedded in a

cultural matrix. This research challenges approaches to learning that disembodiment minds and deny the cultural medium in which minds grow. To truly promote engagement and learning, our philosophies and practices cannot subjugate the concrete body to the abstract mind, conceiving of them as separate entities, nor elevate conceptual knowledge while devaluing perceptual-motor and social activity. Dynamic interaction between action, perception, and conception creates linkages between ideas and concrete experiences, weaving webs of meaning that derive from making sense with bodies engaged with the world (figure 7. 1).

Through observation of children in a museum, we discover patterns that can teach us how to design environments that serve the needs of young learners. When free to explore a museum, children engage in embodied inquiry, multimodal expressions of meaning, and acts of representation and imagination. They enter the museum with rich biological and cultural endowments that they use in fluid coordination with the material and conceptual resources the museum makes available. In this cognitive ecosystem, children adapt their activity to the museum. How do museums adapt to children's needs, abilities, and patterns of activity? More broadly, how do our educational institutions respond to children's drive to explore their worlds? Integration of action and perception happens with individuals and institutions. As researchers and practitioners, informed by disciplined observation and expanded perceptual repertoires, we can create a broader deeper range of learning resources, responsive and adaptive to children's drive to explore, create and express meaning.



Figure 7.1 Active bodies, minds and imaginations are evident in a child's enactment of an erupting volcano and others' focused attention on actions and interactions among children and exhibits. The children explore cause and effect relations at every opportunity and they express ideas with creative imagination.

References

- Alac, M., Hutchins, E. (2004). I see what you are saying: Action as cognition in fMRI brain mapping practice. *Journal of Cognition and Culture*, 4.3.
- Allen, S., Gutwill, J. (2004). Designing with multiple interactives: Five common pitfalls. *Curator* 47(2): 199-212.
- Ayoub, C. C., & Fischer, K. W. (2006). Developmental pathways and intersections among domains of development. In K. McCartney & D. Phillips (Eds.), *Handbook of Early Child Development*, 62–82. Oxford, U.K.: Blackwell.
- Balcomb, F., Newcombe, N.S., Ferrara, K. (2011). Finding where and saying where: Developmental relationships between place learning and language in the second year. *Journal of Cognition and Development*, Vol. 12, No. 3: 315–331.
- Barsalou, L. (2008). Grounded Cognition. *Annual Review of Psychology*, 59: 617–645.
- Borun, M., Dritsas, J., Johnson, J.I., Peter, N., Wagner, K., Fadigan, K., Jangaard, A., Stroup, E., Wenger, A. (1998). *Family Learning in Museums: The PISEC Perspective*. Philadelphia, PA: The Franklin Institute.
- Carey, S. (2011). The Origin of Concepts: A précis. *Behavioral and Brain Sciences*, 34, 113–167.
- Fuster, J. (1997). Network memory. *Trends in Neuroscience*, Vol. 10, No. 10., 451–459.
- Gentner, D. (2010). Bootstrapping the mind: Analogical processes and symbol systems. *Cognitive Science*, 34: 752–775.
- Gentner, D., Boroditsky, L. (2001). Individuation, relativity and early word learning. In M. Bowerman & S. Levinson (Eds.), *Language Acquisition and Conceptual Development*, 215–256. Cambridge, UK: Cambridge University Press.
- Goldstone, R. L., Day, S. B. (2013). Similarity. In H. Pashler (Ed.) *The Encyclopedia of Mind*. Thousand Oaks, CA.
- Goldstone, R. L. (1998). Perceptual Learning. *Annual Review of Psychology*, 49, 585-612.
- Goldstone, 1998), perceptual expertise (Palmieri & Tarr, 2008; Tanaka, Curran, & Sheinberg, 2005), the disciplining of perception (Stevens & Hall, 1998; Goodwin, 1994), and various forms of media literacy (Lemke, 1998
- Goldstone, R. L., & Day, S. B. (2013). Similarity. In H. Pashler (Ed.) *The Encyclopedia of Mind*. Thousand Oaks, CA: SAGE Reference.
- Goodwin, C. (1994). Professional vision. *American Anthropologist*, 96(3): 606–633.

- Goodwin, C., Goodwin, M.H. (1996). Seeing as a Situated Activity: Formulating Planes. In Yrjö Engeström and David Middleton (Eds.) *Cognition and Communication at Work*, 61–95. Cambridge, MA: Cambridge University Press.
- Hutchins, E. (2005). Material anchors for conceptual blends. *Journal of Pragmatics*, 37: 1555–1577.
- Jacobs, R.A., Shams, L. (2010). Visual learning in multisensory environments. *Topics in Cognitive Science*, 2: 217–225.
- L.S. Vygotsky (1978). *Mind in Society: Development of Higher Psychological Processes*, Edited by M. Cole, V. John-Steiner, S. Scriber, E. Souberman. Cambridge MA: Harvard University Press.
- Lemke, J.L. (1997). Cognition, context, and learning: A Social Semiotic Perspective. In D. Kirshner and Whitson, J. (Eds.) *Situated Cognition Theory: Social, Neurological, and Semiotic Perspectives* Mahwah, NJ: Lawrence Erlbaum Associates.
- Lemke, J. (1998). Multimedia Literacy Demands of the Scientific Curriculum. *Linguistics and Education*. Volume 10, Number 3, 247-271(25)
- Palmeri, T.J., and Tarr, M. (2008). Object recognition and long-term visual memory for objects. In S. Luck & A. Hollingsworth (Eds.), *Visual Memory*. Oxford, UK: Oxford University Press.
- Rosch, E. (1978). Principles of Categorization. In Eleanor Rosch and Barbara B. Lloyd (Eds.), *Cognition and Categorization*, 27-48. Hillsdale, NJ: Lawrence Erlbaum.
- Spaepen, E., Coppola, M., Spelke, E.S., Carey, S.E., Goldin-Meadow, S. (2011). Number without a language model. *PNAS*, Vol. 108, N. 8, 3163–3168.
- Stevens, R. & Hall, R. (1998). Disciplined perception: Learning to see in technoscience, in M. Lampert and M. Blunk (Eds.) *Talking Mathematics in School: Studies of Teaching and Learning*. New York, NY: Cambridge University Press.
- Tanaka, J., Curran, T., Sheinberg, D. (2005). The training and transfer of real-world perceptual expertise. *Psychological Science* 16: 2 (145–151).
- Tyler, L.K., Moss, H.E. (2001). Towards a distributed account of conceptual knowledge. *Trends in Cognitive Sciences*, Vol.5, No.6, 244–252.