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Understanding Student Collaboration in Interdisciplinary Computing Activities

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ABSTRACT

Many students are introduced to computing through its infusion into other school subjects. Advocates argue this approach can deepen learning and broaden who is exposed to computing. In many cases, such interdisciplinary activities are student-driven and collaborative. This requires students to balance multiple learning goals and leverage knowledge across subjects. When working in groups, students must also negotiate this balance with peers based on their collective expertise.

Balance and negotiation, however, are not always easy. This paper presents data from a project to infuse computing into high school statistics using the R programming language. We analyze multiple episodes of video data from two pairs of students as they negotiated (1) the statistics and computing goals of an activity, (2) the knowledge needed to meet those goals, and (3) whose expertise can help achieve those goals. One pair consistently reached agreement along these dimensions, and engaged productively with both subject matter and computing. The other pair did not reach agreement, and struggled to accomplish their tasks. This work provides examples of productive and unproductive interdisciplinary computing collaborations, and contributes tools to study them.

CCS CONCEPTS

•Human-centered computing →Collaborative and social computing design and evaluation methods; Empirical studies in collaborative and social computing; •Social and professional topics →*K-12 education; Computer science education;*

KEYWORDS

Collaborative Learning, Research Methods, Interdisciplinary Curriculum, Computing Education, Computational Thinking

1 INTRODUCTION

In the precollegiate curriculum, students are often exposed to computing through its infusion into other school subjects [3, 12, 18, 24]. A biology class may engage students in building computational models of ecological systems. Or, a statistics class may make use of analysis and visualization libraries in R or Python. There is ongoing debate about whether Computer Science should be introduced as a standalone subject or though an integrative approach [24]. Regardless, interdisciplinary computing has taken root in the precollegiate curriculum, supported by large national initiatives including the National Science Foundation's STEM + Computing Partnerships (STEM+C) program. Given the growth and popularity of infusing computing into other disciplines, it is important to understand whether and how learning unfolds in these contexts.

Advocates of the interdisciplinary approach argue that it can expose a larger diversity of students to computing, since science and mathematics courses are core curricular subjects [31] whereas elective Computer Science courses typically serve students that disproportionately identify as White and male [16]. Additionally, mathematics, the sciences, and nearly every other subject is increasingly computationally-driven [2, 6]. Including computing in these subjects, it is argued, reflects professional practice and presents computing as applicable and relevant to learners' interests [22].

Interdisciplinary computing activities are often done collaboratively in pairs or small groups. This makes sense: as problems increase in scope, and as computation offers new tools to deal with scale and complexity, computing has become a team challenge. Having students work together to solve problems also aligns well with sociocultural perspectives that highlight the criticality of discourse and participation in communities for learning [5, 17]. Collaboration has also been shown to provide career preparation and to facilitate retention [20]. Of particular relevance to Computer Science Education is the spread of paired programming–demonstrating benefits ranging from better learning outcomes to better products [7, 33].

Despite these expected benefits, there is evidence that difficulties and inequities can also emerge from collaborative work [8, 27]. Complex social and ideological factors contribute to these difficulties, including friendship, race, gender, access to educational artifacts, and how students' identities are co-constructed over time within a given educational context [11]. One important factor that affects the success of collaborations is what students interpret to be the goal of a given activity. Collaboration requires students to agree upon and work together toward a shared goal [4], and is strengthened when that goal involves mutual understanding of the content to be learnt. Within the domain of computing, Lewis and Shah found that inequitable dynamics emerged during paired programming activities when students' goals were to complete tasks quickly, rather than to make sense of code [19]. How students negotiated shared goals in the moment are in turn affected by systemic

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and local dynamics involving gender, race/ethnicity, perceptions student competence, discourse norms, and more [1].

The complexity of negotiating activity goals can be further exacerbated students are expected to collaborate on interdisciplinary activities. Students with different levels of computing and subject matter expertise may feel more or less prepared to engage in particular aspects of the activity. Or, they may take a 'divide and conquer' approach that creates boundaries between computing and subject matter content, and limits who has access to computing experiences. Additionally, what students are expected to learn about computing versus what they are expected to learn about the subject matter may be unrelated, or even in tension. For example, a course that brought applied mathematicians and biologists together to create models of ecological systems revealed tensions in goals related to domain - mathematicians sought efficient and computationally viable models, biologists sought ecologically faithful ones [28]. In prior work we have found that students who prioritize creating a working program in R over creating a valid statistical model may engage in shallow computation, without learning benefits [32].

What students understand the goals of an interdisciplinary collaborative activity to be, then, is important. It can affect what students learn, and how they interact with one another. This yields the questions: *How do students understand, and come to agreement about, the goals of interdisciplinary collaborative computing activities? And, how do they work to achieve those goals?*

2 THEORETICAL FRAMEWORK

There have been calls to underpin computing education research with rigorous theoretical frameworks in order to facilitate comparison, generalization, and reproduction of studies [13, 21]. Theory-based analytical tools can also help us answer questions useful for software designers (How do students understand their learning environment?), for educational experience designers (How do students take up computing as authentic or inauthentic?), and for learning scientists (How does having a partner change what kind of cognitive work students are doing during computing activities?). Here, we begin by reviewing theoretical literature on *framing*, *perspectival framing*, and *framing alignment*. These constructs provide tools to understand how different people perceive tasks, how those perceptions affect their knowledge and sense of competence, and they come to agreement about those perceptions.

2.1 Framing

Framing explores how people answer the question 'What is going on here?' as they participate in a social activity. Frames are constructed based upon situational cues, and shape what a person pays attention to and how they make sense of things. If a student is told to "think of variables" in a mathematics class, they may think of a letter used to represent a set of numbers that satisfy certain constraints ($x > 3$). If they are in a computing class, they may think about a way to label and store data (`myData = []`). Frames are context dependent, and small changes to a situation may change what students perceive or expect. For example, if a student in a computing class is told to "think of variables" while struggling with a programming task, they may interpret this to mean that there is an error in how they are declaring and setting variables in their program. But if they are told to "think of variables" at the beginning of a new unit, they may expect to be introduced to a new data type. In this way, frames are "structured expectations formed from previous experiences...active and responsive, perpetually evolving as they are informed, shaped and tuned with new experiences" [23, p.47].

Frames are not correct or incorrect, nor are they correctly or incorrectly applied. Different frames foreground different aspects of a situation, and may be more or less useful. Typically, when people find a frame is not useful, they will replace it. For example, one might initially sit down at a restaurant, expecting to have their order taken. If a server does not appear, that person may start looking for a cashier or counter instead [29]. Framing affects what knowledge (e.g., pieces of knowledge and connected knowledge structures; [10]) people believe will be relevant in a given situation [14]. It also affects how notions of competence are constructed in learning environments and beyond, with implications for equity and access to learning opportunity [15].

2.2 Perspectival Framing

Van de Sande and Greeno's notion of *perspectival framing* emphasizes that frames are likely to differ across people as a result of the different sets of knowledge and schemata they hold, based on their individual experiences and perspectives [30]. It contributes analytic tools to highlight how an individual's framing of a situation influences what knowledge they bring to bear, and how they perceive themselves and others. The authors identify three dimensions of perspectival framing: epistemological, conceptual, and positional.

Epistemological framing is "participants' understanding of kinds of knowledge that are relevant for use in their activity and the kinds of knowledge, understanding, and information they need to construct to succeed in their activity" [30, p.2] (see also [14]). A student's epistemological framing answers the question 'What is my goal for this activity?' In interdisciplinary computing activities, it is assumed that students will recognize subject-specific, computing, and even other related knowledge as relevant.

Conceptual framing is "the way or ways in which participants organize information in the situation they are discussing and the problem they are working on" [30, p.2]. Given how they frame a situation, a person will have a set of expectations about a situation that will cause them to foreground and background different knowledge resources. A student's conceptual framing answers the question 'What do I already know that can help me accomplish my goal?' In interdisciplinary activities, it is taken for granted that students will both have (or build) and leverage their subject-specific and computing knowledge.

Positional framing refers to the way participants understand everyone's role in a situation. Positional framing "includes a human participant who is inquiring, which we call a listener, and a source, which may be another human participant or a non-human system" [30, p.1]. The role of listener is fluid; the listener can be a simple recipient, a director of "the interaction, actively questioning the source," or a role taken up "actively and jointly by more than one participant acting collaboratively" [30, p.40]. In interdisciplinary computing activities, it is assumed that learners will share the roles of source and active listener, each contributing to conversation and asking for elaboration as needed.

All three of these types of framing are interrelated. The knowledge a student leverages for an activity (conceptual framing) depends on what knowledge that student thinks is relevant to accomplish their goals (epistemological framing). Knowledge changes for a listener as they receive information and restructure their understanding accordingly, and may change for a source as they adapt the information they are communicating to the listener's needs. And, the position of listener and source (positional framing), or the information that each seeks and provides, may change as participants recognize different goals or knowledge to be at play.

2.3 Framing Alignment

Van de Sande and Greeno emphasize that perspectival framing is rooted in individual perspectives. People may have different expectations for what is going on, different sets of knowledge that they may or may not leverage, and different understandings about who should be the source or listener during an activity. Thus it is unlikely groups will automatically agree in their framing of a collaborative interdisciplinary task.

Framing alignment is defined as a way for participants to co-construct framings of a situation. If two students are employing contradicting frames, they will reach a moment of conflict that they will then try to resolve. For example, if one student frames an assignment as an occasion to demonstrate knowledge and another student frames the task as a chance to check for understanding of previously learned concepts, one student might want to work quickly while the other may wish to take time and review why they got a particular answer. In order for this group to make progress, one or both of the students will need to shift their frame to align with the other student. When their frames align, the conflict resolves, signaling mutual understanding.

Framing alignment has been explored in other work. Scherr and Hammer [26] explored framing in a collaborative educational setting through analysis of student behaviors including vocal register, gestures, and body language. They identified four clusters of behavior they argued indicated different shared framings of educational activities: (1) completing worksheets, (2) discussion, (3) responding to the Teaching Assistant, and (4) joking. For example, completing worksheets was characterized by students with their heads down, writing. Discussion was characterized by students' heads up, shifting gaze to one another and activity materials.

The analysis revealed that individual students would often make bids to move the group from one frame to another through body position. For example, when a student was done working on a worksheet problem, they might sit up, ready to discuss. If after a few moments no member joined them in the new proposed frame, the student would typically revert back to completing worksheets. This demonstrates that students often work to negotiate shared frames during collaborative activities, and that such negotiation is not always straightforward.

Van de Sande and Greeno tracked framing over time to explore how students in a group reached alignment through talk [30]. They presented three ways that participants' conceptual framings can be aligned: (1) participants possess and activate knowledge structures that are well-aligned, (2) the listener lacks pre-existing knowledge consistent with the source and therefore uses information from the source to construct a new knowledge structure, or (3) both participants lack pre-existing schemata, and switch roles as listener and the source to jointly construct new knowledge structures. These processes have different levels of complexity in terms of the work that is required, and the learning that is achieved. An activity that requires students to activate the same pre-existing schema, like something previously learned in class, is likely to be less complex and produce less new knowledge than one where students need to jointly construct a new conceptual frame.

Positional framing alignment is likely negotiated in interaction. For example, a student might take up the role of source by stating an answer. Their peer may respond in a way that accepts role of listener (for instance, by asking for clarification about the answer provided), or by making a bid for the source position (by critiquing the answer provided). The latter represents a misalignment of positional framings; this misalignment would be renegotiated or resolved by future interactions between the students and other materials or people involved in the activity. For example, students may achieve realignment of positional framing by agreeing to consult a textbook, positioning both of themselves as listeners relative to a material informational source.

3 METHODS

Our goal in this paper is to understand students' perspectival framings of interdisciplinary collaborative activities, and how those framings come into alignment. We are interested in what students understand (1) the activity to be, (2) what knowledge they need or have for the activity, and (3) how to acquire or share that knowledge.

3.1 CodeR4STATS and Computing in Statistics

We explore this process in the context of an NSF-funded research project called CodeR4STATS (IIS-1418163), which seeks to transform high school statistics through activities that employ the R statistical programming language to work with large and authentic datasets. Rather than just replacing the graphing calculators typically employed in Statistics classes, R is used to infuse concepts that have been identified as central to computing such as automation, abstraction, modeling, data and analysis, and social dimensions of computing [3, 9] into statistical exploration. For example, one activity involves measuring and documenting the lengths and widths of leaves from two different trees, and then constructing fit models to examine patterns within and across samples. Another involves investigating university admissions reports, and developing an algorithm to help make college admissions decisions for a large, hypothetical set of applicant records.

3.2 Study Context and Case Selection

Our data are drawn from a non-AP statistics class participating in the CodeR4STATS project at a selective public high school in New England. The teacher of this class is a designer of the CodeR4STATS materials, and was accustomed to teaching with R. Over the course of the school year, we captured classroom data daily during periods of time when students were working intensively with R. Two authors of this paper were present during data collection. We captured video and audio of consented students using small video cameras mounted on computer monitors, as well as synchronized video recordings of those student's on-screen activity.

We focus on two pairs of students in this class during a month-long unit about linear and nonlinear regression toward the beginning of the academic year. For these activities students were expected to submit their assignments individually, but encouraged to work collaboratively (including collecting and analyzing shared data). Over the course of the data collection period, these four students often worked together. However, the two pairs were strong sub-units with very different collaborative dynamics. Each focal pair included one student that identified as male, and one that identified as female. These students were not representative of the class as a whole in terms of their collaborative dynamics, class performance, or demographics. Our selection of these cases thus reflected an information-seeking rather than representative sampling method. That is, we selected these two groups because of the dramatic contrast in their interactions, which influenced the ways in which each pair worked to understand one another and their success on group projects.

3.3 Analysis

After the school year was over, video was organized and tagged by one of the researchers present during classroom activities. The data for these two groups, identified in field notes as interesting because of their contrasting collaboration dynamics, were selected for further analysis. A summary of these groups' dynamics over the course of the year was constructed, and several specific video cases representing critical or representative events were extracted and transcribed. This method is particularly well-suited for dense video data collected over long periods of time to study the development of ideas and norms in classroom contexts [25]. These summary analyses and video cases were then shared with a third researcher who was not present during data collection, for triangulation. Analyses were further elaborated through repeated watching and shared viewing, to enhance the validity and clarity of findings.

4 RESULTS

We present episodes from two activities the pairs completed during the curricular unit. In the first set of episodes, the intended emphasis of the activity was a statistical content goal, correlation. In the second set of episodes, the intended emphasis was a computational goal, learning to build plots in R. Transcript excerpts are presented chronologically, and within each set, each group's transcript is from the same day and is using the same activity materials.

4.1 Statistics

As students learned R, the teacher had them engage with familiar statistics concepts. Both groups in the following transcripts discussed the concept of correlation. But while one group engages in a productive debate, the other group's dynamics shut down discussion after one student asks the other to clarify what he is doing.

4.1.1 Group 1: Dan and Mary. The first episode we present demonstrates what we identify as productive pair dynamics, in which students co-construct understandings through discussion during the activity. This pair's excerpt begins with a researcher/facilitator (R) prompting Dan to reflect on the meaning of a correlation he has calculated on the computer. When Dan makes a claim about correlation, Mary quickly begins to challenge him.

1 **R** So what did you learn now that you've plotted it?
2 **Dan** That increase in manatee death is correlated to powerboat registrations?
3 **R** Is that surprising in any way shape or form?
4 **Dan** I mean I could see- I could see the amount of [inflation?] contributing to the amount of like cows being born but that didn't mean anything. Like, it's two variables that correlate but there is no evidence besides numbers. I could throw numbers at you and I could prove anything.

The researcher asked questions they did not know the answer to, in an effort to position themselves as a listener and counteract their intrinsic authority. Dan raises the difference between correlation and causation, emphatically illustrating that they are not equivalent by saying if they were he could "prove anything". With this idea on the conversational floor, Mary moves to engage with the conceptual content of Dan's claim.

5 **Mary** Well if they're wrong numbers, yeah. But right numbers I mean typically -
6 **Dan** I'm saying they're right numbers but they could be two unrelated things
7 **Mary** So it's unrelated that the boats that kill all the manatees and if they're more boats there are more manatees dying?
8 **Dan** No, it's not that -
9 **Mary** It's unrelated?
10 **Dan** It's registration.

Mary challenges Dan's claim, using other information she has about the situation under investigation to assert that the correlation in this case does imply causation. Both Mary and Dan interrupt one another (lines 6,9) during the conversational back and forth. Throughout the exchange, they are listening to and engaging in one another's ideas, rather than attacking or talking past one another.

11 **Mary** And if its registered it's like a car, if it's registered it's there
12 **Dan** yeah
13 **Mary** If you are using your boat-
14 **Dan** You're not listening to me. I am saying that you can have increase in manatee deaths. You could also have an increase in power boat registrations. That doesn't mean that every single power boat going out there is mowing them down
15 **Mary** I'm not saying every single one but this is specifically killed by boats in Florida
16 **Dan** oh
17 **Mary** It literally says in the paragraph. Killed by boats, so you're wrong
18 **Dan** Leave me alone. God.

Although Dan claims at one point that Mary is not listening (line 14), there is evidence that both students are listening to one another and adjusting their own conceptual understandings accordingly. Mary works to make clear to Dan what evidence in the text supports her argument. Once this is presented, Dan finds it convincing, accepts it, and tries to end the conversation. In this way, both students switch back and forth as they negotiating for the position as knowledgeable. At this point, the researcher intervenes, asking a clarifying question about Mary's evidence.

19 R Specifically powerboats?
20 Dan Yeah!
21 R Maybe they are sitting there in a row boat just like clubbing manatees with an oar
22 Dan Yeah. How do you like them apples?
23 R It would be interesting to know like maybe one boat is sitting there doing donuts where there is a lot of them. And maybe that is killing them?

The researcher's effort to present an unlikely edge case disrupts the apparent stability between Dan and Mary. It positions Mary as less knowledgeable, and introduces a new argument in support of Dan's conceptual claim. Dan agrees with the researcher socially, affirming the claim.

24 Mary See if that's the case then that doesn't explain how or why like the increase in power boat registrations-
25 Dan It could really be that one guy who's always killing manatees but goes to where the manatees are and just doing donuts trying to run them over

Mary engages conceptually with Dan and the Researchers' newly presented line of argument, but gets interrupted as Dan takes up and engages conceptually with the edge case. In response to this, Cameron, another member of the group of four focal students who is sitting on the other side of Dan, joins the conversation.

26 Cameron Anywhere where there are actually known manatees there is like a no wake zone. So it's like literally [inaudible]
27 Mary Yeah, they're endangered so they try to preserve them

Cameron's contribution reorients the focus of the discussion away from unlikely edge cases back to real world knowledge. Mary supports Cameron's line of argument, and Dan yields the floor, ending the debate and implicitly accepting Mary's argument.

Employing the notion of perspectival framing allows us to understand the complex dynamics at play during this exchange. The conversation illustrates a negotiation between Dan, Mary, and other interlocutors around the *epistemological framing* of the activity. Dan starts the conversation by making a general proposition about statistics – that correlation does not represent causation (lines 4, 6). Mary re-orients the conversation to focus on the specific textbook problem they are working on (lines 15, 17), which provides additional contextual information that supports a causal interpretation. There are moments, however, where real world knowledge is also included as relevant in the discussion - including unlikely edge cases and known laws (lines 23, 26, 27). Thus throughout the conversation, both students understand the goal of the activity to be reasoning about statistical correlation; and co-construct an understand of what evidence can be used to inform such reasoning.

Between Dan and Mary we see two distinct *conceptual framings*. Dan maintains through the discussion that correlation does not imply causation - on multiple occasions expressing that the two variables are not necessarily related (lines 4, 6, 14, 25). In this way, Dan is leveraging general notions of statistical correlation as his conceptual focus. Mary's conceptual focus, on the other hand, is tied to the specific context of the problem: the negative impact of powerboats on the manatee population. Thus Mary is not appealing to change Dan's general idea that correlation means causation, but rather an effort to re-negotiate the epistemological framing of the activity to recognize that *in this case* it does. These different conceptual framings, Dan's application of general statistical concepts and Mary's application of knowledge about the problem at hand, remain opposed throughout the discussion.

Finally, throughout the discussion, both Dan and Mary adopt the position of both 'source' and 'active listener'. There is evidence throughout the conversation that both Dan and Mary are substantively engaging with one another's ideas, and adjusting their own arguments and interpretations of the situation in response. In this way, we posit that the two students share a relatively balanced *positional framing*.

4.1.2 Group 2: Ann and Cameron. The second episode demonstrates what we identify as unproductive pair dynamics. The excerpt below begins shortly after Cameron had physically taken over Ann's keyboard, after she asked for help identifying errors in her R code.

1 Cameron Let's make some magic happen. I'm going to eventually do this too so.
2 Cameron Model
3 Ann What's abline do?
4 Cameron It means your mom. That's what that means. You don't have like commas anywhere. You don't even have parenthesis around the fucking word. That's not where the parenthesis is.

Here, Cameron begins as the source of knowledge, since he was allowed to take Ann's keyboard. Ann reinforces this position by asking a question about abline (a function in R that adds a trendline to a scatterplot, from which students could extract a calculated correlation coefficient). However, Cameron does not conceptually engage with Ann's question, instead replying "your mom" before chastising her for lack of syntax. While Cameron does address some of Ann's mistakes in the code, the issues he brings up are syntactic and do not relate to Ann's question or the statistics content that is the focus of the lesson.

5 Cameron I can't - why is your shift bar messed up?
6 Cameron You can't use the shift bar? That's stupid
7 Ann It's not working
8 Cameron Okay, that's not-no-you need parentheses
9 Ann That is a parentheses
10 Cameron I mean you need quotation marks
11 Ann Oh
12 Cameron Like that. Alright, umm... comma, okay it's going to assume [inaudible]
13 Cameron I don't know why you put that there

Even when Ann corrects Cameron, he asserts his position as source and treats Ann as listener. Despite these dynamics, Ann is an 'active listener' and tries to direct the conversation toward parts of the code that are related to the statistical content of the lesson.

14 Ann What's lty mean?
15 Cameron It's like the line thingy ma do

16 **Cameron** Yeah, that shit. Um... is your thing good? Is that all you have? so far?
17 **Cameron** I'm going to use more hashtag signs. Hashtag correlation. I misspelled correlation for you.
18 **Cameron** Correlation. Marine corps parenthesis, next we have y.

This time, Ann asked about lty, a way of setting the type of line that will appear on the plot (visually illustrating the correlation between variables plotted on the axes). Cameron again does not take up her question, instead stating aloud the characters her is typing without evident explanation.

19 **Cameron** And then we do it again.
20 **Ann** Why?
21 **Cameron** Because you gotta do it again
22 **Ann** Why, is there like a-?
23 **Cameron** I don't know you gotta tell it to run multiple times. For accuracy. It's like we have to tell it to run [inaudible]
24 **Cameron** But that is all now cuz this is cheese.

Finally, Cameron states that the correlation has to be calculated a second time (line 19). Ann, who has been positioned as listener throughout the exchange and whose questions about statistically relevant parts of the code had not been answered, asks why the calculation needs to be repeated (lines 20, 22). Ann's question is especially important - there is no reason that the correlation needs to be recalculated, and Cameron's repetition suggests a misunderstanding of either correlation as a statistical concept, or the way in which correlation is calculated in R. Cameron offers a noncommittal response and then explicitly ends the conversation (line 24).

Throughout this episode, we see evidence that Ann and Cameron hold very different *epistemological framings* of the activity. Cameron's comments suggest he is most concerned with getting the R code to work quickly. He comments on to syntactical errors in the code, and when prompted to explain the purpose of different functions he either ignores them or responds noncommitally in ways that suggest he does not think such explanations are important (lines 4, 10, 15, 26). Although Ann does not speak much, when she does she is asking questions about the R code Cameron is writing that is most related to the statistical content that is the focus of the lesson (lines 3, 14, 20, 22). This suggests that Ann is framing the activity as an opportunity to learn about connections between correlation as a statistical concept and the R language.

These epistemological framings lead each student to a different *conceptual framing*. Cameron, who is concerned with getting a working program, talks mostly about syntax and does not leverage statistical knowledge or conceptual code-based knowledge in his explanations. Ann, who is concerned about understanding the code in relation to the statistics concepts, seeks such knowledge. She also demonstrates her own conceptual understanding of correlation in questioning an error in Cameron's approach (lines 20, 22).

The *positional framing* of the two students stays constant throughout the transcript. Cameron is positioned as the source, and Ann is positioned as the listener. While Ann plays an active listener, reading over Cameron's shoulder and asking questions, her bids for information are not taken up seriously.

4.2 Computing

The first set of exchanges we presented occurred during an activity that focused on correlation as a statistical learning goal. Similar dynamics were observed when students worked on activities focused on computing learning goals, as well. In the following two episodes, we present data from both groups working on an activity involving creating visualizations in R.

4.2.1 Group 1: Dan and Mary. This excerpt begins as Dan trying to move the plot he created in R to a googleDoc he will submit for a grade. He asks Mary for help, and she points out that his plot is lacking axis labels.

1 **Dan** Wait, how do you do it? Can I just drag the photo?
2 **Mary** What?
3 **Dan** What is it doing?
4 **Mary** What are you doing? Let go
5 **Dan** That's cool
6 **Mary** What are you trying to do? Label it?
7 **Dan** No, I'm -
8 **Mary** No, you have to label it first anyways. You have to put the main title, and the ylab and xlab. The teacher literally just said that.

Mary re-negotiates Dan's goal in this moment by pointing out he missed a step. She tells Dan the commands without other support.

9 **Dan** How?
10 **Cameron** It doesn't do it when you-
11 **Mary** Yeah it does. You put it under plot x y. Right here. Plot x y Your main is your title, xlab is the name for your x, ylab is the label for your y, then the color of the points, and then you do the abline.
12 **Dan** Calm down
13 **Mary** It's the exact same way if you were going to plot anything and then you just tell it all the stuff that you want
14 **Dan** It never worked but okay

Dan asks how to add the labels (line 4), while Cameron claims the method they have been taught does not work (line 5). Mary provides an explanation by describing the optional parameters available for the plotting method they are using, which take strings for the x and y axis (xlab, ylab). When Dan is reluctant (line 7; hesitation to type into his workspace), Mary adjusts her explanation to a level of abstraction that better connects with Dan's existing conceptual understanding (line 8). She notes that it is "the same way if you were going to plot anything", relating to Dan's construction of graphs in past assignments. Dan takes this up and adds the labels to the method call, which then generates a labeled graph.

15 **Dan** Mary can't tell time
16 **Mary** That's fine you can do that

As soon as Dan's graph appears, he teases Mary, whose reaction times on a physical test comprised the dataset.

At the beginning of this episode, we see explicit efforts on Mary's part to understand and align herself to Dan's *epistemological framing*; that is, what his goal is in that moment. She repeatedly prompts him (lines 2, 4, 6) to tell her what problem he is trying to solve. Once she figures out that he is trying to export his plot, she then works to re-orient what he is doing (line 8). We do not see this kind of explicit alignment work in their first episode, where Dan and Mary had a shared epistemological frame (sensemaking). We also do not see this kind of work done by Ann and Cameron, even though there is considerable evidence that their epistemological framings are not aligned.

Having established the mutual goal of adding labels to the plot, Mary explains in greater and greater detail how to do so (lines 8, 11, 13). It is clear that in her *conceptual framing* she understands the idea of method parameters. However, she adjusts these explanations to Dan's needs, first elaborating how labels should be added (line 11) and then connecting the process to what she knows to be Dan's prior experiences (line 13). While there was not as much explicit engagement in each other's conceptual ideas as in the first episode, the episode illustrates that both students have productive computing resources that can be leveraged to help them accomplish what is now their shared goal. We also see Mary not only provide computational code, but also explain that code and connect it to other instances to help Dan situate his knowledge.

Throughout this episode, it is evident that the pair have a shared *positional framing* where Mary is the source and Dan is the listener. Dan is an active listener, asking questions. Mary performs secondary listening and does explicit work to make sure the group aligns both their epistemological and conceptual framings over the course of the exchange.

4.2.2 Group 2: Ann and Cameron. The other group starts a similar way, with one student asking the other for help.

1 Ann How do you get the x and y?
2 Cameron xlab. x
3 Ann xlab equals?
4 Cameron Whatever you want your thing to be then ylab. Think of it as abbreviations for things. X label. Y label. Main title. Scatter plot.

It is unclear at the beginning of this episode what each student's epistemological framing is, and they do not explicitly work to understand or align with one another. It may be that the goals of one or both of the pair are to get these specific labels to show up in the plot, or to understand in more detail how the method works. It is also unclear what Ann is asking of Cameron in line 3. Cameron engages conceptually with Ann's question in a way that may or may not be aligned with her goals, noting that method parameters such as xlab and ylab can be thought of as abbreviations for English language descriptions such as "X label".

5 Ann x lab equals... y lab equals....
6 Ann What is the y again?
7 Cameron Hold on
8 Ann What was the y?
9 Cameron Hold on. You don't have to do the same thing as me. It's an individual project. It's the cheese. So do I get rid of the stupid box now?
10 Ann It said unexpected - it's saying it doesn't work. It's not working

Ann asks what the y label should be, indicating a possible gap in her knowledge about this plot or what it is meant to represent. Cameron begins to reject his position of source, by reminding Ann that they do not have to do the same thing despite using a shared data set. In another bid for help, Ann reads aloud the error that her code is producing.

11 Cameron Oh my god, you have to put commas at the end of things.
12 Ann Where? This? This?
13 Cameron No.
14 Ann Where?
15 Cameron Ask one of the teachers. It's beyond my control now

Cameron identifies a syntactical error in Ann's code unrelated to her earlier conceptual questions. He does not provide enough information for her to fix the error he identified easily, and Ann asks where he is seeing the syntactical error. Cameron again rejects the position of source, redirecting Ann to seek help from others.

Looking at this entire episode, it appears as though Ann and Cameron seem to share an *epistemological framing*. Both are trying to get code to work (lines 1, 10, 11).

In terms of *conceptual framing*, Cameron seems to be leveraging more knowledge related to the shared goal of getting the code to work. At the beginning of the excerpt, he even engages conceptually with Ann's question, providing a way to make sense of the connection between parameters and their meanings (line 4). However, there is little explicit negotiation of conceptual framing between the two students, and the explanation that Cameron provides proves insufficient for helping Ann make progress.

Ann and Cameron's *positional framing* begins as shared, with Cameron as source and Ann as listener. However, Cameron ultimately rejects the position of source (lines 9, 15).

5 DISCUSSION

We present a brief summary of our analysis in Table 1. Together, the episodes illustrate the utility of perspectival framing for providing multidimensional insight into collaborative dynamics. Examining one dimension alone would not have been sufficient for describing these groups and their work outcomes. For example, Episodes 4.1.2 and 4.2.1 both present cases in which group members did not initially hold a shared epistemological frame. Dan and Mary, however, negotiated and ultimately aligned their framing while Ann and Cameron did not, instead "talking past" one another. Episodes 4.1.1 and 4.2.2 demonstrate instances in which each pair held aligned epistemological frames, but only one of these episodes featured productive exchange. Similarly, the productivity of a group was not predicted only by alignment of positional framing.

The episodes also demonstrate that productive group work is not necessarily predicted by full alignment across *all* frames, but rather the acknowledgement and negotiation thereof. In both of Dan and Mary's cases, the initial misalignment of conceptual and (in the second case) epistemological frames provoked productive discussion. Misalignment of more than one frame, however, especially without acknowledgement is a good predictor of unproductive collaborations. When Ann and Cameron lacked a common epistemological frame, they spoke past one another; Ann's conceptual questions were not answered and Cameron did not take up the opportunity to interrogate his statistical understandings. Even when they shared

Table 1: Summary of Framing Dimensions Over Four Cases

Episode	Epistemological	Conceptual	Positional
4.1.1 (Statistics) Dan and Mary	ALIGNED Reason about statistical correlation found in data	CONFLICT M: Correlation provide evidence of a causal relationship D: Statistical correlation does not imply causation	ALIGNED Alternating source and listener
4.2.1 (Computing) Dan and Mary	NEGOTIATED Learn plotting methods in R.	NEGOTIATED M: Knowledgeable about R plotting methods D: Constructing knowledge about R plotting methods	ALIGNED D: Listener M: Source
4.1.2 (Statistics) Ann and Cameron	CONFLICT A: Learn relationship b/t R methods and correlation C: Produce workable code	CONFLICT A: Knowledgeable about statistical correlation C: Knowledgeable about R Syntax	ALIGNED A: Listener C: Source
4.2.2 (Computing) Ann and Cameron	ALIGNED Produce workable code	CONFLICT A: Needs knowledge about R Syntax C: Knowledgeable about R Syntax	CONFLICT A: Listener C: Rejects role as Source

and epistemological frame, their lack of alignment along other dimensions – conceptually, without an effort to understand one another's knowledge, and positionally, as Cameron refused to help Ann, led to a lack of progress.

We are careful to note that of the episodes presented in this paper, only one includes clear evidence of new learning and improved work outcomes, Episode 4.2.1. This is the episode in which Mary helped Dan label his plot, connecting the method to Dan's prior successes constructing plots with other R methods. However, we still understand Episode 4.1.1 as productive insofar as students engaged in reasoned argumentation. We also tentatively highlight an apparent crystalization of perspectival framings over time. Whereas Dan and Mary seem to develop facility in negotiating and aligning frames from one activity to the next, Ann and Cameron's framings (producing working code, Ann as passive listener) continue.

Our findings suggest additional detail is needed about positional framings, beyond mere alignment. Across the episodes, students navigated position in different and consequential ways. In Episode 4.2.1, Mary and Dan's positions as source and listener paralleled those of Cameron and Ann in Episode 4.1.2. However, Mary and Dan treated one another as sources of knowledge, and substantively engaged with conceptual content of one another's talk (even when their conceptual framings were different). Indeed, in Episode 4.1.1, they maintained their relative positionality even as the Researcher, an adult in a position of authority, offered further evidence in support of Dan's claim. In contrast, Cameron actively maintained the role of source but mostly rejected Ann's contributions.

Secondary listening, where a source also takes up a temporary listener role to understand the primary listener's conceptual framing, can help here. This distinction plays out when the sources attempt to help their listeners with computing (Section 4.2). Mary adjusts her explanation of x and y labels to a more conceptual level after realizing that she needed to better situate her advice to Dan. In contrast, Cameron did not react to Ann's bids for more conceptually rich computing help. In this way, attending to secondary listening can reveal mechanisms by which students recognize one another's frames, and thus have opportunities to negotiate and align them.

5.1 Limitations and Future Work

This paper reflects a preliminary effort to analyze collaborative interdisciplinary computing in an educational setting, and is limited in some important ways. Our analysis relies on video of student interactions during R-intensive activities. The collaborative group dynamics observed here may have been consequentially shaped by events not included in our data. Findings would be strengthened by first-hand reports or interviews with students. The analysis reported here is part of a larger effort to explore how collaborative unfold across different groups during interdisciplinary computing activities over the course of a school year. We may find evidence to challenge the findings presented as work continues.

6 CONCLUSION

To understand how students learn computing in interdisciplinary projects, it important to consider what they perceive their goals to be for a given activity. Given that most such activities are collaborative, it is also important to consider whether and how students align their understandings to make joint progress. Interdisciplinary computing curricula often take for granted the strength of conceptual connections between computing and disciplinary learning goals, but those connections may not always be evident to students.

This paper demonstrates the utility of perspectival framing analysis to explore how student groups navigate what they expect to do, learn, and contribute during such activities. It also contributes detailed, concrete examples of how such dynamics unfold across time and task. Understanding student positioning during collaborative work is especially critical for understanding equity and access in computing education as it unfolds alongside other contextual factors (e.g. [15, 19]). Such an approach is especially useful given the interdisciplinary expectations of computing-infused curricula.

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