Meaning-Making in Collaborative Activity: Effort toward Coherent, but Not Shared, Interpretations of the Problem

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Abstract: In this paper we report results from a first iteration of design-based research project exploring the potential of classroom networks of handheld tablets (iPads) to support collaborative reasoning in physics. This paper examines the interpretive acts performed in the collaborative discourse of a group of physics students as enactments of personal understandings, with the goal of understanding how distinct interpretations arise and are elaborated and negotiated by collaborative groups. Specifically we focus on a case in which 'incompatible' interpretations arise, and argue that the group makes efforts after coherent, but not necessarily shared, interpretations.

Keywords: interpretation, classroom networks, handhelds, design-based research, physics

Introduction

CSCL is centrally concerned with intersubjective meaning-making: the processes by which groups of learners construct shared meaning (Suthers, 2006). Still there are various views on the relationship between individual and group meaning-making processes, and individual and group learning. Particularly, this paper looks closely at the role of individual *interpretation* of the meaning constructed in face-to-face collaborative settings. Interpretation has been conceptualized several ways in the CSCL literature. Suthers (2006) focuses on the actions that constitute interpretation—interpretations are enacted in verbal utterances, gestures, manipulations of artifacts; by acting, learners make their interpretations visible, both to their group members and to researchers. Producing an interpretation adds to the available artifacts to interpret, changing the meaning-making landscape from which the other students can form interpretations. In this way, individual contributions take up and build on one another dynamically. On the other hand, interpretations have been conceptualized as personal pre-understandings (Stahl, 2003)—specific to each student, dependent on their prior knowledge and experience—which become problematized, elaborated, and modified during group activity. Meaning is constructed in interaction, however, and exists in the interpersonal space. In this view, learners have (tacit or explicit) interpretations of collaboratively constructed, *shared* meaning. The distinction between interpretation and interpretive acts might be useful in distinguishing these views; interpretation being a personal understanding associated with an individual, and interpretive acts being the ways in which those understandings are enacted in group discourse and made visible to the group and to researchers.

Roschelle (1992) found that individuals working in groups tend to converge on a shared conception of a problem; later work conceptualized collaborative learning as the result of efforts made to maintain such a joint conception (Roschelle & Teasley, 1995). The view of interpretive acts as each building on and modifying one another lends itself to a 'gradual changes' view of the evolution of a joint problem conception. However, it is difficult to use such a lens to understand the collaborative processes behind the major, paradigmatic shifts of interpretation and understanding that are sometimes necessary to solve and understand a complex problem. This paper seeks to examine the interpretive acts performed in collaborative discourse as enactments of particular personal understandings, with the goal of understanding how distinct interpretations arise and are elaborated and negotiated by collaborative groups. Specifically we focus on a case in which 'incompatible' interpretations arise and must be reconciled.

Learning environment design

We locate this design work relative to two distinct axes of prior research. Research in collaborative learning indicates that tasks are likely to be most effective when they are sufficiently open-ended and complex to necessitate contributions from each member (Cohen, 1994), and when participants engage the task and one another in ways that sustain that variety of contributions (Barron, 2003). Relative to this axis, networked handhelds can facilitate greater communication, coordination and negotiation among peers (Zurita & Nussbaum, 2004), and expand and enrich avenues for active participation in joint problem-solving activity (White & Pea, 2011). Along an axis of research more focused on the individual learner, simulations and interactive multimedia can be engaging and assist in complex visualization (Adams et al, 2008); contemporary personal devices such as tablet PCs offer the potential to further enrich those supports through more continual mobile access and intuitive, touch-based interfaces. One aim of this project is to design technology-supported activities that synergistically draw on both the individual and collaborative offerings of networked handhelds.

Technology
Our learning environment is designed to support groups of undergraduate physics students in making sense of the physics of mechanical waves. Each student is given an iPad Air running our iOS application: an interactive simulation of many independent mass-spring oscillators set at equal intervals along the horizontal axis. The oscillators' vertical motion is animated on each iPad when the student pushes a "play" button; the oscillators are returned to their initial positions when the student stops the simulation with a "pause" button. The initial position and direction of each oscillator can be adjusted using an interactive "unit circle" tool, a representation of the unit circle with angle markings at intervals of $\pi/16$. To adjust the position and direction of a selected oscillator, the student drags a point around the circumference of the unit circle to the corresponding phase angle.

When the phases of the oscillators are set at regular intervals, the oscillators will together form a travelling wave, the wavelength and direction depending on the phase interval between adjacent oscillators. The direction of the wave is determined by whether the phase is increasing or decreasing as you move along the x-axis. Each iPad connects to a local server that assigns each student in a group control over a subset of the oscillators. When one student makes changes to the position or direction of one of his or her oscillators, the app messages the server, which then communicates those changes to the rest of the group. When each student reruns the simulation on her own device, the initial oscillator positions are updated. Thus, in order to build a wave together, the students must coordinate the phases of their individual oscillators.

Task design
Our design is intended to encourage student interactions around concepts related to mechanical waves and wave motion. Specifically, we intend the activity to occasion talk about the concepts of phase, relative phase and phase intervals, and how these relate to observable aspects of wave phenomena such as wavelength and wave direction. In order to build a wave, the students must coordinate the phases of their individual oscillators, and performing this coordination will likely require students to take up the concept of phase, and its representation on the unit circle, as meaningful and useful to the wave-building task. Students were given worksheets with task directions. The task progression was to: 1) build a wave with a wavelength of 16 units, 2) build a wave with a wavelength of 8 units, and 3) build a wave with a wavelength of 8 units, but moving in the opposite direction.

Methods

Context and participants
The Physics 7 series at University of California, Davis is a three-quarter introductory Physics sequence for biological science majors. The sequence is unusual in that Physics 7 students spend 5 hours per week in a hybrid Discussion/Laboratory, and only about an hour per week in a traditional lecture. The goal of these Discussion/Laboratory sections is for students to engage in high-level conceptual reasoning about physics concepts, in what the course designers call "active sense-making" (Potter, 2012). Two main instructional strategies serve that goal: small group collaboration, and a focus on a small number of conceptual models. Nearly all class work is done in a face-to-face setting in groups of four to six. Additionally, the course content is structured around a relatively small set of physics models designed to focus the students' attention on the "big ideas" of Physics. In these Discussion/Lab sections students work through problems, discuss, argue, explain and make sense of physics problems. A typical class session has small groups working through conceptual reasoning activities, each group presenting their results on a shared whiteboard, followed by a whole-class discussion of the results led by the graduate teaching assistant.

Our classroom implementation of the Making Waves activity was conducted in the final course of the CLASP series, during the first two consecutive, three-hour discussion/lab sessions at the beginning of the quarter. These first two class sessions are devoted to oscillatory motion and waves. For our intervention sections, we replaced an activity in which students primarily produced and reasoned with graphical representations of waves with modified worksheets with the Making Waves task prompts. We conducted one 'pilot' session in Winter quarter 2013 with one participating class section of twelve students, and a second in Spring 2014 with four course sections (of thirty students each) using this design.

Episode selection

In a typical Physics 7 activity, the TAs walk around the classroom and interact with student groups. Many of these interactions throughout our activity sessions involved the TAs explicitly telling the students what to do to accomplish the assigned task. As we were primarily interested in supporting student-student interactions in small groups, we looked first for episodes in which students reasoned together without substantial guidance by their TA. We chose to analyze an episode in which four students reason about a strategy for changing the direction of the wave they had just built, and construct an accompanying explanation of why their strategy should work. This episode was chosen primarily because it was an instance of group members clearly enacting distinct interpretations—one group member leaves the table while the group discussion continues, then returns and offers his own, very different strategy for reversing the wave direction. Additionally, this episode was chosen in part because these students were particularly vocal and articulate about their strategies, and because each student in the group participated in the reasoning session. The selected episode is representative of the broader data set in that the strategy the students came up with the same as the other groups, but was notable in that the TA did not play a direct role in the construction of the final explanation.

Analytic approach

The goals of our analysis are to uncover the ways in which this group of students enacted distinct interpretations and subsequently negotiated those interpretations—particularly in the instance in which the interpretations were substantially different. As such enactments involve verbal utterances, gesture, body language, gaze and interactions with materials, we employed interaction analysis (Jordan & Henderson, 1995), in which repeat viewings of the selected episode allowed us to make sense of the interaction at both the "macro" and "micro" interactional levels. We first transcribed the episode fully, additionally annotating hand movements used in communication, beginning at the 'problem statement' by the TA and ending when the group had changed the topic of conversation. Within the video segment and using the transcript, we then identified for further analysis three episodes in which distinct interpretations arose.

Results

The selected episodes featured a group of four students: two men (J and S) and two women (A and B). The episode took place after the group had just successfully constructed a wave with a wavelength of 8 units, point-by-point. Some of the group's wave-building activity prior to the selected episode is relevant to understand it: as this was a group of four, their wavelength was divisible by the number of people in the group. This had the effect of J's oscillators each alternating phase between 0 and π—and because of this coincidence, he found during the initial wave building task that these two phases each corresponded to his oscillators each being at the "equilibrium point," in the $y = 0$ position. He noted aloud that both phases corresponded to the same position, but that the difference between a phase of 0 and a phase of π is in which *direction* the oscillator is going—zero corresponding to upward motion, and π corresponding to downward motion through equilibrium.

The selected video segment began as J left the group for a trip to the restroom, and the TA asked the remaining three students how they would reverse their wave's direction. The episode has three parts: in Part One, the group (S, A and B) constructed an initial strategy and accompanying explanation of why that strategy should work; in Part Two, J had returned and proposed an alternative strategy. In Part 3, the full group discusses a reinterpretation of the original strategy.

Episode one: A joint production without shared knowledge

As they finished building their first wave, J left the table for a trip to the restroom, and the other three students remained at the table. The TA approached the group and prompted them with the next question from the activity sheet, asking how they would change the direction of the wave they had just built.

TA:	So… we decided it's moving left, right?
B:	Mh-hm.
A:	Yeah.
TA:	How do you guys think you could make it move right?
A:	What!
TA:	How could you make it move to the right instead?
B:	Change the pha:se/? <tentative>
TA:	I mean yes, but… [everything is changing the phase, right.

A: [Everybody would **shif**: t…<<**go backwards**>>.

S: [Yeah.

TA: [Yes:[

A: [<<Like instead of **going this way**, [we would all **go that way**.>>

TA: [Why would that work?

A: Cau:se…

S: Cause you're reversing the direction of… you're reversing the **oscillation**. So initially, one of these points either starts[

A: [**going u:p** <elevated>

S: like I'm assuming this **starts [up**.

A: [oh: <elevated>

S: **Or down**. If you **reverse that**

A: you're going to now be going

S : you're going to change the **way** everything else **moves**. Like that changes **the direction**.

A: [oh: <elevated>

The TA initially posed the question to the group as "how could you make it move to the right instead [of left]?" B's initial suggestion to "change the phase" was tentative, as indicated by her uptalk and elongation of the word "phase." Her hesitation suggests that she suspected that the strategy would involve phase, but did not yet have a definite picture of how 'phase' related to the making the wave "move to the right." B's suggestion was rejected by the TA as not incorrect ("I mean yes") yet not satisfactory ("but"), and in particular, too general ("everything is changing the phase, right?").

S and A then jointly constructed a chain of concepts linking *phase* to *wave direction*. A first posited that everybody would "go backwards," and elaborated this meaning with "go this way," coupled with a gesture of a smooth rotation motion along the unit circle. The TA immediately affirmed this strategy, but asked for an elaborated explanation ("why would that work?"). A began an explanatory response ("cau:se…") but S filled in the content, explaining that it would work "cause you're reversing the direction of… you're reversing the oscillation." As A did earlier, he related his explanation as a modification to the group's prior activity ("initially, one of these points starts up" … "if you reverse that"). He then continued to relate "reversing the oscillation" to "changing" the wave direction. S's and A's talk is intertwined in this segment, A saying "oh:" and using elongated and elevated tones to indicate a realization or new understanding, while also implying her acceptance of S's contribution. This strategy, and accompanying explanation, was a socially distributed production comprising contributions from each of S, A and B.

What is interesting about this particular exchange is that the two students, S and A, appear to have been talking about two physically different situations—in particular, two distinct interpretations of the relationship between going "backwards" and the oscillators' motion. A appeared to be talking about the effect on the *direction* of motion of each of the oscillators, while S was talking about the effect on their *position:* A used the phrase "going up," while S used just "up." While these may be subtle differences in language use, they are accompanied by significant differences in gestural activity. A showed a smooth motion clockwise around the unit circle, then mimicked *going up*. S didn't refer to the unit circle in his explanation, but continued the verbal explanation (beginning with repetition of A's "cause") of A's "go backwards" strategy, mimicked oscillation with pinched fingers moving up and down, then as he said "starts up" he moved his pinched fingers vertically upward, paused, then as he said "down," pulled his hand backward and moved his pinched fingers to a lower position. He continued "if you **reverse that,**" repeating this up-to-down motion, "you're going to change **the way,**" mimicking waves in place, "everything else **moves**," with a rightward-moving flat hand, indicating a rightward-moving wavefront. His gestures suggest that he interpreted "reversing the oscillation" not as reversing each oscillator's *direction*, as A did, but reversing their initial *positions* from "up" to "down." S even stopped his initial explanation mid-sentence to repeat it specifically omitting the word *direction* ("Cause you're reversing the direction of… you're reversing the oscillation"), suggesting that *direction* wasn't relevant to his interpretation.

This further suggests a possible difference in interpretation of the verbal phrase "go backwards." A's initial "go backwards" was accompanied by a *smooth* clockwise motion around the unit circle. Coupled with her focus on changing the oscillators' *directions*, this may suggest that she took *going backwards* to mean that each point should progress, as time goes on, clockwise on the unit circle rather than counterclockwise (this would indeed have reversed the wave direction). On the other hand, S did not gesture referring to the unit circle (he took up the explanation from there)—yet his emphasis on *changing position* would be consistent with an interpretation of "going backwards" to mean a reversal of their initial wave construction strategy: to now subtract phase as each person sets their points, rather than to add phase with every point.

Episode two: Making two interpretations coherent

At the end of the above segment, J returned from his trip to the restroom, and S asked him how he would change the direction of the wave:

S:	How do you think you'd change the direction… how do you think you'd change the direction of the wave?
J:	Change the direction… it's like, oka:y (turning on iPad and looking down at it) well you change the equilibrium points from… right… you change the zeros… when you change the equilibrium points you like you **flip** the uh… (looks up from iPad at A) wait… what was zero, you'd flip that to pi? Right, and everything? And all the two Pi equivalents… right?
A:	I think so:… it's just the **direction also flips** with it. **Yeah**.
S:	[Yeah. Yeah, yeah.

As J thought aloud in the beginning of this sequence, his reasoning seemed to hinge on the word "change" ("change the direction… you change the equilibrium points… you change the zeros… you change the equilibrium points, you flip the…"). "Change the direction" appears to have been a verbal cue for J, bringing about a recollection of his prior experience during the wave-building activity of "changing the direction" of the "equilibrium points." J made this prior experience relevant to the current conversation through his repetition of the phrase "change the direction," first in reference to the wave, and then in referring the "equilibrium points." He then made the "change" more specific by transitioning from "change" to "flip" ("when you change the [direction through the] equilibrium points… you flip the [zeros to Pis]").

While this contribution also related the wave to the individual oscillators to the unit circle, it did so in a way that was inconsistent with the group's already proposed strategy. According to J, the group would take each of the points along their existing wave and adjust the phase on the unit circle to the "equivalent point"—where the position was the same but the direction of motion was reversed. This would indeed have worked. The strategy constructed by the other students, however, was to redo the point-by-point building of a wave, this time going clockwise on the unit circle. This strategy also works, and ultimately differs from J's only by an initial phase factor. However, the processes being suggested for building the reversed wave are substantially different, and not obviously compatible.

Now we focus on how the group responded to these distinct strategies. In response to J's newly suggested strategy, A began with a statement of agreement ("I think so:…"), elongating the "so" to hold her conversational turn as she thought. When she spoke again, she began with "it's just," then followed it with a point of similarity between her interpretation and J's ("it's just the direction *also* flips", emphasis mine). This suggests that the effort she was making while silent was to reconcile J's "flipping points" with her own interpretation of the original group strategy by finding ways in which they were, effectively, the same. She enacted this reconciliation both verbally and gesturally, by repeating J's use of the word "flip", and modifying her original "direction" gesture to end in a "flipping" motion (see Figure 1).

A and S jointly accepted this connection between the strategies: as she said "Yeah," she gestured toward S with an open hand, palm upward, referring to their previous exchange, that (in A's interpretation) meant that "reversing the oscillation" was sufficient to "change the [wave] direction." A's contribution here, gesturally "flipping the direction" *of the oscillator* and then gesturing to S indicates that her interpretation of the initial explanation was indeed focused on flipping each of the oscillator *directions,* not their positions. While S did not seem to be interpreting *direction* as meaningful before, he nevertheless accepted here that *flipping the direction* was in accordance with the explanation of their previous strategy.

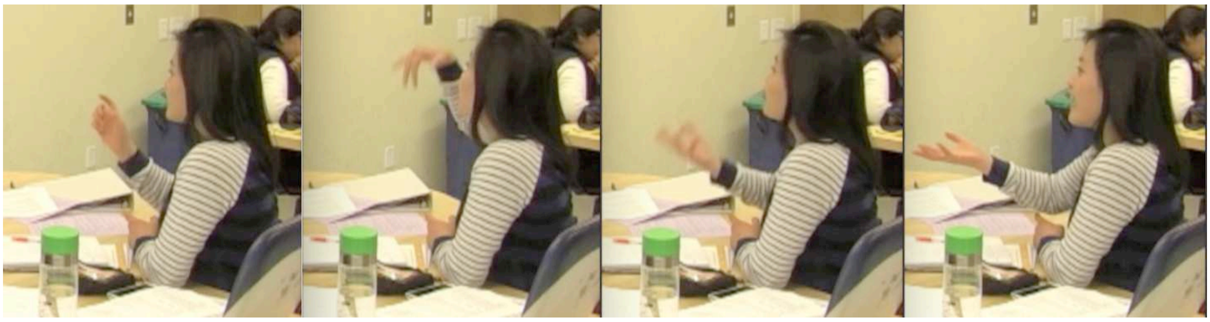

Figure 1. "(a) It's just (b) the direction also (c) flips with it. (d) Yeah."

Episode three: Purposeful reinterpretation

The group had now introduced two qualitatively different strategies: "going backwards," which required the group to restart their coordination efforts, and "flipping points," which involved taking each point as it is in the leftward-travelling configuration, and transforming it by "flipping" it to a new position. J next attempted to re-express his strategy:

J:	So we all need to find an equivalent point that's like… would you not move the dot, would you want it the same area, but like… what did he say, like what did you guys figure out?
[A responds, J asks her to repeat.]	
A:	Like you know how when we did our first one? You were here and like oh she was there and he was there and I was here ... Now we'd have to go.. We have to go the other direction.
J:	Is there a way to think about it mathematically though?
A:	That's what I was think- the negative Pi/? Is there a way/?
B:	This would be pi/2 instead of 3Pi/2, but…
S:	Yeah
B:	Negative?
J:	Like I'm saying if you shift that over…
B:	Isn't that math though, isn't it like this way is positive but if you go this way it's negative?
A:	Negative. So in a way it is mathematically correct?
S:	Yeah.
B:	like it'd be negative pi/2?
J:	OK so if we… **we added pi/8** right? So if we **subTRACT pi/8 from the equilibrium point**…
A:	now you're going in the **other direction**.
B:	negative pi/8…
A:	Now it makes sense.
S:	So we shouldn't think about it as **flipping points**, but we should think about it as **going the opposite direction on the unit circle**.
A:	which makes it negative.
S:	Because… waves behave… **he says** wave behaves like a **sine curve**. Sine curve is like… **choo, choo**… it's **oscillating.** So we oscillate the **other direction**…
J:	that makes a lot more sense.

J attempted to elaborate his "flipping points" strategy, suggesting that they each needed to find "equivalent points" (positions along the unit circle) that would keep their "dots" in the same vertical positions, but change their directions of motion. (This strategy would indeed have worked.) However, A provided no positive feedback while J made this contribution—no indication she shared his interpretation. A then related her strategy to J without taking up any aspect of his "equivalent points" idea. This effectively suppressed J's "equivalent point" idea, as they didn't discuss the way in which this strategy might maintain the "equivalence" of the points, and there was no further effort to reconcile these two strategies.

As A related the strategy, she reminded J of the group's original strategy ("you know how like before when we started") and replayed it gesturally, touching her finger to each point along the unit circle, progressing counter-clockwise at equal intervals ("I was here he was there and you were here"). She then switched to the new strategy in contrast by switching tense ("we would have to go") and replaying her motions along the unit circle but this time moving clockwise ("you are here… I'm here"). In doing so, she ued the group's prior activity to explain the new one to J. She summarized the new strategy ("go this way"). J then, without reference to any details of what A had just said, asked if there was a way to think about A's strategy mathematically. This contribution is noteworthy in that it was a shift from "tool talk" to "concept talk"—rather than being about the procedure of building a specific wave, it was about a particular way to understand that procedure. The group then tried to come up with a way to think about their strategy mathematically, their discussion initially centered on the negative/positive distinction between going clockwise/counter-clockwise on the unit circle. Then, J's mathematical interpretation of the strategy as *subtracting* in contrast to the previous strategy of *adding* became a new explanation for why A's strategy should work. Adding/subtracting $\pi/8$ likely had a higher degree of relation to the strategy A had gesturally enacted than positive/negative.

Saying "now you're going in the other direction" with a tone of relief, A accepted J's interpretation. Her gesture coinciding with the word "other" is interesting—instead of mimicking direction on the unit circle or the direction of an oscillator as she had done before (or taking up S's gesture for the direction of the wave), she summed it all up with a "hand flip" gesture that simply emphasized the word "other." She then gestured "palm up" at S again (the first time she did so, she was referring to flipping the oscillator directions being sufficient to reverse the wave direction). Now repeating that gesture, she effectively completed the explanation. This was in line with A's (apparent) interpretation that the essence of the wave reversal strategy was to make everything (unit circle, then oscillator, then wave) go the *other* direction. S took this up and positioned "flipping points" and "going the opposite direction" as two different ways of thinking about this. However, he did not adopt J's "adding/subtracting" language—he simply reiterated the initial idea about going around the unit circle, now emphasizing "other" as A did, but accompanied by a different ambiguous gesture.

Discussion

The analysis presented highlights the need to attend to distinct, personal interpretations in accounts of meaning-making. In Stahl's (2003) sense, meaning is shared because it is constructed through an interpersonal process of mutual recognition: a reference to something takes on a function in the ongoing discourse and therefore *means* something to the participants. However, trying to understand the group's discourse through this lens is problematic. For example, the initial explanation co-constructed by S and A made use of the phrase "go backwards." However, "go backwards" had two distinct functions in the activity as interpreted by S and A, as evidenced by their distinct gestural activity: either reversing oscillator position, or reversing oscillator direction. Thus it was not that there were two interpretations of the meaning of "go backwards," but that the phrase itself had two meanings, which were not in any useful sense *shared* by S and A. An alternative to a focus on individual interpretations of shared meaning might be found in Greeno and van de Sande's (2007) theory of perspectival understandings, which posits that individuals have personal perspectives – points of view that foreground one particular set of concepts and relationships between them. In this sense, A and S took different perspectives on the relationships between "going backwards" on the unit circle, oscillator position, oscillator direction, and wave direction, without requiring that each of these concepts had a meaning shared by the participants.

The analysis presented also highlights the ways that attention to individual interpretations can help researchers make sense of the interpretive acts by which the group accomplishes meaning-making. Taking the view proposed in Suthers (2006) that intersubjective meaning-making involves the joint composition of interpretations— the producing, taking up, modifying or elaborating a set of shared verbal, gestural or material artifacts— we can interpret A's utterance in Episode Two as taking up both J's statement about "flipping points" alongside her earlier idea about changing directions, and connecting these two conceptually. However, without a focus on individual interpretations it is difficult to see why A might have made that particular connection, or why it was A who made it. Attending to interpretations as personal understandings, her contribution represents an effort to reduce J's proposed idea to something consistent, or coherent, with her own currently held interpretation in which oscillator direction change was important. Additionally, A may have played this reconciliation role because her interpretation enabled her to see potential connection with J's. S's interpretation, on the other hand, in which *position* change was important, may have made it more difficult for him to make a connection to "flipping points"— an action which changes the direction, but not the position, of the oscillators. Lastly, attention to interpretations helps make sense of J's attempt to shift to a mathematical interpretation in Episode Three. In J's own words, he was looking for "a way to think about that"— not for new information, or a "missing" artifact, but a new *organization* of what was already available to him— a new way to interpret the concepts relevant to their wave building activity.

While these students achieved a degree of intersubjectivity sufficient to successfully accomplish the wave building and reversal tasks, and to collaboratively construct an explanation of their reversal strategy acceptable to their TA, they did so without ever sharing interpretations of their activity. To some extent, the students' conceptions of the problem of building a wave, or reversing its direction, must have converged—they could reliably, successfully build arbitrary waves together as a group by the end of the activity, and could not at the beginning. However, their interpretations-- specifically related the conceptual mechanisms of direction reversal-- did not converge, either during the wave-building activity or during the subsequent discussion. This suggests that conceptual convergence, in Roschelle's sense, may pertain to the more pragmatic features of the problem at hand, on which the group must agree to coordinate their actions-- while *interpretations* may be of the underlying conceptual structure of the problem, which need not be shared to succeed. It is an interesting future research question how these two layers relate to one another, and co-evolve in discourse.

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