Students' sense-making with visual data in small-group argumentation

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Abstract: Argumentation is a key component of scientific practice. It involves a dialectical balance of opposition and agreement, requiring negotiation and affording conceptual change through the co-construction of understandings. In classroom science inquiry with complex visual data representations, argumentation is an essential discourse structure through which students make sense of data and domain concepts. This study analyzed the argumentation practices of middle school students conducting an earth science inquiry project using data visualization tools. Analysis of spoken and gestural interactions during small-group work of one group of students in each of three classrooms revealed three common modes in which students employed visual data in argumentation: (1) using data-referenced talk and gesture to challenge authoritative positioning; (2) using gesture to participate in argumentation with incomplete conceptual vocabulary; and (3) using argumentation about data as a means of co-constructing the goals of academic tasks.

Learning to argue about data

Argumentation is a key component of the practice of science, both in the everyday work of scientists (Bell, 2002; Dunbar, 1995; Latour, 1990) and in learning objectives for K12 science education (Andriessen, 2006; NRC, 1996). Leitao (2000) tracked the ways in which the importance of argumentation has been articulated by education researchers since Piaget, and located the importance of argumentation in its potential to impact conceptual change. The essence of argumentation for Leitao (2000) is that it is "a process of negotiating divergence" (p. 335), co-constituted by interlocutors who present opposing viewpoints, justify their own viewpoint, and recognize an opponent's argument in some way. Its significance for learning lies in its potential for establishing intersubjectivity and opening the door to changes in perspective and understanding.

Argumentation is dialectical: it requires both some form of opposition, and some process of negotiation. The coordination of disagreement and agreement provides the leverage to effect conceptual change (Andriessen, 2006; Leitao, 2000). This process is inherently social, occurring in a context that mediates the goals, norms, and cultural tools employed by the arguers (Wertsch, 1998). Argumentation in subject matter learning settings such as K12 classrooms is likely to have different discursive features in comparison to other everyday situations, due to differences in expectations and goals for participants in activities designed for learning (Leitao, 2000). As such, argumentation in service of subject matter learning merits particular attention as a special case of argumentation more generally.

Providing opportunities to learn and practice the skills of argumentation is central to students' understanding of science (Duschl, et al., 2007). Because students' classroom arguments about science topics often feature many properties of informal argumentation (Walton, 1996), a goal of instruction is to move students toward more formal, scientifically acceptable forms of argumentation. This development does not come automatically: students need to be instructed and scaffolded (Andriessen, 2005, 2006; Goldman, Duschl, Ellenbogen, Williams & Tzou, 2003; Linn & Bell, 2000). Andriessen (2006) argues that the purpose of argumentation among students should not be to convince the other of one's point of view, but rather to engage in "cooperative explorations of a dialogic space" of solutions. In so doing, several learning mechanisms can be called into play: knowledge is made explicit, new knowledge is co-elaborated, and interpretations of data are employed as evidence in relation to claims and positions (Andriessen, 2006; White & Frederiksen, 1998).

The present study focuses on one specific context of argumentation: the negotiation of meaning of complex, visually-intensive data in small groups. Increasing use of computer tools for data representation, visualization, and communication, along with increasing access to Internet-based resources in schools, have made the use of rich visual data in classrooms increasingly common (vanJoolingen, deJong et al, 2007). Such data resources both afford and require sets of skills and habits that are highly valued in education, as evidenced by a recent consensus report on science education in the U. S., *Taking Science to School* (Duschl et al., 2007). In science, argumentation requires constructing and evaluating explanations with evidence derived from such data (Duschl & Osborne, 2002; Goldman, Duschl, et al, 2003; Herrenkohl & Guerra, 1998; Stewart, Cartier, & Passmore, 2005). For example, students conducting an investigation using a data visualization environment must coordinate multiple goals and activities of the investigation; make observations; communicate those observations to their peers or group members; coordinate their observations about the data with explanations of the phenomenon; and negotiate different observations that may exist across members of the group (Shauble, Glaser et al, 1995; Radinsky, in press; Tabak, 2004; Sandoval & Millwood, 2005). It is important for the research community to better understand the development of the skills and habits of scientific argumentation with visual data artifacts, as they emerge at the microgenetic level of analysis.

Small-group inquiry situations are important contexts for examining this kind of argumentation with data (Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; Duschl, Schweingruber, & Shouse, 2007). Small-group collaboration provides a space in which students can practice interactional skills that are valued in science learning standards (NRC, 1996), such as joint consideration of data, communicating emergent understandings, and weighing and evaluating alternative ideas or solutions. While all of these skills can be taught, modeled, and practiced in whole-class instructional settings, small-group activities provide the chance for students to practice these skills with more independence; for all members of a class to practice them at the same time; and for the teacher to work more closely with one small group at a time while other groups pursue their work independently (Goldman, Radinsky & Rodriguez, 2007). For learning the skills and habits of effective argumentation, working in small groups affords opportunities to develop better coordination of multiple perspectives, potentially leading to improved reasoning and coordination of evidence with explanations (Kuhn, Shaw & Felton,1997; Linn & Hsi, 2000).

This paper examines episodes in which students in small groups engaged in argumentation about data, in the context of a middle-grades science investigation of plate tectonics. The classes enacted a science unit called *Earth Structures and Processes* (Radinsky, Alamar, Leimberer, Rodriguez & Trigueros, 2005; Radinsky, Leimberer & Gomez, 2000), in which the students used a geographic information system (GIS) computer application as one of the primary tools of their investigation. A GIS is a computer program consisting of a database connected to an interactive map (Audet & Ludwig, 2000). Information in the database can be viewed on the map as objects of different colors, shapes, and sizes. The GIS is interactive, which means that users can zoom the map in and out, turn layers of data on and off, choose how the information should be displayed, and submit queries to the database to answer specific questions. Other data representations used by students included large (4' x 6') paper world maps with GIS-generated earthquake and volcano data plotted, as well as topographic maps and models representing ranges of elevation values for particular areas.

Research methods

This study examined the ways that groups of students engaged in argumentation as part of the larger process of co-constructing the meaning of visual representations of large data sets. The analysis draws from a corpus of data gathered for a larger study of middle-school classrooms in public elementary schools in a large city, enacting inquiry projects using a range of visual data representations and tools. The larger research program is an investigation of ways students develop skills, habits, and dispositions for reasoning with complex data in inquiry projects (Radinsky, Alamar et al, 2005). Data presented here are drawn from two different years of this research program, and from two elementary schools. The student population of each school was diverse in terms of race, ethnicity, academic performance, and language dominance.

In this study, five focal episodes from each of three science classrooms (two 6^{th} grade, one 7^{th} grade) that enacted the *Earth Structures* unit were chosen for analysis. These episodes constitute the class sessions in which students conducted independent inquiry tasks using visual data. ("Visual" here means graphic and spatial representations of data, as opposed to numeric, textual or tabular ones.) Students' curricular assignment during these episodes was to apply concepts introduced in whole-class instruction to generating an explanation for crustal formations (i.e., elevation patterns) and earthquake and volcano data patterns found in a particular place on earth. Each group of students was assigned a different location to study. Students were assigned the tasks of finding the plate boundaries, determining the type of plate motion at the boundaries (e.g. *subduction, rift,* or *buckling*), hypothesizing the direction of plate motion, and preparing a presentation to the class explaining their findings.

In each classroom a subset of three students (a "table group") was videotaped during small-group inquiry activity. The table groups for this study were selected in coordination with the teachers to be representative of the classrooms in terms of academic performance, with students who were neither the highest- nor lowest-performing academically. Two researchers documented interactions among students during science instruction for all class sessions of the *Earth Structures & Processes* unit, one operating a video camera and the other taking field notes. Target episodes for the present analysis included all small-group inquiry sessions in which students were conducting an inquiry task with visual data (GIS or paper maps); five to seven such episodes were identified in each class.

Transcription and coding of speech and gesture

All student speech during each target episode was transcribed and time-coded by one researcher, and each transcript was verified by a second researcher. Discrepancies in transcription were worked out in conference, with reference to the videotape as needed. The primary verbal unit of analysis was the *turn* in group talk, i.e. an uninterrupted speech burst by an individual student with no pause greater than two seconds (though units both within and across turns were employed in coding argumentation moves, described below).

To identify all segments of group work in which students were talking about data, every turn was coded for presence or absence of a *data referent*, i.e. speech referring to data items or relationships among data items, whether described in the visual language of the inscription (e.g., "dots," "a big line"), or in indeterminate indexical terms (e.g., "look at that one right there," "they're close together"). To establish reliability, a second researcher not previously familiar with the transcripts was trained on the coding using two transcripts. After training, two researchers coded three other transcripts independently. Reliability was calculated using Cohen's Kappa (0.7509, n=932 turns coded in the reliability sample). All differences were resolved in discussion, and the remaining transcripts were coded by one researcher.

Analysis of gesture was employed as a second resource for identifying communication about data. Coding for gesture was done from the videotape of the episode with a turn-segmented transcript of the verbal information at hand. Using an adaptation of McNeill's (1992) gesture coding scheme (Singer, Radinsky & Goldman, in press), one researcher coded all five of the episodes for points, traces, and representational gestures. Points were coded if the student used her fingers or hand to indicate some specific location or object on a GIS display or on any of the other materials. Traces were coded if the student moved her fingers or hand along a part of a GIS display or other materials. Representational gestures were coded on two dimensions: hand-shape (e.g., two flat hands with palms faced down or one hand with a closed fist) and motion (e.g., hands moving horizontally toward each other, hands moving horizontally away from each other or hands moving vertically, up and down). The meaning of the representational gesture was inferred based on the context of the accompanying speech.

To establish reliability on the gesture coding, another researcher (one not already familiar with the transcripts) coded two of the small-group class sessions for occurrences of each type of gesture, and for their meaning in the case of representational gestures. The first episode was used to establish code definitions and clarify the gesture-coding process. Reliability on the second episode was calculated separately for occurrence and number of gestures in a turn, each type of gesture (points, traces, and representational gestures), and their meaning. There was 90% agreement on gesture content of each turn, with disagreements resolved in discussion.

Data analysis

References to data, in speech and gesture, were coded at the level of spoken turns, by student and by timecode, which enabled us to identify all periods of time in which students were engaged in communication about data. These engagements around data were then reviewed, using the transcripts and video, to determine the positionality of students with respect to particular explanations or characterizations, constructing them as agreements or disagreements. Exchanges were considered examples of argumentation if they were determined to include at least one *proposition,* a *counter*, and a *reply* (following Leitao, 2000).

A second phase of coding of student speech differentiated the data references into three types: (1) reference to a singular *data item*, (2) reference to *data relationships* (e.g., characterization of a pattern, or relative positions or values of multiple items), and (3) *explanations of data*. This second level of coding enabled us to differentiate among instances of argumentation by the content of the discourse, and to view the ways both speech and gesture were used as communicative resources in each exchange. These representations of each episode of argumentation-with-data highlighted differences in modes of argumentation across episodes within and across groups which were then explored in qualitative analyses of each episode. We treated these analyses as contrasting case studies (Yin, 2002). Characterizations of each student's emergent role in each group (developed in detail in other analyses, including Radinsky, 2000; Radinsky, in press) provided background for analyses of each student's positioning within each episode of argumentation. The case studies examined the role of spoken and gestured references-to-data in the development of each case of argumentation, and evidence of changes in domain reasoning during the episode.

Results: Students' engagement of visual data in small-group argumentation

How did students employ visual data as a resource in argumentation within their small groups? The analyses of the contrasting cases suggests several modes of references-to-data, in speech and/or gesture, that fell within the discursive structure of argumentation. Some of the modes were identified across groups. Three of these modes are presented here, to organize the results section around themes for conceptualizing students' modes of argumentation with visual data:

- Use of data-referenced talk and gesture to challenge authoritative positioning
- Use of gesture to participate in argumentation with incomplete conceptual vocabulary
- Use of argumentation about data to co-construct the goals of activity

Mode 1: Referencing visual data to challenge authoritative positioning

Authoritative positioning by a student in a small group can often contribute to the development of an *absolutist* epistemological perspective (Kuhn, 1991) in group discourse, i.e. a willingness to accept answers as being definitively right or wrong, on the basis of the speaker's perceived authority as being "smart" or having domain expertise. Kuhn (1991; Kuhn et al, 2000) suggests that science learning requires developing an *evaluative* epistemological stance, i. e., one employing evidence in support of claims, and valuing exploration and investigation over closure based on authority.

One mode of engagement with visual data in argumentation, observed in two of the groups (and in others not presented here), was as a resource for challenging absolutist discourse by students who positioned themselves as science experts in the group. For example, in the following transcript segment Mario (an academic leader in the class) authoritatively announced the "answer" to the group's inquiry task (map the boundaries of their plate), but was challenged by Joel (a student who was often marginalized in group work).

1. Mario: THIS is the plate. ((traces a broad circle above the map))

…

5. Joel: The plate boundary is right over HERE, Mario!
6. Mario: Yeah, but it goes up here
7. Joel: But it's over here too – it goes like this!
8. Mario: That's what I'm saying! ((Mario draws line, Joel and Juan watch closely))
9. Joel: Go all the way around
10. Mario: I put it like all of this
11. Joel: That's it
12. Mario: What about down here? That's one plate too!
13. Juan: {inaudible, pointing}
14. Joel: No, but it stops – see right here it stops – No no no – right here it stops! ((lifting Mario's pen from the map)) – and then it starts up again!
15. Mario: I know!
16. Joel: But it's sort of right in the middle

Figure 1. Joel (left front) challenges Mario's authoritative claim by pointing to data, initiating a revision.

Joel here stopped Mario from imposing a simplified conception of the task on the group: a casual tracing gesture around the map (Figure 1, left frame) to characterize the plate boundary. When Joel challenged him (lines 5, 7, and 14) Mario became more tentative, though he tried to maintain an authoritative posture ("That's what I'm saying!" … "I know!"). But Joel had noticed something in the data that Mario had missed: an area of Mario's plate boundary line where there was no earthquake data at all ("See right here it stops … and then it starts up again!"). Mario revised his assertion, using his domain knowledge to cover his retreat with an air of authority (line 21 below), but adopting Joel's interpretation of the data by acknowledging the "big old gap":

21. Mario: Why? Plates are huge, man! There's a plate that takes up the whole Euro-Asia!
22. Joel: Mario, look – this is where it really starts, see it goes up – and look what happens! Look what happens! It starts to drop!
    ((Mario, Joel and Juan huddle over the map))
23. Mario: There's that big old gap! There's a big old hole right there

As evidenced in Figure 1 (right frame), Joel's challenge here established intersubjectivity (three simultaneous points to data in close proximity), problematizing a gap in the pattern of earthquakes and bringing the group into closer examination of the data. This challenge to Mario's authoritative positioning appeared to lead both Mario and Juan to closer consideration of the data, while also requiring Joel to make his initial disagreement more explicit through pointing, tracing, and more carefully describing the data. Similar challenges to authoritative positioning through reference to data were found in each group studied.

Mode 2: Using gesture for domain argumentation with incomplete vocabulary

One possible affordance of visual data in small-group science inquiry is to provide material referents with which students can engage in domain reasoning and argumentation, prior to verbal mastery of the conceptual vocabulary. If visual data are to play this role – i.e., to afford an entry point into domain reasoning– a question is how students are to manage communicating about these data artifacts such that they can engage in argumentation. One answer to this appears to be the use of gesture. Research suggests that gestural reference often precedes speech in some learning contexts (Roth, 2001; Singer, Radinsky & Goldman, in press). Our analysis distinguished between two modes of gestural support for argumentation with incomplete vocabulary: (1) points and traces (Clark, 2005; McNeill, 1992) being used to establish joint attention and building common ground in arguing about data patterns, prior to developing verbal descriptive skills; and (2) representational gestures (McNeill, 1992) being used to argue about abstract concepts and explanations for which vocabulary was incomplete (see also Singer, Radinsky & Goldman, in press). Numerous instances of each of these uses were identified in the data analysis.

In an example of the use of points and traces, the transcript excerpt below is from the initiation of a five-minute episode of argumentation focusing on interpreting a pattern of data in the GIS:

191. C: Go to the main thing ((points))
192. J: I think it's still there because one of them are right there ((points))
193. V: OK, ha ha
194. C: Go to the main one, Violeta ((points))
195. C: Look, see, ((points)), I think the whole planet has one
196. V: ((standing)) Look at the volcanoes! They go like in a, see look, they go like in a line! ((traces))
197. C: I know, that's what I'm saying - it's all, it's all one big *placa*
198. V: ((traces)) Look at that, the volcanoes are all in a line!
199. C: ((points, traces)) I know, down here --
200. V: And it goes right here ((traces))-- vooooom
201. C: See, it's all one big *placa* ((traces right, left, across bottom))
202. J: ((laughing)) That's just great
203. C: It is, Violeta! ((traces up right side, retracts))

Here the negotiation of how to display the appropriate data, and which area to attend to, was carried out primarily through pointing gestures (lines 191, 192, 194), followed by a proposition by Cecilia that "the whole planet has one" (line 195) – i.e., that one plate (or *placa* in Spanish) encircles the globe. This proposition, and its association with a detailed pattern of earthquakes and volcanoes, was articulated through a series of tracing gestures (lines 196, 198-201, 203) without which the discourse would have little geographic meaning. The relatively simple language used to describe the visible patterns of data ("the whole planet has one," "the volcanoes are all in a line") does not prevent the group from establishing joint attention to a detailed and complex spatial pattern, through gesture.

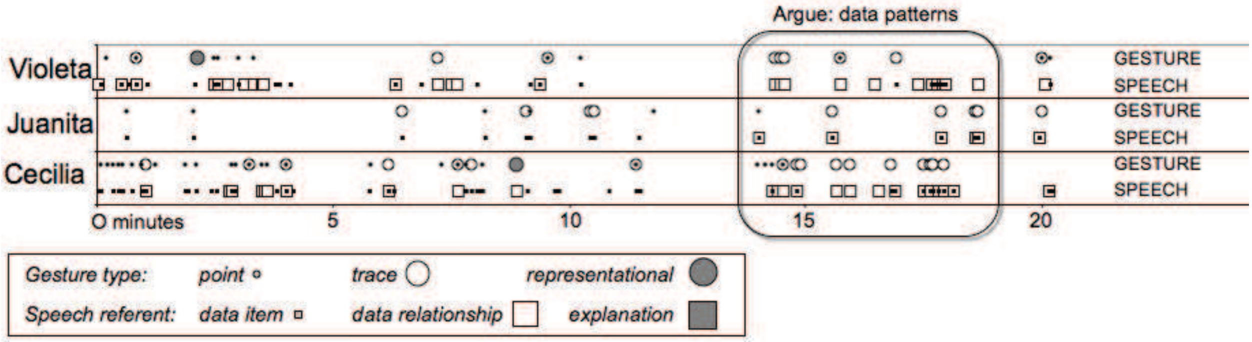

Figure 2. A class session in which a group argued about data patterns (min. 14-18).

This exchange initiated a five-minute debate about whether a single plate could indeed circle the globe (a later episode of which is excerpted below). Figure 2 depicts the pattern of spoken and gestured references to data during the 21-minute session from which this excerpt was drawn; the exchange above marks the initiation of the argument about data patterns (circled in Figure 2), at minute 14. The coding of this session reveals that all three students went on to use tracing gestures (large empty circles), in combination with verbal characterizations of data relationships (large empty squares) to communicate about the data during this argument.

This contrasts with the example shown in Figure 3 from another group, in which Leo, Kerry and Eliana's argument employed primarily representational gestures (large shaded circles) and explanatory domain language (large shaded squares) to conduct their argument about how plates might be moving at their plate boundary (discussed in detail in Singer, Radinsky & Goldman, in press). Figure 3 shows all three students making use of representational gestures as part of their argumentative discourse (with one student, Eliana, also using many points and traces, linking her explanation more concretely to the data). This coding suggests that both argumentation about visible data patterns (prevalent in Figure 2), as well as more abstract argumentation about the meanings of those data (prevalent in Figure 3), can be distributed across speech and gesture.

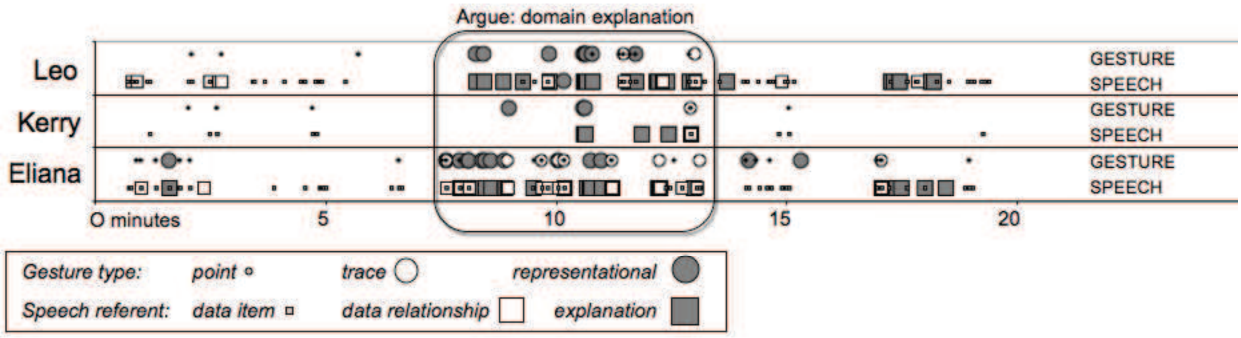

Figure 3. A class session in which a group argued about a domain explanation (min. 8-13).

Mode 3: Co-constructing the goals of the inquiry through argumentation with data

Part of the reality of classroom inquiry (like any other instructional context) is the negotiated nature of any assigned task. Regardless of the degree of specificity of the task charge and the teacher's instructions, there is always a process of negotiation and co-construction as the students jointly establish a shared, and often contested, conception of the task (Radinsky, 2000; Radinsky, in press; Doyle, 1983). This conception of the task includes emergent understandings of the goals of the inquiry. When students are using complex visual data, their articulation of the goals of the inquiry is often accomplished through establishing acceptable ways to talk about the data. The shared understanding of "what we're supposed to do" becomes tightly integrated with developing norms for "how we should talk about the data." This often occurs through argumentation.

For example, Cecilia's group had several episodes of intense argumentation centered on two disputed questions: How big should a plate be? and, What do we do when a boundary doesn't connect? These conceptual issues for interpreting data were argued with warrants based on assumptions about the assigned task and expectations, as seen in the following exchange:

90. Juanita: So what do you think? But then if that's the plate --
91. Cecilia: [Or it could be] up here, but nothing connects there, that's the problem

92. Juanita: If that's the [plate that's gonna be] --
93. Cecilia: [Right there]
94. Juanita: [That's going to be too big] ((points))
95. Cecilia: I know it's cuz it's [lots of plates]
96. Juanita: [And that would be including], another, another area. That would be including the Himalayas or something ((points))
97. Cecilia: (But ...) nothing connects right there ((points))
98. Violeta: [Exactly]
99. Juanita: [Exactly]
100. Cecilia: [That's what] I'm saying
101. Violeta: You're saying that the whole, the whole thing is the plate
102. Juanita: And isn't it too big to be a plate?
103. Cecilia: No, the other ones are big ((points to other groups' mapped plates))

Here we see that the essential science understandings being co-constructed in discourse – the concept of *plate* (lines 90, 94, 95, 101, 102) and criteria for analyzing data (lines 91, 97-100) – are intricately connected with the group's emergent conception of the expectations for the task assignment. For example, Juanita's objection that "that would be including … another area … the Himalayas" (line 96) refers to the fact that another group was assigned the Himalayas, so it could not be on their plate. Similarly, Cecilia responds to the question about how big a plate could be by referencing other students' answers: "No, the other ones are big" (line 103). In these ways argumentation with data became a medium for shared task construction, and vice versa.

Discussion

These examples illustrate some of the ways students employed spoken and gestured references to visual data in argumentation in the small group context. These three modes of using data as a resource in the small-group activity system provide insight into the mechanisms by which science understandings are co-constructed in inquiry. They highlight the intersection of social and intellectual growth in classroom activity, and contribute to our understanding of the emergence of science knowledge at the microgenetic level of analysis.

Data visualization tools like GIS, and inscriptions like data-rich maps, are important means with which to engage in the practices of science. They clearly bring both challenges and opportunities to the science classroom. To understand the nature of these challenges and opportunities, we must attend to social purposes to which such tools may be put, such as challenging or disrupting the discourse of didactic authority, or extending and altering the nature of student-student domain talk during independent work. We must come to understand the multiple ways these cultural tools can become "handles" for students who are not yet conversant in the domain to engage in meaningful disciplinary reasoning – or to avoid or distort it.

We have shown that students can use visual data as a tool for confrontingand disrupting absolutist positioning; that they can employ gesture as a resource for arguing prior to mastering domain vocabulary; and that the negotiation of task expectations can be a meaningful site of sense-making with data. These modes of *argumentation-as-sense-making-with-data* all involve establishing a balance between confrontation and agreement. This dialectic, at the heart of argumentation, presents a significant challenge for young adolescents, as it does for adults. Norms that involve opposition can disrupt discourse and stymie students' decision-making processes, but they also can stimulate reflection on science understandings and conceptualizations of data. Students' positioning in these interactions over time contributes to the development of roles, or emergent identities, as knowers and doers of science (Radinsky, in press). This suggests that it is important for educators and researchers to improve our understanding of how students' contingent and negotiated constructions of the goals and practices of argumentation develop from emergent discourse moves toward stable aspects of identity over time: i.e., the skills and habits of effective scientific argumentation.

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