Children's Discourse and Understanding: A Unit on Buoyancy

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The present study examines an extended argument on density among students in a small multi-graded middle school classroom. Of particular interest in the present paper is the development of children's explanations and understandings as they grapple with their own and the conflicting ideas of others. Although the unit of instruction within which this argument occurred focused on buoyancy, the present paper attempts to address more general concerns of extracting underlying meanings and understandings as they unfold during a fairly free-wheeling and ongoing argument. The following section will provide a brief overview of some key research and theory that relates to looking at student arguments and discourse within a framework of attempting to establish the classroom as a scientific community.

Background

The focus of the present paper concerns an ongoing argument that arose during five concurrent class meetings. However, this argument is embedded in a unit that attempted to incorporate what Perkins and Simmons (1988) refer to as "four frames of understanding." These frames include: (a) content frame, (b) problem-solving frame, (c) epistemic frame, and (d) inquiry frame. In this particular unit, the content frame involved the general concept of buoyancy. The specific concepts focused upon in the unit included (a) density (which turned out to be the primary focus of the argument and many of the investigative activities), (b) pressure (which became a secondary focus of the argument, especially in terms of how pressure affects density), and (c) buoyant force. Although these concepts were the focus of the content frame of the unit, the investigative activities were designed to stimulate student involvement in discussing, arguing about, and constructing their own explanations for the phenomena they observed. Such an emphasis is situated within the inquiry frame, which, in general terms, concerns critically challenging knowledge claims. The challenging of knowledge claims, however, necessitates involving students in providing evidence and rationales for their claims, which falls within the epistemic frame. The problem-solving frame was included in the unit projects to design a boat to meet specific criteria.

Such a perspective of situating classroom instruction in these four frames involves some difficulties that can arise among the students. Such difficulties provide understandings of the problems students can have in developing understandings which are situated in the different frames. Perkins and Simmons (1988) have described these difficulties in some detail. However, a brief overview is warranted here. The content frame involves difficulties with naive concepts, which are generally the intuitive concepts that students construct from their personal experiences and bring with them into instructional settings (an abundance of research studies in alternative conceptions have described such difficulties, such as, Carey, 1985; Gilbert & Watts, 1983; and an overview from Wandersee, Mintzes, & Novak, 1994). Another difficulty encountered within the content frame involves the accessing of knowledge, which is evident when students cannot recall knowledge gained from classroom instruction or from personal experiences. The final difficulty in the content frame involves garbled knowledge, which is apparent when students confuse and combine aspects of different concepts.

The inquiry frame involves difficulties in creating a classroom atmosphere and appropriate activities where students are encouraged to find and identify problems. Another difficulty is found in many classrooms where students are adept at solving "text book" type problems and at memorizing formal concepts and facts, but fail to make connections to how these concepts explain everyday phenomena and to how to solve similar everyday problems. The final difficulty involves not venturing beyond the bounds of the particular theory or framework being studied. In this instance, students are not encouraged to question their own naive theories.

The difficulties involved in the epistemic frame include the pattern of how intuitions mask observations that contradict such intuitive understandings. Students' memories of a particular event often reflect their intuitive expectations, rather than what actually took place. In a related way, another difficulty involves sacrificing internal coherence for intuitive understandings, where a particular conceptual explanation is viewed as nonsensical from an intuitive perspective. The inconsistencies of the intuitive understanding are either not noticed or are viewed as insignificant. Another difficulty involves neglecting the basis for the rules associated with a particular domain. Students may memorize the rules, but they do not understand how these rules were established or why they are important. The final difficulty in the epistemic frame involves confirmation bias, where students tend to use their observations and experimental results to confirm their intuitive understandings.

The problem-solving frame includes difficulties with (a) the erratic use of trial and error; (b) continuing to pursue an unfruitful approach or quitting when no approach is immediately forthcoming; (c) pursuing an approach based on formulating a guess as to the rule, when the rule itself cannot be recalled; (d) using a stock response to a problem without any understanding of the underlying principle; and (e) working backwards towards a solution by trying to use what might seem to be an appropriate equation or algorithm. Each of these difficulties involve problems with understanding the principles and concepts involved in the domain in which students are working.

In addition to the context provided by these four frames, the discourse, which is the focus of the present analysis, can be examined from two very different perspectives: cognitive psychological and philosophical. According to Paul (1990), these two perspectives are not commonly combined in educational research, because of their contrasting assumptions, emphases, and approaches to understanding children's thinking. A few examples of these contrasting positions may help to illustrate Paul's contention. From the cognitive psychological perspective, the comparative emphasis is frequently placed on how novices compare to experts, whereas, from a philosophical perspective, the comparative emphasis is normative, or how particular thinking compares to aspects of logical and rational reasoning. The view of classroom practice, from the psychological view point, tends to be based on the use and development of domain-specific cognitive skills and on activity structures that address the acquisition of specific concepts. On the other hand, philosophers are more interested in developing communities of inquiry that question basic assumptions and foster critical and reflective thinking.

The present paper will try to combine these two perspectives into an analysis of the discourse and argument between the students. From the philosophical perspective, the students' argument offers a rich opportunity to examine the nature of their reasoning and thinking. From the cognitive perspective, the argument also provides an opportunity to examine the nature of the students' conceptual understandings and the use of more specific cognitive skills.

Examining children's discourse provides opportunities to delineate the social and individual dynamics of children's thinking and how they contribute to the construction of meaningful understandings. When analyzing student discourse, a number of underlying assumptions need to be kept in mind. Cortazzi (1993) describes five such assumptions, which are consistent with a constructivist framework:

1. "understanding is a constructive process"
2. "meaning is actively interpreted"
3. "understanding occurs concurrently with information input and processing"
4. "understanding activates and uses presuppositions in the form of previous experiences, beliefs and attitudes, motivations and goals"
5. "understanders and producers use information from events, the situation or context, presuppositions, and existing schemata flexibly and strategically." (pp. 67-68)

These assumptions provide the basis for making sense of student conversations and arguments in the classroom. However, as Gee (1994, April) contends, the everyday language used by students has a tendency to obscure the underlying meaning and reality of their understandings. As Gee suggests, "unfortunately, in science it is often this 'underlying' level which is crucial" (p. 5).

Everyday language is rich in social and cultural meaning, but confounds the process of constructing appropriate and meaningful understandings in science. The contrast between less ambiguous science talk and the potentially more ambiguous everyday talk presents an interesting dilemma to science teachers. As Lemke (1990) contends, children are more likely to pay attention and engage in science class when the talk is characterized as everyday language than when science talk is the primary mode of delivery. Expecting children to make a jump into science talk is daunting. According to Gee (1994, April), Vygotsky's "zone of proximal development" can be used as a framework for establishing an apprenticeship model that can provide support for the novice in developing some of the rudiments of science talk.

Such difficulties in developing the skills of talking, which are less ambiguous and follow some of the patterns of reasoning in science, are similar to those encountered in Perkins and Simmons (1988) "frames" (as discussed on previous pages). The dilemma of everyday and science talk is compounded if we consider that both types of talk are powerful in their own right and in appropriate contexts, as suggested by Gee (1994, April). When we examine children's arguments in science, we can develop a sense of the power and appropriateness of their claims and arguments, as well as the ambiguity and difficulties in communicating meaning. Lemke (1990) suggests that the gap between everyday and science talk can be humanized by using everyday language to soften the potentially difficult task of acquiring science talk.

A number of researchers have begun to unravel the complexity of children's discourse in informal and classroom situations. The social dimension of children's talk has been explored by Garvey (1984). Her analysis of language use focused upon examining units of talk. These units of talk provided a basis for exploring patterns of communication in social situations. Lemke's (1990) investigation of science talk in the classroom explores the difficulty in communicating science understandings and the conflict between everyday and science talk. His extensive examination of classroom talk delineates and describes a number of tactics, strategies, conceptual relations, and other patterns that appear in teacher and student discourse. Lemke's work makes the link between language and the construction of conceptual understandings, although the development of specific conceptual understandings are not emphasized.

During conversations about specific concepts, the depth and extent of children's understandings can be difficult to uncover. Partial statements and vague references and terminology make the task of describing children's understandings difficult. Gee's (1994, April) work in this area is particularly illuminating. The process of abduction, which Gee defines as reasoning that draws on one's own experience in order to formulate plausible explanations and where aesthetics and taste play a major role, is fundamental to understanding how children express their understandings of phenomena. This process is fundamental to working is science, but can take of the characteristics of "everyday" abduction. Such "everyday" abduction relies on everyday language and logic, and on language constructions that are more typical of story telling. As a part of such language constructions, he describes two sets of language patterns that contribute to the confusion of extracting meaning from children's talk. The first set consists of patterns and associations. Patterns tend to create a symmetry in arguments, where two parts of an argument are set up as being similar, but in actuality the parts may contain major differences. These differences are obscured by the apparent symmetry in the argument. In the same way, associations obscure the differences between ideas. The second set of patterns involves repetitions and parallelism. Again, the underlying meaning is obscured by using similar argument constructions across two or more statements. The repeated use of particular terminology and the parallel construction of a number of argument statements can lead the listener or reader into assuming similarity where such similarity does not exist.

Eichinger's (1993, April) study of student argumentation focused on an analytical framework based on the logical structure of scientific arguments. Such arguments contain evidence data, which are used in the process of making conclusions. These conclusions are substantiated with warrants (accepted knowledge), which are generally supported with backing (also based on accepted knowledge). Additional qualifiers or assumptions may be needed to support the argument. Within a scientific argument, we would also expect to see individuals providing rebuttals to the counter claims of others. His results indicated that students did use the authority of knowledge based on warrants, backing, and previous observations or data. However, arguments also were resolved by using personal ideas or experiences, invoking procedural constraints (such as, time limits), and asserting personal power. In addition, he found that a few students tended to dominate arguments, both in terms of what was or was not to be argued about and of how arguments were resolved.

The present paper focuses on one extended argument during a unit on buoyancy. The data presented here represent an argument created and maintained by the students. Investigating the flow and development of the argument is particularly intriguing, because of the extent of student control involved. As opposed to most studies of classroom discourse, the teacher's role in the argument is minimal. One of the difficulties in examining classroom discourse is determining whether the ideas being expressed are the students or whether the ideas and terms used are just being repeated from interjections by the teacher (Edwards, 1993). What we see being discussed, for the most part, are the students' concepts and understandings. With the exception of the term "density," the ideas and terminology in the argument were generated by the students.
In addition, most studies have emphasized the structure of the argument without paying much attention to the conceptual understandings and meanings being expressed during student arguments (Edwards [1993] is one exception). In the following analysis, the underlying understandings and meanings of students' claims are examined within the context of an argumentation process. Several major questions are addressed in the following analysis. What conceptual understandings are evident in the extended argument? What thematic patterns are evident in the argument? What underlying principals or interpretive frameworks influence the students' thinking, and how do they affect their understandings?

Method

The study took place in a small private middle school in eastern Canada, during January and February, 1995. I acted as both researcher and teacher in a multi-graded class of 10 students (one grade 5, two grade 6, and seven grade 7 children; four of whom were girls). The class met two days a week, for the most part, over a period of nine weeks, for a total of sixteen class meetings of 45 minutes each. The students were organized into three groups. Two of the groups (one of three and one of four students) had two girls each. The pseudonyms used in this paper were assigned according to the grade level (i.e., the name starting with "E" corresponds to grade 5, those with "F" correspond to grade 6, and those starting with "G" correspond to grade 7).

The unit on floating was set-up with the goal of each group designing a boat to meet specific criteria. A simulated letter from the minister of tourism and culture provided the details for each group's submission of a proposal for a boat to carry tourists to various natural history sites around the province. The first class meeting was devoted to allowing each group an opportunity to explore the building of a model boat out of aluminum foil. Class 2 through 9 were focused on teacher designed investigations. During classes 10 through 15 the groups worked on their boat designs. Class 16 was used for a self-evaluation activity and a review of the application of a specific concept (how density can be used to predict the water level of their boats). The investigations during classes 2 through 9 are outlined below:

2. Predicted and tested which objects float (11 blocks of wood, from ebony to balsa; a variety of objects made of different metals, including steel, aluminum, lead, brass, and copper; and a variety of other objects, including a glass ball, bees wax, paraffin, cork, ping pong ball, graphite, and plastic). Calculated density of selected items from above objects.
3. Investigated the effect of changing the density of the medium on floating and sinking.
   How can you make ebony float? How can you make rosewood sink?
4. Investigated "Squidy" and another type of Cartesian diver.
5. Built a boat and predicted how much weight it can carry (carrying capacity), based on the density of the object (boat).
6. Continued developing predictions of the carrying capacity of their boats.
7. Finished the carrying capacity activity with a test of their predictions. Investigated water pressure (2 liter soft drink bottle with two holes in it). Began developing manometer predictions.
8. Reviewed carrying capacity activity. Carried out manometer activity.
9. Investigated and measured buoyant force.

Data Collection Procedures

The small class size provided an ideal opportunity to monitor a majority of classroom talk. At the start of each class an audio cassette recorder was placed on each group's table. A video camcorder was placed centrally in the room, so that it could be moved easily to capture portions of each group's discussions or to capture inter-group arguments. The combined use of these four recording devices allowed almost all of the classroom discourse to be captured. The only exceptions occurred with voices being drowned out by extraneous noise, by students talking over each other, or, in one case, by a student turning off the microphone part way through the class. All audio tapes were transcribed within a few weeks of the class session. The video tapes were used to fill in details of missed conversations and actions of the students (video tape technical difficulties occurred during three classes: for one class their was no video at all, for another there was no sound, and for the last there was intermittent recording). Each transcript averaged about 16 pages per group.

Within a couple of hours of the end of each class, I recorded field notes prompted by a review the video tape for that days class. As other thoughts arose in the time between classes, additional field notes were recorded. In addition, each group's work folder was photocopied and kept on record.

Since the focus of the present paper focuses on an analysis of a particular argument that extended over a period of five classes, much of the other pre- and post-unit data collected is not applicable to this analysis. However, some data from the pre- and post-unit interviews is utilized. These interviews were conducted in early December, with one exception of a student who joined the class in January. He was interviewed one day prior to the first class meeting. Post-unit interviews were conducted two weeks after the last class meeting, with the exception of one student, who was sick on that day. This student was interviewed 10 days later. Other data, which are not relevant to the present analysis, were collected prior to the interviews. The pre-unit semi-structured interviews concentrated on three basic questions:

a. how does floating work? How would you define floating?
b. what experiences have you had with things that float?
c. how do you think this "Squidy" (Cartesian diver) works? can you explain it?

The post-unit interviews included (a) and (b) from the pre-unit interviews and also included:

c. what does density have to do with floating?
d. what does density mean?
e. a task to figure the density of a 250 g., 10 x 10 x 10 cm. block, as shown in a diagram.
f. a task to figure the density of a block floating half submerged in water, as shown in a diagram.
g. what does pressure have to do with floating?
h. what is buoyancy?

Specific details of instructional interventions and activities related to the argument theme are described within "The Argument" section.

Data Analysis

The present analysis focuses on an argument that began during the second class and continued for various lengths of time through the next several classes up to and including class six. This argument focused on density, but added factors as the classes progressed. This argument was extracted from the transcripts of all three groups in all five classes. Since the argument involved the whole class, the transcripts of the three groups were merged. The merging of transcripts proved to be helpful, in that incomplete conversations from one tape were often picked up on another group's tape. The merging process was based on looking for identical dialogue across transcripts, then fitting non-matching segments in sequence. In the transcript segments shown in this paper, the line segments were coded to indicate the class and group. For example, the line segment number 5.3.346 indicates class 5, group 3, line segment 346.

The resulting transcript of the argument was then coded descriptively. The intention of this level of coding was to take a detailed look at the substance of the ideas being expressed and at the nature of the discourse. Although some coding descriptors were taken from a variety of sources, a majority of codes were developed to match the specific discourse. This stage in coding utilized two major divisions of codes: (a) aspects of discourse and argument and (b) aspects of conceptual understanding. Examples of "aspects of discourse" codes include, making a claim, stating a condition, stating a result, defining, explaining, posing alternative explanation, posing counter argument, elaborating, using an example, stating an observation, reiterating, exploring an argument, connecting to context, supplying new information, reacting with emotions-values-aesthetics, and so forth. In examining conceptual understanding from the transcripts, there is obviously a lot of overlap with aspects of discourse. The major difference lies in looking at the specific content of the discourse rather than the pattern of discourse. Examples of "conceptual understanding" codes include, micro-level explanation, macro-level explanation, connection to context, example, description of process, definition, personal experience, elaboration, and so forth. Throughout this level of coding, annotations were added to the transcript document. These annotations were analytical commentaries on specific understandings and patterns evident in the data.

Following this level of coding, a more general coding and sorting of the transcript segments was performed. Segments were coded, then sorted into five general categories: (a) conceptual understanding of density, (b) structure of argument, (c) relations to context, (d) personal experiences, and (e) student reactions to argumentative process. Because of the complexity of the discourse, many of the line segments were coded and sorted into two or more categories. Original codes (from the first level of coding) and annotations were maintained with the segments that were coded and sorted in the second level of coding.

Results

The presentation and discussion of the results begins by trying to create a sense of the classroom atmosphere, the teacher's dilemmas, and the students (the first two subsections). The next subsection presents the argument, including the conceptual understanding as the grounding for the argument, the first indications of the development of the conflicting understandings, and the development of these understandings throughout the argument. Within the sequence of the argument, descriptions of relevant classroom activities are included in order to provide a temporal and substantive context for understanding the children's discourse. In the next subsection, an analysis of the argument from within a framework of a thematic web is discussed.

General Observations

Playing the roles of researcher and teacher led to some interesting dynamics and conflicts during the class sessions. On the one hand, I was intrigued by what the students were saying and doing and how they would resolve conflicts. During the argument that is the focus of this paper, I was particularly interested in where the argument would go with little interference on my part. On the other hand, I felt that I should be taking a more active role in controlling the flow and content of the argument and the nature of the behavior. Coming into the classroom situation, I had put a great deal of thought into trying to hand over more control to the students. I wanted them to move towards working as scientists. As a part of this framework, I wanted to encourage student engagement in the argumentative process. At the beginning of class, I posted and discussed with the class some key ideas about working as a community of scientists. These ideas included: (a) negotiate - discuss, argue; (b) organize - experiments, observations, data, notes; (c) explanations - of how something works - produce several different explanations - narrow down to the one that fits with the evidence from your experiments; (d) justify - support explanations with experimental evidence; (e) predict; (f) ask questions; (g) experiment - design you own experiments - how could your experiment get more accurate results? - could you redesign your experiment and make it better?; (h) clarity; (i) examples; and (j) cooperate. The conflict over control was never resolved and provided a tension for decision-making throughout the class. Tomanek (1994) describes a similar unresolved dilemma of "curriculum control and quality discourse" (pp. 403-404).

In addition, once the class was underway, I experienced a particular hesitation about delving into certain conceptual areas. This hesitation was especially evident when some students started to consider a molecular explanation of density. I was not expecting this notion to be brought up, and had not planned on covering this topic in class. When this topic did arise, I was hesitant about focusing on the topic, because of some concern for what I perceived at the time as a conceptual area that might create more confusion for a majority of the students. When reviewing the transcripts after the class was over, I had second thoughts about this choice of not focusing on the molecular explanation. The students' understandings of the molecular explanation of density were flawed, as will be discussed later. Yet, some students kept referring back to this explanation throughout the ongoing argument.

As a final note about the general nature of classroom talk, the focus of the dialogue varied from moment to moment in each group. Side conversations took place on a variety of topics not related to the class. For the most part, the transitions to and from the on-task topic were virtually seamless. With little or no teacher intervention, the students moved from the on-task topic to their own conversations and back again.

The Students

The students were organized into three groups. Group 1 consisted of George, Gina, Eric, and Gail. Group 2 consisted of Greg, Frank, and Fred. Group 3 consisted of Grace, Gloria, and Graham. Students were assigned to groups on the basis of information I collected from other teachers in the school. In general, I tried to spread particular strengths among the groups.

Most students were generally attentive and engaged in discussions on the topic. However, the degree of involvement in on-task discourse varied among the students. The most vocal students were Gina and Greg. Other teachers in the school identified both of these students as displaying strong leadership skills, as well as demonstrating strengths in math and language. Both Gina and Greg enjoyed engaging in arguments and discussions. Gina, however, sought confirmation (that her ideas were correct and everybody else's were wrong) from the teacher on several occasions. If she did not receive this confirmation, she tended to withdraw from participating in class discussions and activities. Greg seemed to enjoy arguing and playing with ideas without any particular need for confirmation.

One particular student, Grace, rarely participated in the whole class discussions and arguments. In fact, Grace seemed to spend most of her time avoiding participation in the class activities, and especially avoided engaging in any kind of focused discourse on the on-task topics. Although other teachers identified her as displaying leadership skills, she did bring these skills to the class in any constructive way. Another student, Fred, was particularly reserved. However, he seemed to be attentive, and would add the occasional comment. In several instances, he made humorous or sarcastic commentaries on the particular topic or discussion. Feedback from other teachers indicated that Fred had strong math and language skills. For the most part, Graham had difficulty staying focused on discussions and other non-hands-on activities. He drifted in and out discussions frequently. He was most focused and involved when he could physically manipulate materials, especially constructing boat models. Gloria can be characterized as a serious student. She worked on activities diligently, but tended to shy away from more intense discussions and arguments. She also had strong math and language skills. Frank was attentive and readily engaged in the activities. Although he was not a dominant figure in classroom discourse, he was articulate and did not shy away from adding his comments and ideas during arguments and discussions. Gail lacked confidence in her own abilities, but seemed to gain more confidence as the unit progressed. She tended not to engage in arguments, but added judgmental comments about the students involved. She was identified as being weak in math and language. She was not identified as having strong leadership skills, which was evident during the first few classes and certainly corresponded to her lack of confidence. However, as her confidence increased, she started to display leadership characteristics (e.g., assigning other group members to tasks, identifying what needed to be done, etc.), especially in the absence of Gina. Eric tended to be quiet and attentive. He did jump into arguments with appropriate ideas. Other teachers identified him as being a strong reader, but weaker in math and writing.

The Argument

On the first day of class, the students were excited about designing their own boats. During the class, the students displayed a lot of enthusiasm as they worked on an initial boat design. All three groups spent considerable time discussing their designs. They spent a great deal of time considering solutions to the problem of stability of their boat in heavy seas, and, to a lesser extent, solutions to the problem of carrying capacity. One group (Group 3) spent nearly the entire period discussing and diagramming specific design characteristics for their boat.

The second class started off with the task of predicting and then testing which of a variety of objects would float (a list of these objects appears in the Method section). Most of their predictions were correct, except for the piece of ebony, which sank. During the discussion, the students were asked why they thought the ebony sank. Gina suggested that the ebony had more oil in it. Other students suggested that ebony is "a heavy wood," "is dense," and is "petrified." The teacher asked, "what if I put [in the water] a great big piece of one of these other pieces of wood that is much heavier than that little piece?" Several students responded that it would still float, while others continued to suggest that the reason ebony sank was because it was a denser wood. During the discussion that ensued, the argument, which was to reappear in upcoming classes, began. The following transcript segment begins shortly after one student, Gina, said that the reason ebony sank was due to its being more "dense" than water (the teacher's talk is boldfaced; UV = unidentified voice; underlined words indicate spoken emphasis):

2.2.599. Greg But then.. uh, Jeff? Then

2.2.601. Greg ... if you scaled up the big piece of wood, then you have to scale up the water too. You have to make the water ...

2.2.602. **Tchr Yeah, you'd have to make (???).**

2.2.603. Greg So, then it would float.

2.2.604. **Tchr But even if we took one out into the lake, that little piece, and put it in the lake...**

2.2.606. Frank It would sink.

2.2.607. **Tchr It would sink.**

2.2.608. Greg Yeah, Yeah.

2.2.609. Fred But if you put it in a (???)

2.2.610. Greg No, it wouldn't. It would go along to the bottom.

2.2.612. **Tchr [To class.].. What does dense mean? What does density... mean?**

2.1.509. Frank Density?

2.3.440. Graham [Not quite loud enough for the whole class.] Like someone next to me has a dense head. Ha, ha, ha.

2.1.510. Frank It means the ...

2.3.438. Greg Pushed together!

2.1.511. Gina [Interrupting Frank.] It means the amount of molecules that are in the... thing. Like the molecules are closer together and they ...

2.1.512. UV ... they compress!

2.3.439. Fred Dense.

2.1.513. **Tchr What you said... I have another way of talking about it, you know? Now, these blocks of wood are about the same size, right?**

2.2.619 UV It's put together tighter... it's like... squeezed

2.1.514. Greg Yeah.

2.1.515. **Tchr If you take these two pieces of wood, that are about the same size... what are we saying?**
2.1.516. Gina There's more molecules per ...
2.1.517. UV ... per s-
2.1.518. Gina ...centimeter.
2.1.519. UV ... per square millimeter.

Greg introduces the notion of proportionality in line 2.2.601, when he talks about scaling up the wood and water. Both lines 2.2.601 and 2.2.691 are the first indications of the conceptual claim (conceptual theme) made by Greg that served as the basis for the beginning of the argument. At this point, the claim basically states that the density of the same quantity of water changes when the size of the container holding the water changes.

The students began to calculate the density of several different blocks of wood after the teacher elicited the critical variables of volume and weight from the students. The formula for calculating density was written on the board (weight ÷ volume = density). The students were then asked to calculate the density of water. After a short time, the discussion continued after the teacher's reiteration of the meaning of density:

2.1.581. **Tchr So, when you do this, you take how much weight is in the volume, right. That's the density. How much weight is in the volume. How can we figure out the volume, uh, the density of water?**
2.1.582. Gina Uh, we ...
2.1.583. UV Weigh it.
2.1.584. Frank Measure it then weigh it. And how much ...
2.1.585. Gina Does all water have the same amount of molecules in it?
2.1.586. Gina Like, if you just...
2.1.587. Gina ... took water from the tap and ...
2.1.588. [indecipherable comment - about sea water?]
2.1.589. Gina No, because water has salt in it. Never mind.
2.3.468. Frank Uh, H_2O. No, that's the molecule. Uh, water... I'm not sure.
2.3.469. Fred Uh, zero ...
2.3.470. Frank Well, it can be a lot. It can be a little.
2.2.691. Greg If you took all this... if you took all this water and put it in a container smaller, it would still weigh the same, but it would have a different density, because the volume is... uh... smaller.

The other notable characteristic of Greg's statements is the "if...then" structure of his argument. As we will see in upcoming excerpts of discourse, this structural pattern of children's arguments is fairly typical.

The first notion of Greg's conceptual understanding of the nature of density became apparent in the previous excerpt (leading up to and including line 2.2.691). However, the full extent of his understanding is not yet clear. As the conversation continued, we begin to see the development of the underlying meaning:

2.2.692.	**Tchr The volume is smaller?**
2.2.693.	Greg If you put it in a smaller container. Then the volume will be smaller ...
2.2.694.	**Tchr D'you agree with that?**
2.2.696.	Greg ... and there's more weight in ...
2.2.697.	**Tchr So if you just took the same amount of water and put it into another container ...**
2.2.698.	Greg Smaller container.
2.2.699.	**Tchr ... smaller container.**
2.2.700.	Greg The volume would be smaller, that means ...
2.2.701.	**Tchr Would you...**
2.2.702.	Greg ... the weight ...
2.2.703.	**Tchr ... agree with that?**
2.2.704.	Greg ... but it'd be the same weight.

This sequence, at first glance, appears to be indicative of Piaget's pre-operational stage, where quantity is not conserved. However, there seems to be much more going on here. Greg suggested that when you pour water from a large container into a smaller container the density changes. He says that the weight stays the same, but the volume decreases. Although the conceptualization appears to be at the pre-operational level, the ensuing discussion and argument reveal a different scenario.

Class 3 started with a request to review what had been discussed in the previous class. The following excerpt shows Greg's continued development of this idea.

3.1.22.	Greg But, however, if you had the same amount of ebony that you had in a much larger volume, possibly it would float because it [I assume he's referring to water] wouldn't be as dense
3.1.24.	Greg ... because it wouldn't be as dense.
3.2.30.	Fred No. That's not right.
3.1.25.	**Tchr Now, okay, what was that again?**
3.1.26.	Greg The ebony possibly could float if there was the actual amount of ebony in a larger volume, 'cause it wouldn't be as dense.
3.1.27.	**Tchr Does everybody agree with that?**
3.1.28.	[Fred and Frank.] Yeah.
3.1.29.	UV No.
3.1.30.	**Tchr Okay, say it again. So, you're saying...**
3.1.31.	Greg Well, the theory of volume is that objects are as dense as they are compacted, so...

Greg's understanding is still unclear. He contends that water will become more dense when put into a larger container, but how he sees this working is not mentioned at this time. However, we do see indications of understandings beyond the pre-operational stage as suggested previously. In line 3.1.31, as well as in line 2.2.626 from class 2 (Greg: "There are more molecules in it."), Greg talks about molecules moving closer together when the water is placed into a smaller container. The notion Greg is describing in these two excerpts have to do with the molecular structure. Density is determined by how close together the molecules are. In some sense, he seems to think that all molecules are the same size (as suggested by Gina, as well, in lines 2.1.511 to 2.1.585). They suggest that density has to do with more molecules per "square" [cubic] centimeter. This would hold true for one particular substance, but not for comparing across substances, where the size and weight of molecules differ.

He takes this notion further in discussing the relationship between volume and density in the next two segments (underlined words indicate speaker's emphasis):

3.2.54. Greg Also the smallest thing <u>could</u> float, if it was in a larger volume, because it was the same small thing...

3.1.140. Greg Unfortunately the theory of relativity and physics, uh, will not let us change the density of the ebony. However, we <u>could</u> change the density of the water, by putting it in smaller or bigger containers.

In the above two segments, Greg seems to be focusing on "volume" as the critical criterion of density: the larger the volume, the greater the density. This criterion could be a source of the confusion over density. The understanding of how molecules affect density was another major conceptual area of contention for the students. The following argument segment elaborates on this understanding:

3.1.66. Greg No... the density is the larger the volume the larger the...
3.1.67. Gina No... the thickening molecules. The amount of molecules per square... the volume.
3.1.68. **Tchr How can we... How do we measure density?**
3.1.69. Gina Um, by weighing.
3.1.70. **Tchr By weighing?**
3.1.71. Gina Like if you compared, like if you compared one piece of ebony to one piece of pine that were the same size...
3.1.72. **Tchr Right.**
3.1.73. Gina And you put them on a scale, that ebony might weigh more, and you would know that the molecules are denser in the ebony. But I don't know how they could find out how much denser, like how many molecules...

3.2.91. Greg Right.
3.2.92. Gina But I don't know how they could find out how <u>much</u> denser, like how many molecules...
3.1.74. Greg You can measure ...
3.1.75. Gina Like I know on a penny ...
3.1.76. Greg You can measure ...
3.1.77. **Tchr [To Greg.] Go ahead.**
3.1.78. Greg ... density by length times width times height, because that's volume.
3.1.79. **Tchr Volume ...**
3.1.80. Gina Yeah, but that doesn't show how many molecules there is, because...
3.1.81. Greg No, it doesn't show how many ...
3.1.82. Gina ... because... because look!
3.2.102. Greg But if you could...
3.3.117. Gloria You take the height... I don't want to get into this argument.
3.1.84. Gina Wait, Greg, Greg. If the pine... it has the same measurements, it'll seem like it has same amount of molecules, so that wouldn't work.
3.1.85 Greg I agree. You're right there and I'm wrong.

The metaphorical explanation of "thickening" molecules, in line 3.1.67, depicts a sense of fluidity to Gina's understanding of molecules. As we can see throughout this segment, the idea seems to be one of equivalence of molecular size and shape across different substances. The difference between the density of substances is determined by how thickly compacted the molecules are. In line 3.1.73, she figures that weight is an indicator of molecular "thickening." However, in the last line, Gina, who initiated the idea of a molecular explanation of density, seems to have come across the problem in her own understanding of molecules. Two different kinds of wood of the same size would appear to have the same number of molecules. If all molecules were the same size this logic would work, but she realizes her argument does not make sense. The point of confusion remained as the topic of discussion changed direction.

In the previous excerpts, Gina worked from the position of the degree of molecular proximity as the defining feature of density. On the other hand, Greg contended that pressure is affected by volume and therefore affects density. These two conceptual positions served as the basis for the argument. During classes 2, 3, and 4, the classroom discourse on these topics can be characterized as exploratory and constructive. The students hashed out ideas, had minor disagreements, and worked out details of and elaborated upon their ideas. The previous excerpt, from lines 3.1.66 to 3.1.84 typify much of this sort of constructive discourse. In class 5, the discussion became more heated.

The rest of class 3 was directed at having the students figure a way to get ebony to float and rosewood to sink. The intention of these activities was to elaborate on the notion of density in general and to work with the relationships between the densities of various media and the densities of different objects. Some of the initial ideas generated by the class of how to get ebony to float included, letting the ebony stay in the water and get "water-logged" and hollowing out the block. The teacher also reintroduced an idea brought up in the previous class about temperature affecting density. Gina provided an example of baking a cake. The teacher asked about hot air balloons, and the students responded with "hot air rises." A short discussion ensued about the density of hot air. The teacher then asked about water and ice. Greg responded that "ice is very much more dense." The teacher followed with, "if ice is denser than water...", but was interrupted by Gina saying, "it would sink." The class then continued with their activities of getting ebony to float (mixing salt with water) and rosewood to sink (using alcohol as the medium).

Near the beginning of class 4, a short follow-up discussion of class 3 took place. The discussion was prompted with an attempt to connect what the students had worked on with real ships they see in the harbor:

4.1.173.	**Tchr ...now what happens if you've got this metal hull... just like the piece of ebony and it's hollow inside. What's the relationship of the density of that total object, including the air in the hull, to the water.**
4.1.174.	Gina Oh, I know. Well, if it's heavy on the bottom and heavy on the top, then it might sink. But if it has a hollowed out space... on the top, then it's not gonna sink, because it doesn't have as much weight to carry...
4.1.175.	Greg Yeah, but...
4.1.176.	**Tchr Yeah, so the weight, I mean density, is the amount of weight you've got in a particular volume.**
4.1.177.	Gina So maybe, wait... Maybe if a piece of wood had, had a volume, but had less... like it was carved out, so it had less density to the volume, then it would float.
4.1.178.	Greg Obviously though, like if... when there's... it's just a big chunk of ebony, it's not going to sink. I mean it's going to sink, but if it's <u>hollow</u> also, when it... if it tries to sink in the water, that... that there's not enough room, 'cause air... can't be in water, so when the air from the... inside of the ebony tries to enter the water, the water has to go to the side, and there's less density. [Rather remarkable stillness in the room as Gina and Greg speak.]
4.1.179.	**Tchr Yeah, that's actually called the displacement.**
4.1.180.	Greg Yeah.

The focus of the above segment was around the notion of displacement. This particular theme arose out of a cooperative discussion of how to manipulate a block of ebony - by hollowing out the block - in order to get it to float. In line 4.1.177, Gina attempted to apply the notion of density to hollow block. She appeared to confuse the term "density" for weight, however, in line 4.1.174, she used the correct concept of weight ("doesn't have as much weight to carry"). Greg's continuation of this line of thought points to the idea of displacement as he worked with the notion of how the air in the hollow block cannot mix with water. The last part of this line of thought is more confusing when he related water being pushed aside with a resulting decrease in density.

Following the original plan for class 4, the remainder of the class was devoted to investigating a toy Cartesian diver ("Squidy") in a two liter plastic bottle. The Squidy's tube of the diver is covered with an opaque piece of rubber. By squeezing a two liter plastic soft drink bottle, you can get the Squidy to sink. The students generated some hypothetical explanations, followed by an investigation of a Cartesian diver with all of the parts visible (a partially filled and inverted test tube as the diver and a clear graduated cylinder covered by a piece of balloon). After this class, I felt that investigating pressure was premature and that the students needed more time to work with the concept of density.

Initially, other activities had been planned for class 5, but the need to further explore density initiated a new activity. The task for this class was to apply what they had been working with to the design of a vessel. The students were asked to construct a boat out of aluminum foil and predict how much weight it could hold without sinking. Part way through the class, the formula for density was again written on the board. The argument began after I asked the class if they remembered the density of water. One student responded with "depends", then the following discussion commenced:

5.1.268.	Gina No, (???) little cup of water, and you pour a little cup of water into a big bucket it still weighs the same.
5.1.270.	George It's true.
5.1.271.	Gina If you pour a little cup of water...
5.1.273.	Gina ...into a big basin, you'll have the same amount of water in the big basin...
5.1.275.	Gina ...than in the little cup of water.

In this example, there was general agreement that the quantity remains the same when water is poured from a small container into a larger container. However, I asked the next question about density:

5.1.277.	**Tchr Yeah, but is the density the same?**
5.1.278.	Gina Yes.
5.1.279.	[Other voices saying, "Yes."]
5.1.280.	Greg Yes, because it changes in a smaller volume, because the density gets...

5.1.282.	Gina Well, I'm sorry...
5.1.283.	**Tchr ...but, if you change the volume, you change the weight, too.**
5.1.284.	UV Yeah, so (???)
5.1.285.	Gina Well, maybe slightly, but I'm sorry to say, when I drink a glass of water, I don't notice any difference. I don't feel any heavier, or I don't feel the water's thicker than when I take a big bucket of water and drink it.
5.1.287.	Greg That's because the water comes out ...
5.1.289.	Greg It's different when you drink a cup of water...
5.1.290.	Gina See, see, he just said the density's gonna be the same, no matter what you do.

In line 5.1.280, Greg appeared to agree initially, but brought up his argument about the volume of the container affecting density. Gina responded somewhat indignantly (line 5.1.282) and continued with a rebuttal from her personal experiences of drinking water. Greg countered with the beginning of an explanation that the density changes once the water comes out of the container. Gina interpreted Greg's statement as a concession to her point of view.

Several seconds later, a rapid firing of adamant accusations occurred (underlined words indicate speaker's emphasis):

5.1.295.	Gina But you're wrong, Greg. You're wrong.
5.1.296.	Greg No, what we said was... density... density changes in a smaller volume.
5.2.413.	Gina You're wrong.
5.2.414.	Greg No, what we said is... the density... dense- I don't know... it changes in a smaller volume.
5.1.297.	Gina That's not true.
5.1.298.	Greg Yes, it is. It's the same...
5.1.299.	Gina You're wrong.
5.2.418.	**Tchr [To Greg.] Well... we're not convinced.**
5.2.419.	Greg That's what you said.
5.2.420.	**Tchr Convince us. I'm not convinced, and she's not convinced.**

Both students felt they were correct in their positions. Gina appeared to have a strong emotional connection to her position as she lashed out at Greg. Greg triedto restate his position (line 5.2.414), but was rejected by Gina.

After the previous verbal skirmish, Greg posed a significant question about how density can be the same in a "whole sea." Another student offered support for Greg's position, then Gail suggested that another factor ("salt") may be a problem in Greg's example. Such criticisms of potential influencing factors or variables were fairly common throughout discussions in the class. This exchange was followed by some negotiation of terms between Gina and Greg (lines 5.2.433 and 5.1.313). Finally, Fred suggested a problematic factor ("mud") with the lake example. Fred's comment was seemingly ignored, and the argument continued:

5.1.303.	Gina	You're wrong, Greg.
5.1.304.	Greg	No, I'm not.
5.1.305.	Gina	O-oh, yes, you are.
5.1.306.	Eric	[To Gina.] He's right, you know.
5.1.307.	Greg	How can density be the same, if you have a whole sea?
5.1.308.	UV	Yeah.
5.1.309.	Greg	Okay, if you have...
5.1.310.	Gail	The sea has salt water in it.
5.1.311.	**Tchr**	**Wait, okay...**
5.2.433.	Greg	Okay a fresh water sea like in a...
5.1.313.	Gina	Fresh water lake.
5.2.436.	Fred	That has mud in it.
5.2.437.	Greg	And then you put that in a tiny little centimeter cube ...
5.1.316.	Gina	You can't put that in a tiny little...
5.2.439.	Greg	Yes, if you compacted it, there would be a lot...
5.2.440.	Frank	You can compress it.
5.1.318.	Gina	You can't compress water!
5.2.442.	George	You can so. You can compress water.
5.2.443.	Gina	You can't take a big thing, and compact it into a little thing. You can't.
5.1.321.	**Tchr**	**Well, if you could that'd (???)**
5.1.322.	Greg	The density will change.
5.1.323.	Gina	Right, if you could.
5.1.324.	Greg	That's just an example. The pressure will change ...
5.2.448.	Gina	If you could, it would happen, but you can't.

As can be seen in the above segment, Greg's understanding of change in density when water is poured from a small container to a large container involves the notion of pressure. He contended that water can be and is compressed when put in a larger container. As in an earlier segment, the larger the volume the greater the density: (3.1.66. Greg "No... the density is the larger the volume the larger the..." [density]). What appeared as pre-operational thought at first is much more complex. To an extent, Greg was correct in contending that pressure affects density. However, his comments suggest that pressure changes the density of the entire body of water, rather than increased pressure and density with increased depth. In addition, Greg's claim that you can "compact" water initiates a new point of contention. Although pressure had been addressed previously, the notion of pressure was a passive one. At this point, the notion of pressure takes on an active characteristic -- pressure can be applied to water to compress it in to a smaller volume. During this back and forth exchange, Greg tried to focus the new direction of the argument on density (line 5.1.322). Gina agreed with the resultant claim, but not with the initial assumption that water can be compressed.

A short time later, after several comments from other students, Gina went to the chalkboard to make her point:

5.1.330. Gina Wait a second! [Goes to the board.] Wait. Wait.
5.3.302. Greg No, I'm right. I'm right.
5.1.332. George If you took a glass ...
5.1.333. Gina If you took a big tall container and a big thin container, the density doesn't change. The water level on here is just higher than it is over here. If you have the same size thing, and a huge thing over here...

Gina tried to explain that a change in size and shape of container (the condition) changes water level, but does not change the density. This explanation is characterized by an example of a situation (the two containers), an unjustified claim (density doesn't change), and an alternative, observational claim (water level changes). The apparent logic of Gina's argument is that the alternative claim is sufficient evidence to support the unjustified claim that density does not change.

A short while later, after much back forth yes-you-cans, no-you-can'ts, and other comments from Greg, Gina, and several other students, the argument resumed:

5.1.352. Greg You can compress it.
5.1.353. Gina No! I can't pour a full thing of this into a small thing of this.
5.3.324. Gloria [Laughs.]
5.1.354. Eric Yeah, I know, but if you had a lot of pressure, you can...
5.1.355. Greg You can... how do you think they ...
5.1.356. Gina How are we gonna get that pressure?!
5.1.358. Eric We aren't ...
5.3.330. NB You're wrong.
5.1.360. Greg Yeah, Gina. We just have... (???)
5.1.361. **Tchr Okay, let Greg talk for a minute.**
5.1.362. Greg If... I'm not saying that we can... but, it's true. People do put this amount of water into a little thing like...
5.1.363. Gina No! If you're not saying they can, then how do they?
5.1.364. Greg You can.
5.1.365. Gina No, you can't.
5.1.366. Greg Yes, you can.

Gina's challenge, in line 5.1.353, was rebutted by Eric, adding the active sense of pressure. Gina, then, questioned how that pressure can be applied. Greg tried to justify the claim (in line 5.1.362) with an unjustified and vague reference to people accomplishing this task. Gina closed in on the mark with a question directed at supplying more information on how compressing water is done.

A couple of minutes later, I asked a question that opened up a new perspective of the students' understandings:

5.1.392. **Tchr We have fluids all around, right? Air is a fluid, right?**
5.3.367. Gloria Yeah.
5.1.393. Gina Right.
5.1.394. UV Right.
5.1.395. **Tchr It moves. And we can compress air...**
5.1.396. Greg Yes! There you go. And the density of the air changes.
5.1.398. Gina But, no, it doesn't. The density does not change.
5.3.375. Greg Oh, yes, it does.

Apparently, Gina did not see a relationship between the compression of a fluid and density, although she seemed to agree with the potentiality earlier in the argument (lines 5.1.322 to 5.1.323).

The argument continued for several more minutes. Then, just before the groups resumed work on their investigative activity, Gina tried to get in the last word by walking up in front of the video camera and talking:

5.1.537. Gina Now let me give you a (???). If you had a five ton piece of wood and a five ton piece of rock, which would float? Now... you have to think that the wood would float because it has a lesser density than the five-ton rock. So that's how it works. [With indignation:] I hope you can figure that out some day in your life.

Gina's summation posed a problem of two different objects of the same weight. This question and answer sequence is suggestive of a Socratic approach. Yet, she falls short of providing an adequate explanation of the phenomena by not defining how density works.

Class 6 resumed the previous activity of building an aluminum foil boat and predicting its carrying capacity based on the relative density of the vessel. The argument drew to a close during class 6. A few minutes into this period, Greg picked up the discussion with an example to support his idea that water can be compressed:

6.2.105. Greg Right. I know how you can put pressure on water, Gina. And I have this person to back me up. You know, you know those things that you drink where you use a pump and you get a little rocket?
6.2.106. Fred Yeah.
6.2.107. Greg And you pump it up and then it shoots into the air?
6.2.108. Fred Yeah.

6.2.109. Greg Well, that you're putting pressure on the water because you're pumping air into this little container.
6.1.83. Gina No, but, but it's not compacted. The thing is ....
6.3.98. Graham Yes it is, Gina.
6.1.84. Greg Yes it is.
6.1.85. Gina No. What's going on is it's ...... so it has to put all that pressure that you're giving it up into the rocket.
6.3.100. Graham Yes. But, that still, you're, this is like .... You're still ..... You still put pressure inside the container.

As mentioned in a previous section, Greg tried to back up his claim with a vague reference to a person. However, he then provided an example of a toy that compresses water. He continued to elaborate on his claim in line 6.2.109. Gina's rebuttal (line 6.1.85) vaguely referred to "giving" up the pressure into the rocket. Graham, in one of his rare contributions to the argument up to this point, suggested that the pressure inside the rocket affects the water. Moments later, Graham continued with his claim:

6.2.117. **Tchr Wait, wait a second. Let... Okay. Let Graham... ...**
6.3.102. Graham But, you're still putting the pressure inside of it. You still have it in there.
6.2.118. Gina You're still putting pressure on it.
6.2.119. Greg Exactly.
6.2.120. Gina But the molecules won't compact...
6.2.121. Graham Yes they will.
6.3.105. Gina 'Cause they have to shoot out.
6.2.122. Graham Yes. But, after, after... a certain amount of t...
6.2.123. **Tchr We'll be looking at this a little bit more. Uh, Friday. If we get through this class today. But that's...**
6.3.110. Frank Yeah, and some air. But, it's because, it's because there, when the rocket... if it was compressing against the water, the only thing that would come out was air. And when you shoot the rocket, water comes out. So it must be compressed.

Gina's response refers back to her previously discussed molecular explanation for density. Her causal explanation (line 6.3.105), as to why the molecules cannot be compressed, does not appear to follow from her initial claim. However, the highlight of this sequence occurred when Frank contributed an articulate argument (line 6.3.110) supporting the compression of water. In this argument, he posed a hypothetical condition, "if [air] was compressing against the water" and not compressing the water, and follows with a logical result that "the only thing that would come out was air." He then supplied observable evidence that refuted his hypothetical condition and result, followed by a conclusion that the water "must be compressed." Although this point could be argued, he has supplied a clear and fairly complete argument structure.

The argument drew to a close with some further discussion that added the expansion of water to the argument about compressibility:

6.2.136.	Frank	But, air, but, water can be stretched apart, put into a bigger volume.
6.1.96.	Gina	It's not stretched apart. It just fills up the bottom.
6.2.140.	Frank	No. But when it's steamed.
6.3.120.	Gina	What it can't do, what it can't do. Okay. All right.
6.3.122.	Graham	Yeah, steam, steam, damn it, steam.
6.3.123.	**Tchr**	**Gina, maybe you can just listen to Frank**
6.2.142.	Frank	If something can be compressurized or whatever you can call it, it can probably be compacted.
6.3.125.	Graham	Same with evaporation. Evaporation. It's just ......
6.2.144.	Frank	Cause when it's steamed, it's just barely anything.
6.2.145.	Gina	But, can I say something? It's not ......
6.2.146.	Greg	No you can't.
6.2.147.	Fred	No, of course. Because you're going to be wrong.
6.1.100.	Gina	It's not just... It's changing its shape. It's not compressurize. See, the water, if you have it in a big container, it's not going to just... and you pour it into that container, which is higher because it can't compress into that... low of a spot right there. And you pour it into here, it's not just going to stay as one big thing. But, it's not going to be from being compressurized, it's just going to flow out... (?)
6.3.130.	Graham	Without force.
6.2.149.	Greg	No, without force, Gina, but with force it will.
6.2.150.	Frank	It will.
6.2.151.	Fred	With force, it will.
6.2.152.	Graham	It will compress...

The argument here, from Gina's perspective, suggests that water, although fluid in character, has the characteristics of a solid in that it cannot be compressed. As we have seen, Gina agreed that gaseous fluids (i.e., air) can be compressed, but liquid fluids cannot. This conceptual "block" appears to have prevented her from grasping the basis for the others' argument.

The extent and dynamics of this free-flowing argument have brought to light the complexity of children's thinking and understandings. The most common components of the students' arguments consisted of (a) using examples derived from their personal experiences, and occasionally their prior school-type knowledge, in supporting particular claims or as contradictory rebuttals; (b) organizing statements in condition-result and "if...then" sequences, but with some degree of variation in the completion of the ideas contained in specific arguments; and (c) rejecting or accepting claims with little or no elaboration.

By far, the most intriguing aspect of the ongoing argument was the use and development of various conceptual understandings. The argument began with two basic notions involved in density. One concerned the proximity of molecules, but appeared to be based on the assumption that all molecules were the same size. The other concerned the density of water and was based on the idea that the volume of the body of water affected the overall density. In the latter case, the assumption appeared to be that density was uniform throughout the medium. As the discussion and argument progressed, new facets of the students' understandings were added. Adding substances, such as salt, to water was immediately recognized by the group as a means of changing the density of water. The next major conceptual aspect to arise involved the notion of pressure affecting density. This particular idea grew from the volume problem. The students contended that a greater volume of water was subject to greater pressure, which would increase the density of the water. However, they also asserted that water could be compressed, therefore increasing density. On the other hand, Gina's molecular view of density conflicted with this claim. She felt that the molecules could not be compressed, and, even if they could, the density would not change. The final contribution to the argument dealt with stretching molecules apart, as in steam or the evaporation of water. Once again, most students supported this claim, but Gina maintained that stretching the molecules apart would not affect the density.

Thematic Web of Argument

A number of themes are evident from the previous discussion and argument during classes 2 to 6. As the teacher, I found it difficult, in the heat of the moment, to identify the existence and significance of some of these themes. During the analysis of the transcripts, the themes became more obvious. As we can see in figure 1, the two major sides of the argument contained a number of themes, some of which extended over one or more classes. In several instances, the argument picked up on statements made in previous classes. One such example is seen in the in the continuation (from class 3 into class 6) of the argument about density being in proportion to the size of the container.

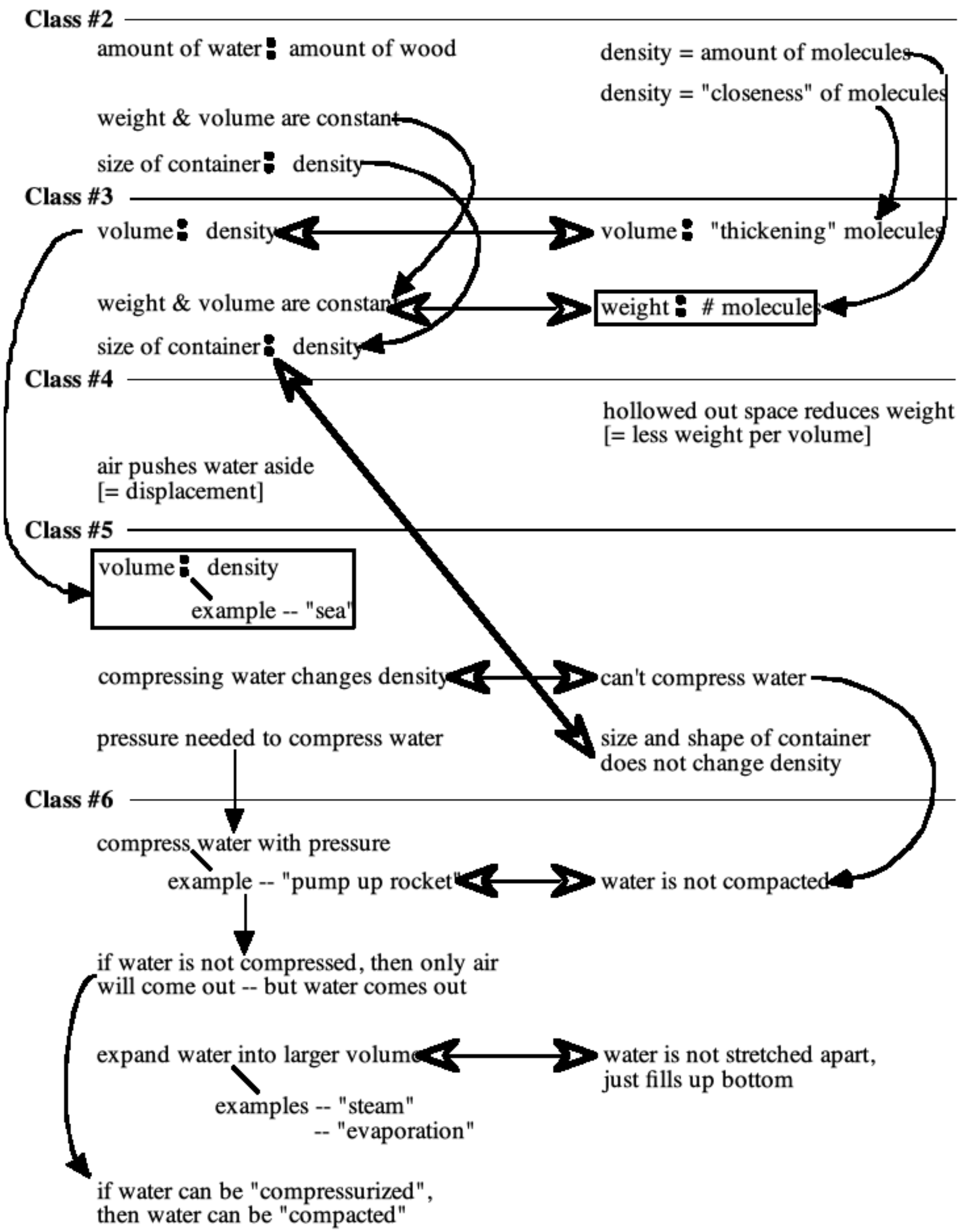
In addition, the ideas discussed at one point in the argument either carried over to following classes or lead to or created the basis for new points of departure. During classes 2 and 3 and the beginning of class 5, one side of the argument (left side of figure 1) was concerned primarily with proportionality among density and quantities of the medium or object. The culmination of this particular theme focused on the proportionality of the volume to the density of the medium. An example of the "sea" was used to support this claim. At this point in the argument, a new theme was needed to support the previous one. The notion of "pressure" became this new theme. Pressure became a necessary factor in supporting the previous claim that the greater the volume of the medium (i.e., water) the greater the density. This theme split almost immediately into two sub-themes of pressure as a passive factor and pressure as an active factor (i.e., the act of compressing).

The other side of the argument was based on one theme, which took a molecular view of density. The ideas discussed in class 2 were carried forward to class 3 as proportional relationships between volume and the proximity of molecules and between volume and the number of molecules. Although the theme was not explicitly extended into later classes, it did appear to influence the thinking evident in the challenging to the "pressure" side of the argument.

The themes just discussed are marked by particular terms or phrases. In the midst of rapid fire classroom dialogue, teachers may find identifying significant themes to be a difficult task. The notion of thematic or contextual markers (Bateson [1979], Bruner [1986], and Lemke [1995, April, personal communication] refer to such markers as "context markers," "triggers," and " sign-posts," respectively) may provide a way for teachers to identify relevant themes upon which to build further activities and discussions. The three major themes evident in figure 1 are (a) proportionality, (b) molecules, and (c) pressure (including compression). However, another more subtle and fundamental theme is present, as well. The markers for this theme appear inside boxes in figure 1. This theme is "uniformity," and forms the underpinnings for both sides of the argument. The notion of uniformity acts as an interpretive framework (Bloom, 1992a, 1992b) or an underlying principle (Lemke, 1995, April, personal communication, meeting of the American Educational Research Association, San Francisco) that guides the making of inferences, connections to other ideas, and so forth. Uniformity of pressure became evident when Greg puts forth the example of the "sea" as an example of volume being proportional to density. Certainly, the pressure at the bottom of the sea is greater than at the surface. However, according to the chain of this argument, the density at the bottom of the sea is not greater than at the surface where the pressure is lower. Rather, the density is greater throughout the sea, since the view of the students suggests that the pressure is uniformly distributed throughout the body of water.

On the molecular side of the argument, the notion of uniformity becomes more obvious in the statement that the weight of an object is proportional to the number of molecules. Such a statement may be true with objects made of the same material, but is not true with objects made of different materials (or of liquids at different temperatures, etc.). Uniformity of molecules suggests that all molecules are of similar size, shape, and weight. In addition, this side of the argument suggests another characteristic of molecules (that are uniform): molecules in an object or liquid medium cannot be compressed.

The underlying meanings associated with the students' argument and other dialogue are difficult to extract in the fast paced action of the classroom, but, at the same time, they are crucial for understanding what it is that students are trying to say. Looking for and identifying potential context or thematic markers may be one way to facilitate this process. The more a particular marker is repeated, the more likely it is that the marker signifies a major framework or principle at work.



Class #2
amount of water : amount of wood
density = amount of molecules
density = "closeness" of molecules
weight & volume are constant
size of container : density
Class #3
volume : density
volume : "thickening" molecules
weight & volume are constant
weight : # molecules
size of container : density
Class #4
hollowed out space reduces weight
[= less weight per volume]
air pushes water aside
[= displacement]
Class #5
volume : density
example -- "sea"
compressing water changes density
can't compress water
pressure needed to compress water
size and shape of container
does not change density
Class #6
compress water with pressure
example -- "pump up rocket"
water is not compacted
if water is not compressed, then only air
will come out -- but water comes out
expand water into larger volume
water is not stretched apart,
just fills up bottom
examples -- "steam"
-- "evaporation"
if water can be "compressurized",
then water can be "compacted"

<u>Figure 1</u>. Chain or web of themes and points of contention in argument about density. (= points of contention; = thematic continuation; = proportional to; box = interpretive framework marker).

Discussion

Although the argument began and was dominated by two students, most of the other students became increasingly involved as the argument progressed over several class meetings. The nature of student involvement, beyond the two dominant students and the one totally uninvolved student, ranged from engaged listeners, who added significant comments to the discussion, to periodically engaged or confused listeners, whose comments tended to be more superficial to the content of the argument. Although the class was small, a similar pattern to Eichinger's (1993, April) description of dominance and engagement was apparent.

The most common patterns of argument used by the students included (a) "if-then" structures, (b) confrontational questions, and (c) blanket assertions. Within these patterns, students commonly used examples from personal experiences to support their claims. The patterns of argument evident in the students' discourse are reasonably sophisticated. The "if-then" pattern provided a means for students to propose particular conclusions based on specific observational evidence (mostly from personal experiences) or on specific warrants. This pattern provided a basic approach to structuring their arguments. However, the problem with many of these argument patterns involved (a) insufficient or incomplete information from experiential or formal knowledge and (b) deferring to a vague authority or to an unnamed "truth." Partial and incomplete understandings of formal concepts remained a difficulty throughout the extended argument.

In addition, many of the supporting examples and ideas referred to are deeply embedded in personal experiences. Not only do the students appear to rely upon such examples to support their arguments, but these examples seem to provide a strong anchor for their own idiosyncratic understandings. Gina and Greg, in particular, held to their own points of view with great tenacity (as we will see later). And, both of them generated significant support from their own experiences. The support students generate from personal experiences in a real world context may play a major role in why

Following the progression of the argument provides some interesting insights not only into the understandings students hold, but also into the potential for teachers and researchers to misinterpret the ideas students express. Looking at Greg's initial comments about density changing when water is poured from a small container into a larger one could easily be attributed to pre-operational thinking. Such statements are easy to pigeon-hole: we can label it, file it, then move on to the next item of investigation. However, as we saw, Greg's thinking and understandings were much more complex than what were initially expressed.

As we look at the two positions of Greg and Gina unfold, the underlying meanings and understandings become more apparent. What is particularly interesting about these two positions is their fundamental similarity. Greg contends that the volume of the medium (i.e., water) affects the density. The larger the volume, the greater the pressure, and therefore the density will be greater. Gina's position holds that a liquid medium, such as water, cannot be compressed, and that the volume of the medium does not affect the density. She agrees that the pressure might increase, but that the molecules cannot be compressed. Both of these contentions are based on the notion of uniformity. Uniformity of pressure and density throughout the medium characterizes Greg's position. Gina's position is characterized by molecular uniformity across substances -- molecules are the same shape and size across substances (solids and liquids) and behave in similar ways (i.e., they can't be compressed). This notion of uniformity can be seen in terms of what I have referred to in previous papers as an interpretive framework (Bloom, 1992a; 1992b). This underlying notion of uniformity guided the students thinking about density and the nature of various substances. Such an interpretive framework provided a means for making sense out of their experiences, but also provided an obstacle to developing more accurate understandings. Following the "guidance" of this particular framework helped to confound their thinking and logic. At one point, in lines 3.1.66 to 3.1.84, Gina paints herself into a corner with the logic of uniformity. The uniformity of molecules led her into a what Bateson (1979) calls a muddle. She realized her logic did not work, but had no way of resolving the difficulty.

From another perspective, we can see how this interpretive framework (or underlying principle) of uniformity relates to the difficulty of sacrificing internal coherence for intuitive understandings in the epistemic frame discussed by Perkins and Simmons (1988). Such interpretive frameworks can provide the basis for what are loosely referred to as intuitions or intuitive ideas. Many researchers refer to children's intuitive ideas as ideas based on personal experiences, but the notion of intuition has always posed a nagging question in my own mind. As mentioned earlier in this section, it easy for researchers and teachers to label a particular concept expressed by a student as pre-operational, but the same holds true for labeling a particular concept "intuitive." The term intuitive seems to be a term of convenience, a word that can mask underlying uncertainty and confusion. However, we might be able to start to define the territory of "intuition." What we see as intuitive might be comprised of specific thinking processes and interpretive frameworks that guide these processes.

Personal experiences and school-type knowledge are incorporated into and processed by interpretive frameworks. As we can see throughout the argument, students commonly drew on examples from personal experiences embedded in real world contexts and from learning experiences in school. They utilized these examples to support their claims and counter arguments. At the same time, these personal experiences anchor the students' arguments in a sort of emotional "glue." Students develop an emotional stake in their ideas and knowledge claims. We saw throughout the argument the frequent emotional vehemence in the students' discourse as they dug in their heels and defended their positions.

Another contributing factor to the students' emotional stake in particular aspects of the argument involves underlying motivations. Gina appeared to be driven by a desire to be "right" and to receive some recognition for having the correct answer. Greg's motivation was not quite as clear. He certainly appeared to driven by a desire to have the correct answer, but seemed less concerned with receiving recognition. However, the fundamental point here is that children develop an emotional connection with their particular motivations. And, these motivations further entrench their emotional attachment and allegiance to their own individual ideas.

The combination of the emotional stake in their personal experiences and understandings, the apparent sensibility of interpretive frameworks, and their emotional connections to their individual motivations creates a highly resistant situation. The well documented difficulty of getting children to learn accurate scientific concepts and explanations when they hold entrenched alternative conceptions is confounded by the complexity of emotional connections to their own personally constructed conceptions. It is fairly clear that direct instruction does not help children to change or modify their understandings. The problem becomes not only one of modifying understandings, but also of working with children's emotions. Obviously, further research is needed in this area. However, we may want to consider several suppositions that may help guide our investigations in this area:

1. children identify with or perceive their emotions as real and rational.
2. emotions are deeply connected with an individual's sense of identity.
3. dismissing children's emotional connections to their understandings can be seen as an affront to the children's perceptions of self.
4. children's emotional connections to ideas should be acknowledged and supported.

These suppositions provide a basis for guiding our actions in the classroom. However, we may not always be able to address such emotional needs appropriately. In the present study, the problem of dealing with Gina's emotional connections with her ideas and her need to be confirmed presented a difficult dilemma. In this situation, these two emotional connections were in conflict in terms of the actions that could be taken by the teacher. Allowing her to express her ideas freely and openly and without judgment conflicted with her need to receive positive judgment and her desire that her classmates receive negative judgments. Hedging your bets by confirming that she had a good idea and that the other students also had good ideas did not satisfy her emotional needs. As a result, she tended to withdraw from the class activities. As with any dilemma, the answers are not always clear.

In terms of the other dilemma that I confronted between encouraging or controlling the argument, there are some intriguing implications for teaching and confronting children's personally held conceptions. As Tomanek (1994) suggests, such dilemmas are difficult to resolve, since there are no clear-cut, correct answers. However, the tension inherent in the dilemma provides for all sorts of possibilities. Exerting more control over the flow of the argument could have risked not allowing the students to express fully their ideas. On the other hand, addressing particular concepts, such as molecular explanations of density, could have allowed the students an opportunity to modify their existing ideas. However, the extended argument did allow the students to contend with their understandings and confusions and to build a base upon which later instructional experiences could build. Throughout the course of the unit and the argument, instructional activities, including direct instruction, were initiated to address thematic topics and issues that arose in previous class meetings. The difficulty in interceding with appropriate instruction is determining the appropriate time to do so. In retrospect, the initial emergence of the molecular explanation may not have been the most ideal time to intercede. The students were just beginning to work through their ideas, which had not been completely expressed. The point at which Gina corner herself in her own logic (lines 3.1.66 to 3.1.84) may have been a more appropriate time to introduce investigative activities focused on the structure and behavior of molecules. The conflict in her mind set the foundation for further exploration. But, would such a divergence to molecular investigations have been as appropriate for the rest of the students? Again, another dilemma in instructional decision-making with no clear answer.

Straddling the division between a cognitive approach and a philosophical approach, as discussed by Paul (1990), makes the decision that much more difficult. If we are more concerned with children's learning "correct" and accurate content, we may make an early decision to intervene, as in working in the content frame as described by Perkins and Simmons (1988). On the other hand, if we are concerned with quality discourse, we may decide to intervene more on the level of refining their arguments. However, it may be more useful to engage students in analyzing and critiquing their arguments, their personal experiences, and their explanations. From the perspective of Perkins and Simmons, such an approach would fall within the epistemic frame. From such an analysis, students could be guided through the process of finding problems, such as with molecular structure and behavior in the present study, which falls within the scope of the inquiry frame.

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