Classroom Discourse and Cognition: An Extended Argument about Density

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Submitted to the American Educational Research Journal
July, 1995

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.

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 principles or interpretive frameworks influence the students' thinking, and how do they affect their understandings? What patterns of argument and reasoning are evident during the students' argument? How do specific patterns of argument and reasoning influence developing understandings?

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 (some exceptions include: Edwards [1993], Orsolini [1993], and Resnick, Salmon, Zeitz, Wathen, & Holowchak [1993]), 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 combines 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. In order to combine these two perspectives, the present study examines the patterns and nature of student discourse and reasoning and their contribution to the developing understandings evident in the students' talk.

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).

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 arise, 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 alluded to earlier, I attempted to hand over more control to the students. As a result, I made a conscious effort to talk less and allow the students to freely engage in the argument as much as possible. As is evident in Figure 1, two students had greater involvement in the ongoing argument in all but the first session (class 2). By the final day of the argument, four students talked more than the teacher. When I did engage in the discourse, the intent was most often to (a) ask students to clarify statements, (b) justify claims, and (c) ask questions to extend or elaborate on the argument.

INSERT FIGURE 1 ABOUT HERE

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.

<u>The Students</u>

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. Specifically, I spread particular strengths among the groups (e.g., mathematical ability, writing and reading ability, and leadership).

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 not 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 introduced the notion of proportionality in line 2.2.601, when he talked 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 teacher responded with a new scenario that challenged the claim (line 2.2.604). Frank replied with an answer that contradicted Greg's line of reasoning (line 2.2.606). Greg seemed to agree (line 2.2.608), but in line 2.2.610 he reaffirmed his disagreement (although the exact content of this disagreement is somewhat confusing).

This sequence of argument was followed by the teacher's request for further discussion on the meaning of density (line 2.2.612). Following an alternative meaning response about dense heads (alternative context of meaning, as described in Bloom [1992a]) in line 2.3.440, the other major conceptual theme was introduced by Gina (line 2.1.511). This theme which develops into the other side of the argument is based on the quantity and proximity of molecules as the defining feature of density. In lines 2.1.513 and 2.1.515, the teacher posed a different line of thinking about density, and Gina's molecular definition of density was reiterated in response.

The basic pattern of teacher interaction apparent in the above transcript excerpt is typical throughout the argument. Typically, the teacher posed different ways of looking at a particular problem or topic, which often challenged the particular line of thinking of the students, and then asked for student response. In addition, the teacher focused or refocused the discussion on defining or clarifying particular terms, concepts, or ideas. The role of the teacher tended to be one of promoting the argument and discussion, while exerting little or no authoriatarian control.

Following the above discussion, 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. The discussion continued, after the teacher repeated the definition 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.

A typical characteristic of students' logic in their arguments is the "if...then" structure. An example of this structure appears in line 2.2.691. Using such an argumentative structure, Greg was able to state a condition (putting water from a larger container into a smaller container) and to provide two results (weight remains the same and density changes). In addition, the addition of "because" allowed him to provide a reason for the results.

The initial notion of Greg's conceptual understanding of the nature of density became apparent in the previous excerpts (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 said 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 these ideas.

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 contended that water becomes more dense when put into a larger container, but his specific understanding is not yet revealed. 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 talked about molecules moving closer together when water is placed into a smaller container. The notion Greg described in these two excerpts have to do with molecular structure. Density is determined by how close together the molecules are. In some sense, he seemed 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 understanding holds true for one particular substance, but not for comparing across substances, where the size and weight of molecules differ.

He took 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 could 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 could change the density of the water, by putting it in smaller or bigger containers.

In the above two segments, Greg seemed to be focusing on "volume" as the critical criterion of density: the larger the volume, the greater the density. This criterion can 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 much 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 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 particular substances. In line 3.1.73, she figured that weight is an indicator of molecular "thickening." However, in the last line, Gina, who initiated the idea of a molecular explanation of density, seemed to have come across the problem in her own understanding of molecules. Two different kinds of wood of the same size appear to have the same number of molecules. If all molecules were the same size this logic would work, but she realized her argument did 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 are 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, the Squidy sinks. 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. [spoken with some indignation]
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 [as she made drawings of these containers on the board], 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 fell short of providing an adequate explanation of the phenomena by not defining how density works.

In Class 6, the previous activity of building an aluminum foil boat and predicting its carrying capacity based on the relative density of the vessel was resumed. 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 referred 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 conception 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

Each side of the argument was based on a major theme: (a) density depends on volume and pressure and (b) density depends on the number and proximity of molecules. Figure 2 graphically depicts the thematic continuity and major points of contention of these two sides of the argument. A quick overview of the Figure shows thematic continuity throughout the extent of one side of the argument (volume and pressure side of argument at top of figure). The students involved in this side were concerned with getting their points across, which is evident, not only in the thematic continuity, but also in the increasing complexity of their discourse in classes 5 and 6. The other side of the argument (number and proximity of molecules side of argument at bottom of Figure) shows less extensive thematic continuity and less complexity. The molecular side of the argument, however, tended to challenge points made by the other side without extending and elaborating the molecular theme.

The volume-pressure side of the argument began with the notion that the size of the container is proportional to density. However, in class 5, a critical juncture occurred when the example of the "sea" was introduced to support the idea of proportional of volume and density. From this juncture, the notion of pressure became the critical factor in the argument. In addition, this juncture (indicated by a box in the Figure) points to the first occurrence of what can be called a context marker or a pointer to an underlying principle (such markers or pointers have been discussed by Bateson [1979], Bloom [1990, 1992a], Bruner [1986], and Lemke [1995, April, personal communication, AERA, San Francisco]). The underlying principle or conceptual context of understanding evident at this juncture is the notion of <u>uniformity</u>. In this case, uniformity of pressure throughout the medium acts as an interpretive framework (Bloom, 1992a) that guides the thinking of the students. When we understand this particular interpretive framework, the argument of the volume-pressure side begins to make sense. So, when there is a larger column of water, the density is greater, and not at the bottom of the column, but throughout the column of water. Using this underlying principle as a framework for thinking about their argument, the students were able not only to make sense of a variety of familiar phenomena, but also to make convincing points in their argument.

INSERT FIGURE 2 ABOUT HERE

The notion of uniformity is also evident in the molecular side of the argument. The particular context marker for this notion occurs during class 3 and is indicated by the box. The contention that weight is proportional to the number of molecules points to an underlying framework in which molecules are uniform in size and weight. Density is then a matter of the proximity ("closeness") of the molcules to one another. Although the proximity of molecules as a characteristic of density may be an accurate statement within a specific substance, it is not accurate between substances, where size, shape, and weight of molecules can differ. Again, however, an understanding of this interpretive framework allows students to make sense of phenomena and proffer convincing arguments.

The interpretive frameworks based on uniformity provide significant consistency to the students' arguments. The two notions of uniformity provide simple and elegant bases for making sense of phenomena and constructing lines of argument. At the same time, these interpretive frameworks become useful tools with considerable explanatory power. Although useful to the students, these interpretive frameworks are also problematic. Because of the simplicity, elegance, and power, these frameworks become obstacles to constructing or developing more scientifically accurate understandings. They act to solidify the students' own conceptual understandings. As in science, where we look for simple and elegant understandings, the students' interpretive frameworks provide a simplicity and elegance that resists change. At some level, we, as human beings, may desire simplicity and elegance in understanding our world. In the present study, this desire appears to manifest as a strong reliance upon uniformity as an interpretive framework.

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 to periodically engaged listeners. 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) challenges in the form of questions and statements, 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. In 57% of the instances of "if-then" statements, students added justifications in the form of "because" statements. However, students provided extensive justifications for their statements that were not in an "if-then" form. Both Gina and Greg went to the chalkboard to draw diagrams. Several students used props and examples from personal experiences to support their claims and demonstrate their explanations.

As opposed to the findings of Resnick et al. (1993), students in the present study did not soften their challenges by starting off with concessions. Their challenges were often frontal attacks, which led to intense back and forth exchanges on a couple of occasions. Resnick et al. found that concessions were attacked or capitalized on, while challenges were followed by no direct response or by single answers. However, in the present study, only one concession (line 3.1.85) occurred, which did not lead to further discussion. On the other hand, challenges were almost always followed by further discussion (e.g., assertions, explanations, justifications, etc.).

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 provide a strong anchor for their own idiosyncratic understandings. Gina and Greg, in particular, held to their own points of view with great tenacity and generated significant support from their own experiences. Such support from personal experiences may play a significant role in why student conceptual understandings are so difficult to change.

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, the underlying meanings and understandings become more apparent. What is particularly interesting about these two positions is their fundamental similarity. Greg contended 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 agreed 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).

The interpretive frameworks based on uniformity provide significant consistency to the students' arguments. The two notions of uniformity provide simple and elegant bases for making sense of phenomena and constructing lines of argument. At the same time, these interpretive frameworks become useful tools with considerable explanatory power. Although useful to the students, these interpretive frameworks are also problematic. Because of the simplicity, elegance, and power, these frameworks become obstacles to constructing or developing more scientifically accurate understandings. They act to solidify the students' own conceptual understandings. As in science, where we look for simple and elegant understandings, the students' interpretive frameworks provide a simplicity and elegance that resists change. At some level, we, as human beings, may desire simplicity and elegance in understanding our world. In the present study, this desire appears to manifest as a strong reliance upon uniformity as an interpretive framework.

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). Interpreting contradictory data to fit students' "intuitive" understandings may be the result of interpret frameworks guiding their thinking. 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 previously in this section, it is 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 may be able to start defining the territory of "intuition." What we see as intuitive might be comprised of specific thinking processes and interpretive frameworks that guide sense-making and knowledge construction.

According to Edwards (1993), discourse provides a means for examining children's conceptual development, but does not provide a "window on the mind" (p. 213). Edwards challenges the work of Donaldson (1978), Driver (1983), and Solomon (1983) saying that discourse does not uncover "underlying and stable cognitive representations" (p. 208). However, the underlying interpretive frameworks found in this study appear to be relatively stable. The more explicit verbalizations, however, may be more volatile and subject to considerable variation.

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 that point to underlying interpretive frameworks 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.

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 understandings.

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 may have prevented the students from expressing fully their ideas. On the other hand, addressing particular concepts, such as molecular explanations of density, may have provided students with opportunities to modify their existing ideas. .

However, taking the stance of teacher as researcher -- encouraging the argument -- helped to (a) advance the student argument, (b) allow students to take control, and (c) provide students with ownership over the argument. Most of the teacher's talk concerned questions of clarification, challenges to student assertions, and questions that extended student claims to new contexts. Such contributions advanced the argument without taking on an authoritarian stance. A climate was created that allowed the students to take control and ownership over their understandings and discourse. As a result, the argument increased in complexity over time. The challenges from the teacher, and students, stimulated more elaborate responses. In trying to create a classroom climate that encourages students to work as a community of scientists within an inquiry frame, as suggested by Perkins and Simmons (1988), students have to take ownership over the ideas and directions of discussion. The difficulty in creating such an environment, from the teacher's perspective, is a perceived loss of control. Even for experienced and confident teachers, such a perception of loss of control can be unsettling. However, the pay-off comes when students engage seriously in conceptual arguments.

Acknowledgments

This research project was funded by a grant from the Social Sciences and Humanities Research Council of Canada (grant #410-92-0110). I would like to thank the middle school for their support and gracious in accommodation of my research needs. I am especially appreciative of the ten students who put up with numerous data collection tasks, interviews, and the constant presence of audio and video recorders. They were a lively, delightful, and challenging group of young people, who taught me more than they can imagine. I am extremely grateful to David Birch and Andrew Smith for the speedy and accurate transcription of a seemingly endless flow of audio tapes, as well as for the many insightful comments about the children and "the argument." Comments from Steve Norris, Nancy Hutchinson, and Peter Chin on an earlier draft were invaluable and greatly appreciated.

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Figure Caption

Figure 1. Percentage of student and teacher talk (by number of words spoken) during density argument.

Figure Caption

Figure 2. Thematic web and interactions between both sides of density argument.

Figure 1

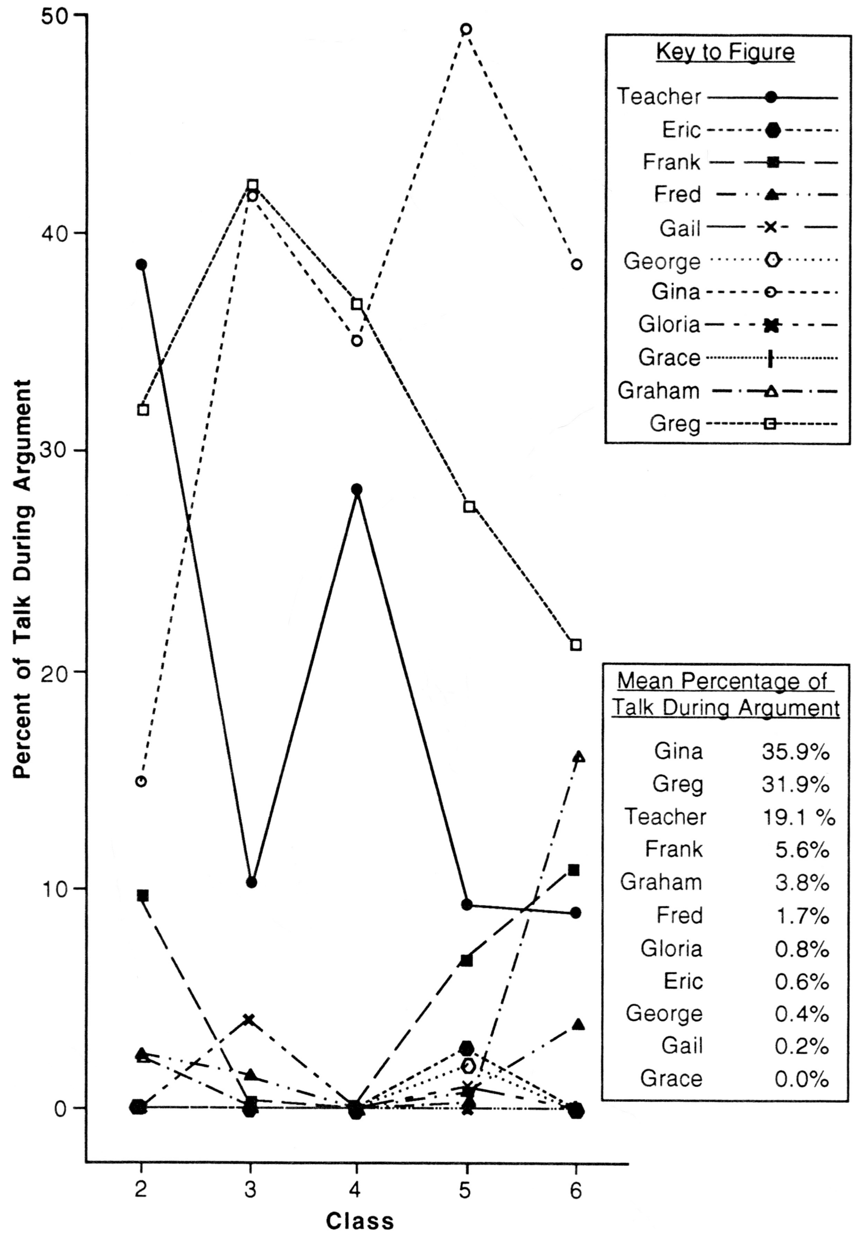
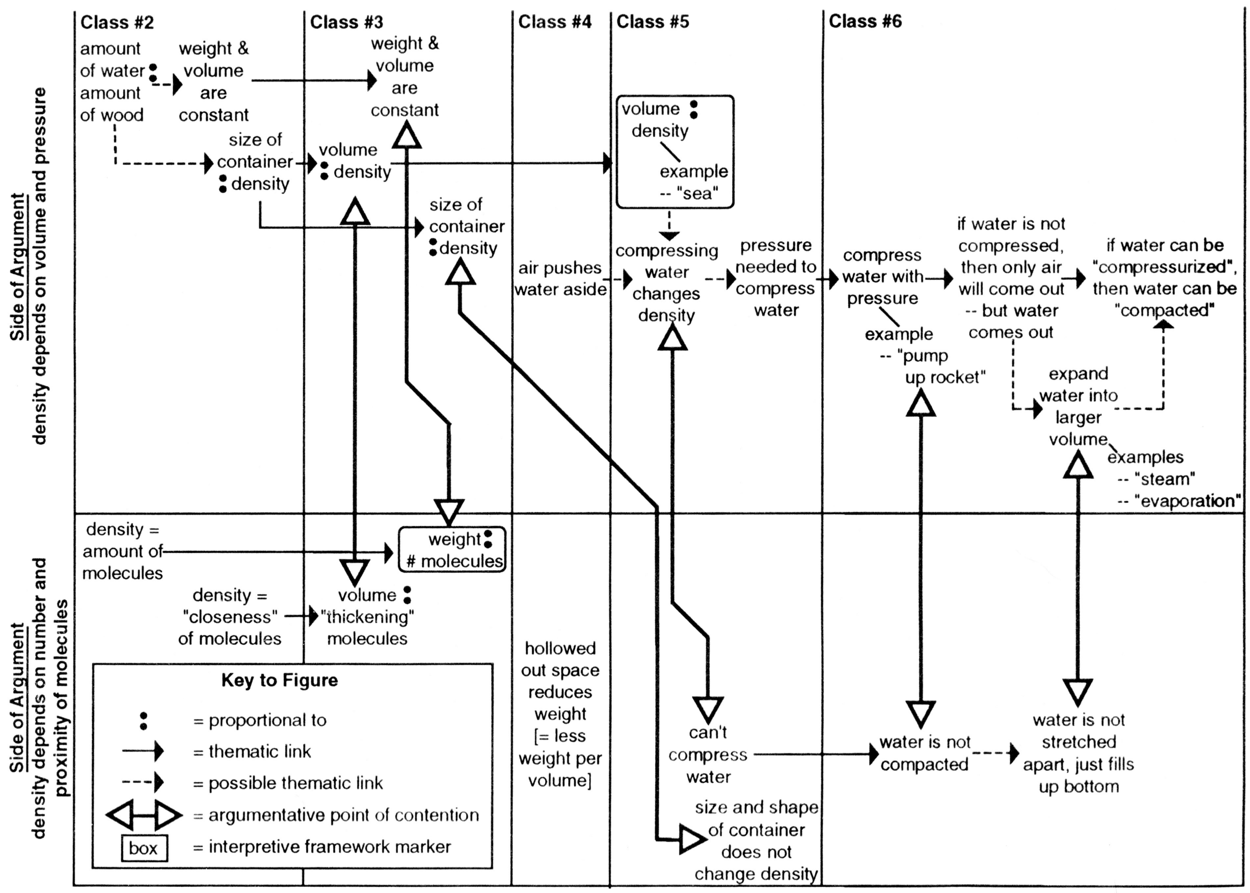

50
40
30
20
10
0
Percent of Talk During Argument
2
3
4
5
6
Class
Key to Figure
Teacher
Eric
Frank
Fred
Gail
George
Gina
Gloria
Grace
Graham
Greg
Mean Percentage of Talk During Argument
Gina 35.9%
Greg 31.9%
Teacher 19.1 %
Frank 5.6%
Graham 3.8%
Fred 1.7%
Gloria 0.8%
Eric 0.6%
George 0.4%
Gail 0.2%
Grace 0.0%

Figure 2


Side of Argument
density depends on volume and pressure
Side of Argument
density depends on number and proximity of molecules
Class #2
Class #3
Class #4
Class #5
Class #6
amount of water
amount of wood
weight & volume are constant
weight & volume are constant
size of container
density
volume
density
size of container
density
volume
density
example -- "sea"
air pushes water aside
compressing water changes density
pressure needed to compress water
compress water with pressure
example -- "pump up rocket"
if water is not compressed, then only air will come out -- but water comes out
if water can be "compressurized", then water can be "compacted"
expand water into larger volume
examples -- "steam" -- "evaporation"
density = amount of molecules
weight
# molecules
density = "closeness" of molecules
volume
"thickening" molecules
hollowed out space reduces weight [= less weight per volume]
can't compress water
size and shape of container does not change density
water is not compacted
water is not stretched apart, just fills up bottom
Key to Figure
= proportional to
= thematic link
= possible thematic link
= argumentative point of contention
box
= interpretive framework marker