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Discourse, Cognition, and Chaotic Systems: An Examination of Students' Argument About Density

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This article examines an extended argument about density among a small, multi-graded, middle school class of 10 students. The argument is examined from several perspectives with the primary focus on (a) the argument as an example of a chaotic and complex system, (b) the emerging development of understandings, and (c) the underlying cognitive structures affecting the students' understandings. Student talk during the class sessions were audio and videotape recorded. Each group of 3 or 4 students was individually audio recorded. A single video recorder was used to capture excerpts of each group's dialogue, as well as intergroup dialogue. The argument began after students predicted which of an assortment of different objects would or would not float. The specific case of a block of ebony initiated the argument and acted as the initial attractor, which developed into 2 opposing assertions: 1 side proposing that the pressure on a larger volume of water affects the density and the other side proposing that the molecules of water cannot be compressed. Extensive conceptual development occurred as the argument progressed with a variety of bifurcation points leading to new but related conceptual themes and higher levels of complexity. Several underlying structures, which have been referred to as interpretive frameworks (Bloom, 1992a) and *p*-prims (diSessa, 1993), played a central role in the development of both understandings and the argument itself. Such interpretive frameworks included (a) uniformity of molecular size and weight across different substances, (b) directionality of pressure, (c) external forces (e.g., gravity) affect pressure, (d) pressure affects density, and (e) surface area affects action of external forces on pressure.

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The intent of this article is to explore the development of conceptual understandings as a chaotic system during a student dominated argument about density. Analysis of this argument will help further our understandings of the nature and dynamics of student-to-student discourse and of how teachers can help to foster and promote such discussions. In addition, this article will examine how student controlled discourse can expose underlying, problematic understandings, as well as lead to more complex understandings.

In contrast, most studies of classroom discourse in science education focus on the interaction of the teacher with students. Very few studies examine primarily student-based dialogue. An exception is the extensive look at "Science Talk" sessions with young children by Gallas (1995) and a study by Anderson, Chinn, Chang, Waggoner, and Yi (1997). The study by Anderson et al. looks primarily at the logical structure of children's arguments. However, this study examines an argument that arose spontaneously after an activity that required a group of Grades 5 through 7 students to predict which of an assortment of objects would float. This argument spanned five class sessions and was characterized by the students' ownership of the ideas expressed and by greatly reduced overt control by the teacher over the content and flow of the discussion.

Of particular interest in this article are (a) the structure, content, and processes of student-to-student discourse and how such discourse affects student learning and (b) the development of the students' 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 "floating," this article addresses the more general concerns of extracting underlying meanings and understandings as they unfolded during a fairly unstructured and spontaneous argument characterized by the emergent organization, processes, and structures characteristic of chaotic systems. The underlying understandings driving the argument involved two types of interpretive frameworks (Bloom, 1992a, 1992b): (a) a phenomenological primitive (*p*-prims; diSessa, 1993) involving the notion of pressure and (b) a naive model of molecules.

This article reveals the dynamics between prior and emerging conceptual understandings during the course of the student-controlled argument. The major questions addressed in this article include the following:

1. How can the argument's emergent organization, structure, and processes, as exemplified by the characteristics of chaotic systems, provide clues to how such arguments can be promoted and facilitated in the classroom?
2. What prior and emerging conceptual understandings are evident in the argument and how can teachers uncover such understandings?
3. What underlying principles or interpretive frameworks influence student thinking, and how do they affect student learning?
4. How can student-to-student discourse assist teachers in identifying such underlying principles and frameworks?

The particular significance of these questions relates to the current emphasis in the National Science Education Standards on creating classroom communities, constructing meaningful understandings, and engaging in science talk (National Academy of Sciences, 1995). In creating such communities, children take on more control and responsibility and have an increasing sense of ownership over the ideas, discourse, and products generated in the classroom.

The first question deals with the characteristics of a primarily student-controlled argument, where the students "own" the conceptual content. Addressing this question is critical to developing understandings of how teachers can promote and facilitate arguments and discussions, which exemplify the kinds of discourse found in communities of active learners. The last two questions address aspects of children's cognition and learning. Developing understandings of these aspects of children's cognition and learning, in turn, provide the knowledge and skills required by teachers in assuming new roles. Such roles move away from being the knowledge authority and the focal point and controller in classroom discourse. In assuming these new roles teachers need to identify the major conceptual understandings and interpretive frameworks arising from the students' talk, so that appropriate questions, comments, and activities can be used to challenge students' inaccurate knowledge claims. From this perspective, teachers become participants in the discourse and activities of the community in ways that assist students in examining their own understandings and knowledge claims. Such an approach maintains the integrity of student control and ownership in the classroom community, while providing an effective means of addressing students' alternative or inaccurate conceptions.

THEORETICAL BACKGROUND

Attempting to establish a classroom community of scientists served as the foundation for the instructional approach that provided the basis for the investigation of student discourse. Within this foundation, three general theoretical perspectives inform the way in which we can perceive and analyze the data presented here. These three perspectives are (a) language and discourse, in terms of their relation to emergent understandings and learning; (b) systems, such as that provided by chaos and complexity theories; and (c) cognition, in terms of learning and the factors that affect knowledge construction. Each of these theoretical perspectives will be discussed briefly in the following subsections. Also, throughout this article the term *context* is used to describe pedagogical situations or settings and cognitive or epistemic frameworks.

Language and Discourse

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 should be kept in mind. Cortazzi (1993) described 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. This study examines how the dynamics of student discourse affect the development of more complex understandings through cycles of information input and processing (as addressed by the second assumption). However, as Gee (1994) contended, the everyday language used by students has a tendency to obscure the underlying meaning and reality of their understandings. As Gee suggested, "unfortunately, in science it is often this 'underlying' level which is crucial" (p. 5). Such previously existing underlying meanings and understandings often affect the construction of new scientifically accurate understandings (which is the focus of the third assumption).

Addressing concerns at this underlying level, where the depth and extent of children's understandings can be difficult to uncover, requires concerted effort beyond what is typically required in teacher-directed approaches. Partial statements and vague references and terminology make the task of describing children's understandings more troublesome. Edwards and Mercer (1987) contended that "investigators rarely dig for the roots of misunderstanding in the communicative processes of education, in the meeting of two minds which education is contrived to achieve" (p. 49). Gee's work in this area is particularly illuminating. The process of abduction, which Gee defined as reasoning that draws on one's own experience 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 in science, but can take on the characteristics of "everyday" abduction. Such everyday abduction relies on everyday language and logic, and on language constructions, which are more typical of story telling.

As opposed to the type of discourse described by Cortazzi (1993) and Gee (1994), most studies of classroom talk have focused on teacher–student interactions, rather than student–student interactions. Such teacher-controlled discourse limits the extent to which students can construct more complex understandings and to which teachers can identify students' problematic underlying understandings. The focus on such teacher–student interactions has arisen from the work of Vygotsky (1962, 1978), who saw the role of the teacher as one of helping students move towards higher levels of understanding. As Cazden (1988) noted, Vygotsky's work on the relation of speech and thinking focused on the interaction of students with adults and did not consider peer interaction. The situation of student-to-student interaction in the development of discourse skills and thinking was not considered, and has only begun to be considered by contemporary researchers, such as Cazden (1988) and Gallas (1995). The move towards greater student-to-student participation is evident in the recent development of apprenticeship models (Gee, 1994; Lave & Wenger, 1991), where the roles of teachers have moved towards facilitating student induction into the talk of learning communities.

For students to acquire discourse skills in science, they must be exposed to opportunities to practice talking about science topics. In her work with young children, Gallas (1995) formalized such opportunities in the form of regular "Science Talk" sessions. In contrast to the typical classroom, in which "the teacher is in charge of what is said about a subject" (p. 10), Gallas set up situations in which the teacher remains relatively silent while students discuss and argue about their developing conceptions and theories. She suggested that

> when a community of learners begins with the act of dialogue about the world, and when that dialogue occurs outside of the theoretical and conceptual influence of the teacher, it moves more naturally and vitally toward theory and a readiness for instruction and study. (p. 3)

Over time as students engage in such a process, they "take on the voice *and the authority* of scientists" (p. 3; emphasis in the original). As Cazden (1988) suggested, student-to-student talk without the "limitations and rigidities characteristic of most teacher–student interactions" (p. 134) allows students to develop attitudes that bridge the differences between individuals. Such an approach to classroom talk (a) provides students with more control and ownership over their dialogue and learning, (b) allows them to reach and explore the limits of their knowledge, and (c) allows them to experience the "kinds" of discourse that can occur in science disciplines.

The kinds of discourse evident in science are not only different from one another, but are vastly different from those of other disciplines and of everyday life. Bakhtin (1981, 1986) and Lemke (1988, 1990) considered such variation among discourses in the form of speech genres. Genres are context-dependent ways of talking or writing. They usually have a specific type of thematic content, certain stylistic characteristics, and a particular compositional structure. Bakhtin (1986) suggested two general types of genres: primary or simple and secondary or complex. Moving from primary genres, typical in everyday talk, to secondary genres, typical of specific disciplines or areas of expertise, is certainly a goal of science education. However, to accomplish such moves from primary to secondary genres, we need to recognize that this can only be done through students' interactions amongst themselves and with teachers.

The difficulties in developing the skills of talking in ways that are characteristic of secondary genres, 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." These frames include

1. The content frame, where students engage in developing or constructing accurate explanations and understandings (e.g., understandings of density, pressure, etc., in this study).
2. The problem-solving frame, where students use effective strategies in reaching solutions to problems (e.g., attempting to solve the problems involved in student disagreements over a viable explanation for why ebony sinks).
3. The epistemic frame, where students analyze the coherence of their observations, experimental results, and explanations (e.g., where students examine one another's claims about density, pressure, etc.).
4. The inquiry frame, where students engage in finding and identifying problems, as well as in developing explanations of particular phenomena and solutions to problems (e.g., suggesting explanations of density and engaging in investigations in an attempt to support or refute specific knowledge claims).

These frames not only point to specific types of science classroom activities, but they also suggest rather specific ways of talking. For example, generating explanations in the content or inquiry frames versus analyzing the validity of explanations in the epistemic frame require different types of language and thinking or different secondary genres (types of science talk in this article).

The evident dilemma in the contrast between everyday and science talk is compounded if we consider that both types of talk are powerful in their own right and in appropriate contexts (these contexts can include Perkins and Simmons [1988] "frames"), as suggested by Gee (1994). 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) suggested that using everyday language to soften the potentially difficult task of acquiring science talk can humanize the gap between everyday and science talk. In addition, his work helps create a link between language and the construction of conceptual understandings, although the development of specific conceptual understandings is not emphasized. However, his approach to identifying and describing thematic patterns provides a useful approach to understanding how meaning forms during classroom discourse: "a thematic pattern is a way of picturing the network of relationships among the meanings of key terms in the language of a particular subject" (p. 98). The implication of thematic patterns concerns how concepts and understandings are grounded in and constructed by the dialogue that takes place in the classroom. As we proceed with this discussion, this notion of a network of thematic patterns will prove to be an important basis for examining the emergent patterns of chaotic systems. For the sake of clarity, when referring to thematic patterns, I see these as nearly equivalent to emergent understandings. In other words, as student understandings emerge and develop through the discourse, they are the thematic patterns to which Lemke refers.

Chaos and Complexity in Discourse

Although previous research has been informative in terms of helping develop specific understandings of classroom discourse, the nature of discourse from a more holistic perspective is still somewhat elusive. In this study, concepts from cybernetics, chaos, and complexity theories will be used to formulate a descriptive model of student discourse. Such a model has the potential to inform the education community on how student discourse can be initiated and maintained, even though specific initiators and outcomes cannot be predicted (note: unpredictability is characteristic of chaotic systems [Capra, 1996]).

In particular, the notion of *feedback loops* from cybernetics (Bateson, 1979; Capra, 1996; Weiner, 1948) contributes a framework for how the discourse process interconnects across differing points of view and provides for the development of more complex and emergent understandings. Such feedback loops characterize nonlinear processes, which work towards either balancing or reinforcing the particular process. This feedback loop process is depicted in this article as the claim–counterclaim or challenge pattern characteristic of arguments.

In the case of the student argument discussed in this article, the process tends to be self-reinforcing, where the continuation of the process (i.e., argument) tends to amplify the effect of the initial disagreement. Such amplifying effects arise out of what Bateson referred to as symmetrical relationships, where the party (or parties) on one side of a relationship compete with the party (or parties) on the other side. This pattern of relationship (or self-amplifying process) can lead to an inescapable divergence. On the other hand, the prototypical classroom tends to operate as a self-balancing system, where the teacher strives to control the action and limit student-to-student discourse. In addition, the teacher and students tend to lock into complementary relationships (Bateson, 1979), where the teacher is in control and the students are subservient. Although such relationships also tend to diverge, the divergence may be less explicitly observable. Ideally, the healthiest relationships are those that are reciprocal, where both parties engage on equal ground and in a negotiative process of give and take.

To extend the descriptive base for our understandings of the dynamics of student discourse and of emergent understandings, chaos and complexity theories provide insights into additional processes involved in classroom discourse as a system. Capra (1996) classified the criteria of systems under three broad headings:

1. Patterns of organization, which involve the relationships that provide any particular system's characteristics and include autopoeisis.
2. Structure, which is a system's physical presence (i.e., actual components) and includes dissipative structures.
3. Process, which continually generates the structures that manifest the patterns of organization and includes cognition (broadly defined as the process of life by Bateson [1979] and Maturana & Varela [1998]).

Autopoeisis is concerned with the patterns of self-generating and self-maintaining systems, which operate through networks of production processes. At points of instability and at points far from equilibrium, new forms of order are generated, which, in turn, lead to higher levels of organization (Maturana & Varela [1998] referred to such organization as circular) and increased diversity (Capra, 1996; Maturana & Varela, 1998). Although autopoeisis is concerned with biological systems, some researchers are drawing links to social systems (Luhmann, as cited in Capra) and specifically to classrooms (Barab et al., 1999). Ongoing arguments tend to display the characteristics of self-maintaining systems, such as circular patterns of organization, over limited periods of time.

Dissipative structures self-maintain an organized structure through self-amplifying feedback loops at points that are far from equilibrium. These structures develop around attractors, which are "points" around which activity occurs, such as the center point around which a pendulum swings or the center of the vortex of a tornado. As such structures self-amplify, new attractors known as bifurcation points may arise. At these points, new structures may develop with an increase in complexity (Capra, 1996; Prigogine & Stengers, 1984). Essentially, such structures maintain patterns of organization, yet are unpredictable in terms of specifying precise future events or conditions. Just as a tornado maintains its overall pattern of organization (i.e., characteristic shape), it continually changes its specific shape and may even split into two or more funnels (which are the result of bifurcation points). In student-to-student arguments, the attractor may be one event (e.g., in this article, the event is ebony sinking), from which student claims or counterclaims (i.e., circular feedback loops) arise and continue to maintain the overall discourse structure as new information is introduced and pursued (i.e., bifurcations points and divergence), and the overall complexity of understandings increases.

The processes of chaotic systems are production processes. As mentioned previously, these processes are considered to be cognitive in the broad sense of communicating information. In terms of classroom discourse, cognition as an individual process and as a communicative process among classroom participants is the process that produces structures, which represent emergent patterns of organization. For instance, as students begin discussing a particular topic (i.e., attractor) patterns of organization in the discussion emerge and produce a structure characteristic of the particular discussion. The more students disagree (i.e., the farther they are from equilibrium), the more the processes push the discussion toward higher levels of organization and complexity.

Student Cognition

In terms of student cognition, there is abundant research in science education, which focuses on children's misconceptions or alternative conceptions. Most of this work identifies and describes children's concepts in specific domains, but does not address issues of the formation of such concepts or how they affect student discourse in science classrooms. However, two related and key notions of children's cognition in science are significant in understanding the development of concepts. These notions are interpretive frameworks (Bloom, 1990, 1992a, 1992b) and the subset of phenomenological primitives or *p*-prims (diSessa, 1993), both of which are powerful influences on inferring and constructing new knowledge. Interpretive frameworks describe the broad category of cognitive structures that affect and guide thinking and concept formation. Such frameworks include (a) beliefs, which can range from personal to culturally embedded; (b) common interpretive structures, such as anthropomorphism and anthropocentrism; and (c) experientially based and phenomenon-specific structures, such as diSessa's *p*-prims. *P*-prims arise from children's experiences with particular phenomena. Such structures are intuitive explanations of phenomena, which cannot be explained by the holder of the *p*-prim. From this perspective, students see their explanations based on *p*-prims as self-evident and needing no further explanation. A simple example of such a *p*-prim is a young child's explanation of earthworms: "that worm is bigger, it's a male worm" (Bloom, 1992b). From this child's perspective, it is self-evident that males are always bigger than females. From the child's experience, men are bigger than women. This pattern recognition becomes embedded as a guiding principle or framework for explaining new observations. In some cases, as diSessa commented, their influence leads to understandings that are currently accurate. In other cases, however, the result is in faulty understandings. If we refer back to Gee's (1994) notion of abduction, we also can see how interpretive framework, including *p*-prims, can serve as the basis for such dialogic events. From this perspective, however, abduction does not have to fall into the story-telling pattern of discourse, but can occur within scientific genres, as well.

The data included in this article 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.

Whereas most studies of classroom activity have investigated either the nature of discourse or student learning (Edwards [1993] is one exception), this study not only examines the interaction of discourse and the development of understanding, but also uncovers underlying conceptual principles (J. L. Lemke, April 19, 1995, personal communication) or interpretive frameworks (Bloom, 1992a, 1992b) that influence student thinking, discourse, and understandings. 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 in this article, for the most part, are the students' concepts and understandings. With the exception of the term "density," the students generated the ideas and terminology in the argument.

In summary, this article will address the importance of student-to-student discourse as a chaotic system in extending our understandings of student learning and in providing teachers with the necessary tools to facilitate and utilize the information arising from student discourse. Although unpredictable in nature, such discourse can help teachers to identify underlying problematic understandings, as well as to promote the construction of more complex and meaningful understandings.

METHOD

The study took place in a small, private middle school in eastern Canada, from November 1994 to March 1995. I acted as both researcher and teacher in a multigraded class of 10 students (one Grade 5, two Grade 6, and seven Grade 7 children; four of whom were girls). The class met 2 days a week, for the most part, over a period of 9 weeks (from January to March), for a total of 16 class meetings of 45 min each. The students were organized into three groups. Two of the groups (one of three and one of four students) had two girls each, whereas the third group comprised three boys. The pseudonyms used in this article 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 intent of the instructional unit was to have students engage in the process of doing science, including arguing and negotiating their knowledge claims, while working towards developing understandings of the concepts involved in floating (i.e., density, pressure, and buoyancy). Part of the first day of the unit was devoted to discussing the nature of science and how scientists worked. The ideas discussed included

1. Negotiate: discuss, argue.
2. Organize: experiments, observations, data, notes.
3. Explanations: of how something works, produce several different explanations, narrow down to the one that fits with the evidence from your experiments.
4. Justify: support explanations with experimental evidence.
5. Predict.
6. Ask questions.
7. Experiment: design you own experiments, how could your experiment get more accurate results? could you redesign your experiment and make it better?
8. Clarity.
9. Examples.
10. Cooperate.

Although the particular argument that arose was not expected, the notion that students would engage in arguments about their knowledge claims at some point was anticipated and encouraged.

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. Classes 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 next:

1. Class 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 the aforementioned objects.
2. Class 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?

3. Class 4: Investigated "Squidy" and another type of Cartesian diver.
4. Class 5: Built a boat and predicted how much weight it can carry (carrying capacity), based on the density of the object (boat).
5. Class 6: Continued developing predictions of the carrying capacity of their boats.
6. Class 7: Finished the carrying capacity activity with a test of their predictions. Investigated water pressure (predicting and testing water flow from 2-liter soft drink bottle with two holes in it—one near the bottom and one near the top). Began developing manometer predictions of water pressure at different depths.
7. Class 8: Reviewed carrying capacity activity. Carried out manometer activity.
8. Class 9: Investigated and measured buoyant force using hook scales and weights.

In preparation for this unit, a detailed concept map on "floating" was constructed as a planning tool. The concept map served as a means for identifying the key concepts to be learned and for the development of investigative activities. However, two ideas that arose during the argument, which are examined in this article, are not addressed in the concept map: (a) compressibility of water[1] and (b) molecular explanations of density. The compressibility issue was neither expected nor considered, and the molecular was not addressed because of the grade level (an underestimation on my part).

The pattern of interaction normally found in classrooms, the triadic sequence (i.e., IRE—teacher Initiation, student Response, teacher Evaluation) as discussed by Lemke (1990) and Cazden (1988), is used rarely throughout the entire five-class argument. Instead, the typical pattern of my interaction, as the teacher, involved posing different ways of looking at particular problems or topics, which often challenged the particular line of thinking of the students. Other patterns of interaction involve focusing or refocusing the discussion on defining or clarifying particular terms, concepts, or ideas. My role tended to be one of promoting the argument and discussion, while exerting little or no authoritarian control (i.e., neither as knowledge authority nor as disciplinary authority).

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 audiocassette recorder was placed on each

[1]The notion of the compressibility of water became an issue among the students. The teacher's goals included encouraging students to debate conceptual issues, and therefore did not interject any statements about whether this statement was correct or not. Water is generally considered not to be compressible. However, the density of water increases with decreasing temperature to 4° C, at which point the density decreases until the water freezes.

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 audiotapes were transcribed within a few weeks of the class session. The videotapes were used to fill in details of missed conversations and actions of the students (videotape technical difficulties occurred during three classes: for one class there was no video at all, for another there was no sound, and for the last there was intermittent recording).

Within a couple of hours of the end of each class, I recorded field notes prompted by a review the videotape for that day's 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.

Additional data on the students' conceptual understandings were collected during pre- and post-unit interviews. The post-unit interviews, utilized in this study, included questions asking students to explain floating, density, pressure, and buoyancy. One set of tasks about density presented students with two drawings: (a) one that required an (algorithmic) understanding of the formula for density, by showing a block of wood with its dimensions and weight (mass) and (b) one that required a conceptual understanding of density, by showing a block of wood floating with exactly 5 cm above and below the water.

The pre-unit interviews were conducted in December, prior to the January unit. The post-unit interviews were collected during the second week after the conclusion of the unit. All interviews were audio and videotaped, then transcribed.

Data Analysis

The analysis of the data focused on two major areas: (a) the overall structure and processes of the argument as an emergent phenomenon and (b) the students' specific conceptual understandings of density and related phenomena. The first area (i.e., structure and process) presents a holistic view of the entire event (i.e., the argument). The second area focuses in on the conceptual substance that initiated and maintained the argument. Both of these areas involved complex analytical issues in identifying, representing, and verifying the data. As a result, the approach to analyzing the data utilized aspects of several theoretical or paradigmatic perspectives generally associated with qualitative research.

The major approach taken relates to the study's emphasis on chaos and complexity. As described by Patton (1990), analysis based on chaos and complexity theories focuses on exposing the underlying order in seemingly disorderly phenomena. As opposed to how chaos and complexity theories are used in science with a heavy emphasis on mathematical modeling, the use of these theories in the social sciences is based on the metaphors and assumptions suggested by chaos and complexity. Such metaphors and assumptions include

1. Nonlinearity of processes.
2. Small events can have critical effects.
3. Emergent patterns arise from or are embedded in seemingly chaotic situations or systems.
4. The simplicity of a system can lead to complex outcomes.
5. Dynamic systems and phenomena require nonstatic descriptive approaches.
6. Chaotic systems are unpredictable at various levels of specificity.

In this study, the analytical goals involved identifying and describing

1. The dynamics of the processes underlying the argument.
2. The emergent patterns of organization.
3. The emergent patterns of conceptual understandings that initiated and maintained the argument.

Because chaos and complexity are fairly new to the social sciences, specific analytical strategies have not been established (Patton, 1990). Therefore, strategies from other paradigms and theoretical approaches have been modified and utilized in this study. Grounded theory with its emphasis on emergent patterns (i.e., theory) provides two useful strategies: constant comparison and thick descriptions (Strauss & Corbin, 1994). In this study, emergent patterns in the students' discourse and conceptual understandings were compared back to the transcripts, field notes, and videotapes, as well as post-interview data for the reconstruction of the underlying meanings of the students' conceptual understandings. The thick descriptions, in this study, included the verbatim transcripts of all of the classroom dialogue, interview transcripts, and the researcher's field notes and post-teaching unit modeling and diagrammatic representations. In contrast to much of Strauss and Corbin's descriptions of grounded theory methodology in terms of tracing the effects of specific social concepts within a group, the approach in this study traced the development and divergence of specific conceptual understandings, as well as the overall patterns of the argument and the effects of various factors (e.g., counterarguments, contradictory evidence, etc.) on the argument's organization and structure.

The other major contributing analytical framework involved discourse analysis, as described by Lemke (1990). Such analysis was used to identify and describe specific thematic patterns and conceptual understandings. However, as opposed to Lemke's analysis at the level of a phrase or sentence, the strategy in this study looked at the whole dialogue, as well as post-unit interviews, for clues to the meanings underlying student's particular claims. As diagrammatic representations were developed, they were compared back to the dialogue and interview data.

The data analysis and model development (Figure 1) were completed by the researcher. As suggested in the previous commentary, the data analysis went through many iterations as new insights from more specific analyses of the argument dynamics and conceptual understandings arose. Challenges arising from the researcher's questions about the validity of particular interpretations always led to reassessments and refinements of specific claims and to modifications in the model. In one particular instance, a manuscript reviewer's challenge to one particular interpretation led to a more thorough re-analysis of the data around that interpretation, as well as all related interpretations.

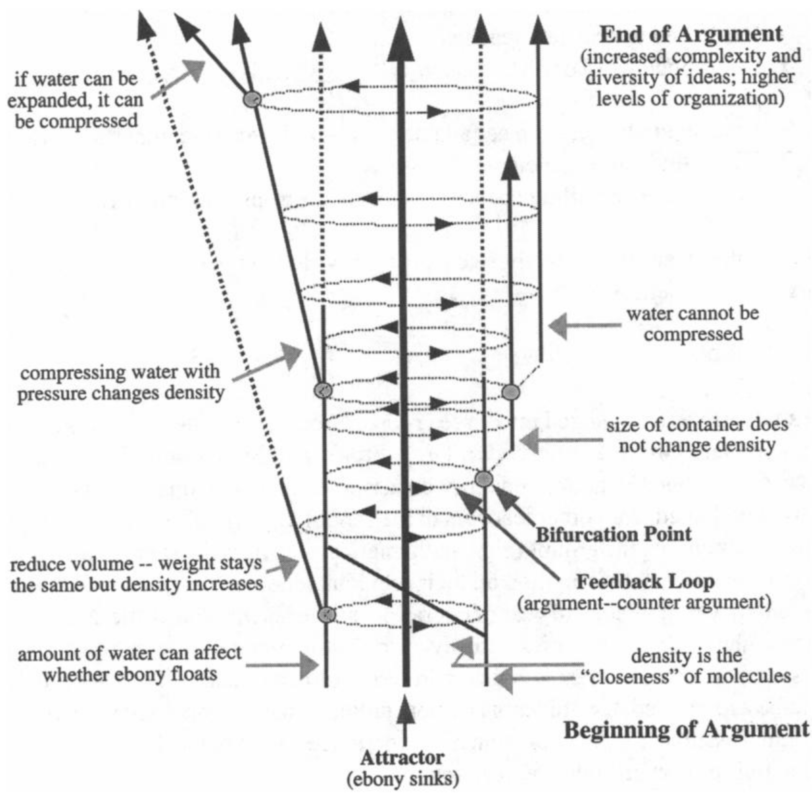

FIGURE 1 A representation of the argument's emergent structure based on elements from chaos theory (i.e., the argument as a self-maintaining dissipative structure).

Transcript Conventions

The transcript conventions used in the excerpts throughout this article are described next. Following Bakhtin's (1986) assertion that the most meaningful unit of speech is an utterance, which is a "complete speech act" (Bakhtin, 1981, p. 264), the transcript line numbers precede complete utterances, rather than lines of text as they fit on a page.

- Line numbering, such as 2.123—The first number indicates the class session (Class 2 in the example). The second number refers to the line number or utterance turn.
- **Tchr**—teacher/researcher (the author of this article).
- Student name—pseudonyms—first letter of name refers to grade level (i.e., E = Grade 5, F = Grade 6, and G = Grade 7).
- UV—Unidentifiable voice.
- Boldfaced utterance—teacher's talk.
- Underlined word or phrase, such as "... wait ..."—indicates speaker's emphasis.
- Bracketed phrase, such as [adamantly]—indicates researcher's comment.
- (???)—indecipherable speech.
- ... —pause or trailing speech or speech interrupted by another speaker.

The complete transcript, less those excerpts provided in the text of the article, appears in the Appendix.

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. Specifically, I spread particular strengths among the groups (e.g., mathematical ability, writing and reading ability, and leadership). Information on their previous school experiences was limited. The school was in its second year of operation, so the teachers had little direct experience of the students' histories. However, from student interviews none of the students expressed an interest in science in terms of career aspirations. As much as could be ascertained, the students had not studied density or buoyancy previously, although I assume that some of them had experienced the typical "floating and sinking" activities earlier in elementary school.

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 temporarily from participating in class discussions and activities. Greg seemed to enjoy arguing and playing with ideas without any particular need for confirmation. All but one (i.e., Grace) of the other students, whose participation in the argument varied, tended to be attentive to the argument content, while proceeding to work on inquiry activities assigned for the particular class session.

RESULTS

The presentation and discussion of the results begins with an examination of the general characteristics of the argument, including a description of the activities and initial talk that led up to the argument, the amount of teacher and student talk, and the nature of teacher talk. Within the sequence of the argument, descriptions of relevant classroom activities are included to provide a temporal and substantive context for understanding the students' discourse. The second subsection will examine in greater detail the emergent organization and processes from the perspective of chaos and complexity theories, as well as the conceptual understandings that acted as the grounding for the argument, the first indications of the development of conflicting understandings, and the development of these understandings throughout the argument. The last subsection delves into the students' emergent understandings in greater depth.

The Argument

The intent of this subsection is to provide a description of the instructional context that led up to the argument, as well as an overview of the general characteristics of the argument. This overview includes analyses of the frequency and nature of the classroom talk. Such a background provides a sense of the classroom environment that allowed for the development and continued generation of the argument, as well as for the emergence of more complex conceptual content.

On the first day of class, the students were excited about designing their own boats. The students displayed a lot of enthusiasm as they worked on an initial boat design. All three groups spent considerable time discussing their designs. All of the groups considered 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 ebony had more oil in it. Other students suggested that ebony was "a heavy wood," "dense," or "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, whereas 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 after one student, Gina, said that the reason ebony sank was that "it's a denser wood" than water and another student, Greg, suggested that "if you scaled up the big piece of wood, then you have to scale up the water too."

Throughout the argument, student talk was significantly greater than teacher talk. Table 1 shows this dominance of student talk, which ranged from 68% in the first class to 89% in the last class. This ratio of teacher to student talk is just about the inverse of the typical ratio of teacher classroom talk (Edwards & Mercer, 1987). Although the argument began with and was dominated by two students (Gina and Greg), more students became involved as the argument extended over the five class sessions. The fact that the argument extended over multiple class sessions is in itself significant. The students were not just going through the motions

TABLE 1
Percentage of Classroom Talk During Period of Density Argument (Calculated by Number of Words Spoken)

	Class 2 (%)	*Class 3 (%)*	*Class 4 (%)*	*Class 5 (%)*	*Class 6 (%)*
Eric		3	4		5
Frank	5	5		5	18
Fred	5	6		4	5
Gail			2		3
George			2		2
Gina	26	23	35	32	30
Gloria			3		3
Grace			1		
Graham	1	4		1	15
Greg	13	23	36	21	20
Unknown	15	2		0.5	1
Teacher	32	25	29	24	11
Total student	68	75	71	76	89

of participating in class; they were seriously involved. This engagement drew other students into the argument, especially by Class 5. In addition, students other than Greg and Gina who participated in Classes 5 and 6, such as Frank and Graham, made significant and meaningful contributions. Such participation suggests that students were paying attention to the developing argument (as noted by words of agreement or disagreement) during the first few class sessions, even though they were not adding significant information.

The extent and dynamics of this student-centered argument brings 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 from 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.

When the teacher 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. Table 2 provides a summary of my (teacher) questioning during the argument. In general, the percent of teacher questioning decreased over the term of the argument. During Class 2, most of the questions were more typical of teacher instruction, focusing on content recall and confirmation. However, from the second argument session, the percentage of argument facilitating and conceptual extension questions increased. Such a pattern in conjunction with an overall decrease in teacher talk (see Table 1) indicates a decrease in my (teacher) control over the instructional agenda, and an increase in my facilitation of the argument.

TABLE 2
Summary of the Teacher's Questions During the Density Argument

	Classes					
	2	*3*	*4*	*5*	*6*	*Total*
Total number of talk segments	25	66	4	74	13	182
Total number of questions	15	26	1	6	1	48
Percent of questions per total talk segments	60%	40%	25%	8%	8%	26%
Percent of argument facilitating questions per total questions	13%	46%	—	50%	33%	35%
Percent extending conceptual depth questions per total questions	7%	15%	100%	17%	—	10%

The Argument's Emergent Organization, Structure, and Processes

The goal of this section is to develop a model of the argument based on the characteristics of chaotic and complex systems. As this model is developed, specific instances from the transcripts will be used to characterize each aspect of the model (e.g., attractors, bifurcation points, etc.). The implications of how such a model can help teachers facilitate such dialogue and arguments (i.e., the last part of the first research question) will be addressed in the discussion section.

In looking at the overall structure of argument from the perspective of cybernetics and chaos theory, we see a coherent process that maintains its overall structure and increases in complexity as it proceeds. Figure 1 was developed to represent an overall "picture" of the dynamics. Initial diagrams, extending from Lemke's (1990) specific thematic pattern analysis to a "meta-view" of conceptual themes, were developed to show the linking and divergence of conceptual themes. Additional facets of the diagram were added to show the interactions among the players, such as, counterarguments as cybernetic loops. The central focus of the argument involves the initial event of the block of ebony sinking. This event acts as the "attractor" around which the entire argument revolves. However, additional lines of the argument branch off as the argument proceeds (many smaller branches occur throughout the argument; only the major branches are indicated in the figure). As the argument continued, one student's claims were countered by another's. These counter arguments were, in turn, met with responses, which often introduced new information to support the original claim. Such a dynamic is shown as a cybernetic feedback loop. Such looping processes lead to an increase in complexity of the argument by initiating a branching off of additional conceptual lines of thought in response to counterarguments. These branches occur at "bifurcation points," which are new (secondary) "attractors."

In the context of this classroom argument, the attractors (including bifurcation points) are events or statements that do not correspond with previously held concepts, theories, or beliefs. The initial attractor, which was the event of ebony sinking, did not fit with the students' commonly held notion that wood floats. However, this event in itself may not have been enough to start the argument. As in nuclear reactions, you need a critical mass to carry out a sustained reaction. This critical mass was achieved when Greg introduced the notion that the amount of water can affect whether ebony floats: "if you scaled up the big piece of wood, then you have to scale up the water, too.... So, then it would float." In response, I (the teacher) said, "but, even if we took one out into the lake, that little piece, and put it in the lake." This statement was followed by a number of supportive comments from students and a contradictory claim by Greg. At this point, the entire process was set in motion.

As the argument proceeded, Gina introduced the notion that density has to do with how closely packed the molecules are: "It means the amount of molecules that are in the thing. Like the molecules are closer together and they compress!" After some discussion, Greg's side of the argument (left side of Figure 1) agreed with the molecular explanation of density, even though Gina continued to use this notion to counter opposing claims about how ebony could be made to float. In addition, Gina's introduction of the notion of "compression" at this early point in the argument is interesting in that the same notion arises as a major bifurcation point and line of argument in support of Greg's claim that ebony "could" float. Here, the feedback loops associated with the molecular explanation of density versus the amount of water affecting whether ebony floats not only serve as a point–counterpoint process, but also introduce information from one side of the argument into the substance of the other side. In addition, we can see how such feedback loops by serving as point–counterpoint processes (a) push participants to rethink their positions, (b) introduce information from one side of the argument to the other, and (c) increase the conceptual complexity.

The next major bifurcation point occurs during the same class session (i.e., day 2 of unit and day 1 of argument). The dialogue just preceding this point concerned the molecular explanation. Then, Greg stated that, "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 smaller." Although this claim is an elaboration on the previous point about increasing the amount of water for ebony to float, the notion of weight remaining constant provides a slight deviation in the line of thinking. Greg's statement not only provides a substantive elaboration on the existing theme, but also provides a supposition that underlies the argument through to the end. As the argument continues, Gina's side of the argument bifurcates in response to the size of container changing density issue. Shortly afterward, Greg's side of the argument bifurcates in contending that pressure will compress water and thereby change the density:

5.309	Greg	How can density be the same, if you have a whole sea?
5.310	UV	Yeah.
5.311	Greg	Okay, if you have …
5.312	Gail	The sea has salt water in it. [stands up]
5.313	**Tchr:**	**Wait, okay …**
5.314	Greg	Okay a fresh water sea like in a …
5.315	Gina	Fresh water lake.
5.316	Fred	<u>That</u> has mud in it.
5.317	Greg	And then you put that in a tiny little centimeter cube …
5.318	Gina	You <u>can't</u> put that [claps while still standing] in a tiny little …

5.319	Greg	Yes, if you compacted it, there would be a lot …
5.320	Frank	You can compress it.
5.321	Gina	You can't compress water! [with raised voice]
5.322	George	You can so. You can compress water.
5.333	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 … [this entire segment was at a near yell]
5.334	Gina	You don't have to yell!
5.335	Greg	But you can …
5.336	Gina	[All but screams.] No!
5.338	**Tchr:**	**Gina? Gina? Hold on.**
5.339	Gina	But just tell him he's wrong! Just tell him he's wrong!
5.340	Fred	[Close to mike.] David is right.
5.341	**Tchr**	**Wait a second, wait a second …**
5.342	Greg	I'm so right.
5.343	Gina	[Laughing.] You're so wrong.
5.344	Greg	[At the blackboard.] You can put … you can put …
5.345	**Tchr**	**This is good. This is good.**
5.346	Greg	(???) fill it with water …
5.347	**Tchr**	**This is what scientists do. They get just as vehement about their arguments.**
5.348	Greg	… and then you have a smaller thing …
5.349	Gina	[Also at blackboard.] (???) put this into that.
5.350	Greg	You can. You …
5.351	Gina	No!
5.552	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 ample sarcasm:] I hope you can figure that out some day in your life.
5.353	Greg	You can compress it.
5.354	Gina	No! I can't pour a full thing of this into a small thing of this. [demonstrating with two different size containers]
5.355	Gloria	[Laughs.]
5.356	Eric	Yeah, I know, but if you had a lot of pressure, you can … [seriously and with raised voice while standing next to Greg at the blackboard]
5.357	Greg	You can … how do you think they …

5.358	Gina	How are we gonna get that pressure?! [loudly]

In the middle of this transcript excerpt, Greg is continuing to argue that the density of water changes in different size containers. In lines 5.319 and 5.320, the notion that water can be compressed is introduced (bifurcation point). Throughout the middle part of this excerpt, the students, in the fashion of feedback loops, argue back and forth about whether water can be compressed. Then, in line 5.356, Eric introduces the notion that with a lot of pressure water can be compressed (bifurcation point). Each bifurcation point occurs after the conceptual development of the argument reaches a point where a new concept is needed (and introduced) to support or challenge the previously developed ideas.

In the previous excerpt, Gina contends that water cannot be compressed. This bifurcation point on her side of the argument is in response and a challenge to Greg's side.

Finally, the last major bifurcation point occurs on Greg's side, when Frank and others contend that if water can be "stretched apart" then it can be "compressed":

6.105	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?
6.106	Fred	Yeah.
6.107	Greg	And you pump it up and then it shoots into the air?
6.108	Fred	Yeah.
6.109	Greg	Well, that you're putting pressure on the water because you're pumping air into this little container.
6.110	Gina	No, but, but it's not compacted. The thing is …
6.111	Graham	Yes it is, Gina.
6.112	Greg	Yes it is.
6.113	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.
6.114	**Tchr**	**Wait, wait a second. Let … Okay. Let Graham …**
6.114	Graham	Yes. But, that still, you're, this is like … You're still … You still put pressure inside the container. [standing and demonstrating with a gallon milk container]
6.117	Gina	You're still putting pressure on it.
6.118	Greg	Exactly.
6.119	Gina	But the molecules won't compact …
6.120	Graham	Yes they will.
6.121	Gina	'Cause they have to shoot out. [stated emphatically, while standing and demonstrating with her arm how water shoots out]

6.122	Graham	Yes. But, after, after ... a certain amount of *t* ...
6.124	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.
6.136	Frank	But, air, but, water can be stretched apart, put into a bigger volume.
6.137	Gina	It's not stretched apart. It just fills up the bottom.
6.140	Frank	No. But when it's steamed. [emphatically]
6.141	Gina	What it can't do, what it can't do. Okay. All right.
6.142	Graham	Yeah, steam, steam, damn it, steam. [emphatically]
6.144	Frank	If something can decompressurize or whatever you can call it, it can probably be compacted.
6.145	Graham	Same with evaporation. Evaporation. It's just ...
6.146	Frank	Cause when it's steamed, it's just barely anything.

Looking at the argument in its entirety, the overall pattern is one of generating and maintaining itself. In other words, the cyclical patterns (e.g., feedback loops) of discourse tend to feed information from one loop to the next in a spiral pattern. In fact, several spirals related to each bifurcation point thread their way through the temporal sequence of events, where one loop feeds into another loop further along the sequence, such as where "compression" is introduced and is brought up again in a later feedback loop.

In addition, the *symmetrical* pattern (i.e., where both sides are vying for control or, in this case, vying for the correct explanation) of relationship among the participants provides a fundamental characteristic for stimulating a conflict (i.e., argument) from which divergent lines of thought emerge and grow in complexity. There is, of course, another critical element to the initial generation and continued maintenance of the argument: Student engagement arises from taking the content of the argument seriously. In other words, students must feel a sense of ownership over the content and process of the argument. Such ownership is evident in the impassioned dialogue during Classes 5 and 6 (as noted in the transcript segments: lines 5.318, 5.321, 5.333–5.336, 5.343, 5.354, 5.356, 5.358, 6.121, 6.140, 6.142).

The *production process*, which connects the pattern with the structure, is fundamentally the students' cognition. Their inferring, generating supportive and contradictory examples, dismissing others' claims, explaining, providing counter arguments, and so forth are the specific processes. These processes in turn manifest as the cyclical and spiraling cybernetic feedback loops.

In terms of the *structure* (emphasis added to highlight key terms), two aspects or levels of structure are evident. The first level involves the actual components of the argument: the conceptual content. The structure and organization of the ideas generated change as the argument proceeds. In other words, the structure and organization is *emergent*. This notion of emergence is important in understanding the nature of chaotic systems. The specific conceptual outcome of such an argument cannot be predicted, because of the inherent variation in the ideas generated and in the production processes that manifest. However, such variation provides for the possibility of the emergent development of increasingly complex conceptual understandings.

At a more holistic level, the structure of the argument as a whole is quite similar to a *dissipative structure*. As discussed previously, dissipative structures operate far from equilibrium and are nonlinear. The oppositional nature of any argument is an indication of being far from equilibrium. At the same time, the argument, in this article, does not follow a linear path. In fact, the model depicted in Figure 1 looks much like a tornado, which is a classic example of a dissipative structure. The "production processes" that generate the basic "patterns" serve to continually reinforce and perpetuate the overall structure of the argument. In other words, the students' cognition as expressed in the dialogue manifests as circular feedback loops and as spiral patterns that "carry" ideas and concepts forward. The result is the nonlinear, self-maintaining argument that generates increasingly complex conceptualizations.

Emergent Understandings and Underlying Principles

The discussion in the previous section provides a skeletal outline of the major elements of the argument from the perspective of chaos theory, as well as an overview of the major emergent understandings that run through the argument (see Figure 1). In the following section, we will explore the specific understandings for each side of the argument, the conceptual understandings involved, and the underlying principles or interpretive frameworks (i.e., phenomenological primitive and cognitive model) that influenced the emergent understandings. In this discussion, rather than follow the back and forth dialogue, specific lines of thinking will be extracted and examined in detail (see the Appendix for the entire transcript). The first line of thinking will involve Greg's side of the argument (referred to as the "pressure–volume problem"). The next will be the "molecular problem," which was initiated by Gina (note that the entire class agreed with and adopted this explanation of density, even though most students disagreed with Gina's dismissal of the pressure–volume explanation).

Pressure–volume principles or p-prims. In this section, the conceptual development of Greg's side of the argument will be analyzed in greater detail. Greg's statement contains the word *scale*:

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 ...
2.603 Greg So, then it would float.

This notion of proportionality, or "scale," is the central component of the students' emergent understandings. The contention is that the ability for a piece of wood to float is based on the ratio of the size of the block of wood to the size of the body of water. This sequence is the first indication of the conceptual claim made by Greg, which serves as the basis for the beginning of the argument. At this point, the claim states that the density of the same quantity of water changes when the size of the container holding the water changes. Later, Greg reiterates his claim, but the *size of the container* is replaced with *volume*:

2.652 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.

In class 3, Greg continues his argument that ebony could float:

3.14 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.

There is a problem in interpreting this statement, because of the use of a vague word: *it*. Does *it* refer to ebony or to water? If *it* refers to ebony, the claim would be that ebony could float if the block of ebony was expanded to fill a larger volume thereby reducing its density. From a scientific perspective, this claim is accurate. Keeping the mass constant and expanding the volume reduces density. If *it* refers to water, the claim is confusing. If the block of ebony was placed in a larger volume of water and the water (*it*) was not as dense, the ebony would still sink. At this point, we might think that Greg is referring to the prior meaning of *it*, which makes more sense scientifically. However, we might want to consider that in the heat of the moment the use of particular words may not reflect what was intended. For instance, Greg may have intended the following: the block of ebony could float, if the block was placed in a larger volume of water, because the water would be denser. In this case, Greg would be asserting that larger volumes of water are denser than smaller volumes. Such a claim is consistent with the statement in line 2.652.

In line 3.019, Greg states that density relates to how compacted the substance (i.e., molecules) is

3.19 Greg: Well, the theory of volume is that objects are as dense as they are compacted, so ...

This statement supports the scientific interpretation of line 3.014. This same interpretation is again supported in line 3.050:

> 3.50 Greg: Also, the smallest thing could float, if it was in a larger volume, because it was the same small thing …

However, in line 3.055, Greg's states that the density of ebony cannot be changed, but the density of water can be changed by putting the water in different size containers:

> 3.055 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.

If this statement is reflective of his intent in line 3.014, then the interpretation is that the *it* in that line refers to "water," and what he meant was that the water ("it") would be "denser" and not "wouldn't be as dense." With the claim made in lines 2.652 and 3.055, that the density of water changes in different size containers, the consistency of the emergent pattern of understandings appears to support the "it = water" and "water is denser" interpretation of line 3.014.

In Class 5, a key point occurs when the example of the "sea" is introduced to support the idea of proportionality between volume and density. From this point, the notion of pressure becomes a critical factor in the argument.

5.296	Greg	No, what we said is … density … density changes in a smaller volume [persuasive emphasis on "changes" and "smaller volume"]
5.309	Greg	How can density be the same, if you have a whole sea?
5.317	Greg	And then you put that in a tiny little centimeter cube …
5.319	Greg	Yes, if you compacted it, there would be a lot …
5.320	Frank	You can compress it.
5.322	George	You can so. You can compress water.
5.325	Greg	The density will change.
5.327	Greg	That's just an example. The pressure will change …
6.105	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?
6.107	Greg	And you pump it up and then it shoots into the air?
6.109	Greg	Well, that you're putting pressure on the water because you're pumping air into this little container.

6.116	Graham	But, you're still putting the pressure inside of it. You still have it in there.
6.120	Graham	Yes they [molecules] will [compact].
6.124	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.

Four underlying principles or interpretive frameworks evident at this juncture are the notions (i.e., *p*-prims) of (a) *pressure affects density*, (b) *directionality of pressure*, (c) *external forces affect pressure*, and (d) *surface area affects the degree to which external forces affect pressure*. These four notions involve different levels of analytical inference. The first notion, pressure affects density, is based on a low-level inference and is fairly obvious in the transcripts (e.g., line 5.327). Although the second and third notions are less obvious in the transcripts, Greg's response in the post-unit interview suggests such directionality to pressure, as well as external forces affecting pressure:

JB: Okay. yeah, what does pressure have to do with floating?

Greg: Um ... well, the pressure ... um ... I don't ... let me see. I guess it's the pressure on the object, from ... I think, because buoyancy, like the force of buoyancy, is pushing up on it from the water and gravity is pressing down, so there's sort of pressure on the block.

The notions of directionality of and external forces affecting pressure also are evident in lines 6.105 to 6.124, where the example used in these lines is one of a rocket, in which a pump is used to increase the pressure inside. Although the air is being compressed, the students contend that the water is being compressed. The key point in this example is the image of a pump to increase the pressure. Our everyday experiences with the use of the term *pressure* suggest directionality to pressure: We press down on a pump, we push down to apply pressure to stop a cut from bleeding, and so forth. Such notions are indicative of diSessa's (1993) *p*-prims (i.e., based on everyday experiences, have a sense of being obvious, etc.). In addition, certain phrases and terms (such as, *pressure on the object*, *compacted*, etc.) point to the occurrence of what can be called a context marker or a pointer to an underlying principle (such markers or pointers have been discussed by G. Bateson [1979], J. W. Bloom [1990, 1992a], J. Bruner [1986], and J. L. Lemke [April 19, 1995, personal communication, American Educational Research Association annual meeting, San Francisco]). *Context*, as used here, refers to a cognitive or epistemic domain, in which a particular term marks or points to a greater context of meaning (in this case, a specific *p*-prim or interpretive framework).

A higher level of inference is involved in contending with the fourth notion or *p*-prim: "Surface area affects the degree to which external forces affect pressure." Although Greg's response in the interview indicates that external forces affect pressure, the connection between (a) forces and pressure and (b) water and surface area are not indicated. In fact, his response shows how opposing forces put pressure on the block of wood. This interview segment suggests that such opposing forces would increase the density of the block of ebony. Of course, such a claim does not support the contention that ebony could float. However, in the post-unit interview, when attempting to solve a problem (i.e., what is the density of a block of wood, which is 5 cm above and below the surface of the water?), he suggests that the block of wood's presence in the water changes the density of the water (interviewer's "okays" and "ums" have been omitted):

Greg: Um … so since the density of the water is one …
Greg: then is it … that it's … I think it's called water displacement? I'm not exactly sure.
Greg: Um … I'm not sure … what the density is. I think … it just … Well, since the density changes … let me see … the water level would rise …
JB: This block's just sort of floating freely …
Greg: Yeah.
JB: … in the water.
Greg: It's sort of weird though, because it'd still have the same amount of molecules, but it … and it's still the same size, but the density changes. I'm not sure how though.
JB: What do you mean … the density of the block changes?
Greg: Uh … yeah.
JB: Or the density of …
Greg: Um … Oh no, wait. It displaces the … oh, yeah … it displaces the density of the water,
Greg: And so … it would be, like, say, twenty by twenty by twenty, or whatever …
Greg: So … but it displaces because it fills up … it takes out half … it takes out five centimeters of space …
Greg: … from the water. So the molecules have to move, and they … it gets higher …
Greg: … so the molecules get further awa …
Greg: … nd that changes density of the water … from one to, um, higher.

In this interview segment, Greg suggests that the presence of the block of wood in the water raises the density of water. Although the logic of his argument is somewhat confusing, he does indicate that the density of water can be changed. The same notion is evident at numerous points in the transcript of the argument. However, in line 3.50, where he states "also, the smallest thing could float, if it was in a larger volume, because it was the same small thing..." and in line 5.309, where he asks, "How can density be the same, if you have a whole sea?" he suggests that ebony could float if put in a larger body of water. So, we have two notions: (a) The block of wood changes the density of water and (b) larger bodies of water have different densities. The underlying principle for this second notion is more problematic. Although very tenuous, this notion may suggest that the downward direction of gravity (external force) pushes down on the water. The greater the surface area of the water (larger volume) the greater the effect of gravity on increasing pressure downward. Thus, an increase in pressure will compress or "compact" the water and increase its density.

These three, possibly four, principles act as interpretive frameworks (Bloom, 1992a) or *p*-prims (diSessa, 1993), which guide the thinking of the students. Such *p*-prims act as consistent explanatory mechanisms. Such mechanisms provided the consistency in the development and emergence of the argument, as well as in helping to self-maintain the chaotic system (e.g., the argument as a dissipative structure).

Molecular model. The molecular explanation of density was first suggested by Gina in line 2.617:

> 2.617 Gina: [Interrupting Frank.] It means the amount of molecules that are in the ... thing. Like the molecules are closer together and they ...
> 2.621 UV: It's put together tighter ... it's like ... squeezed
> 2.624 Gina: There's more molecules per ...
> 2.625 UV: ... per s-
> 2.626 Gina: ... centimeter.
> 2.627 UV: ... per square millimeter.

This claim suggests that the number and proximity of molecules in a particular substance determine density. Although what is described in lines 2.624 to 2.627 is the number of molecules in a particular "area," the intended claim appears to suggest the number of molecules per unit volume, which is confirmed in a statement from Class 3:

> 3.67 Gina: No ... the thickening molecules. The amount of molecules per square ... the volume.

Shortly after the explanation of density, Gina expresses some uncertainty about the consistency of the number of molecules in water:

> 2.644 Gina: Does all water have the same amount of molecules in it?

Although this question did not evoke any discussion, it points to a level of uncertainty in Gina's understanding of molecules and density. This uncertainty arises again later in the argument:

> 3.71 Gina: Like if you compared, like if you compared one piece of ebony to one piece of pine that were the same size …
> 3.73 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.
> 3.75 Gina: But I don't know how they could find out how <u>much</u> denser, like how many molecules …
> 3.82 Gina: Yeah, but that doesn't show how many molecules there is, because …
> 3.87 Gina: Wait, Greg, Greg. If the pine … it has the same measurements, it'll seem like it has the same amount of molecules, so that wouldn't work.

In lines 3.71 and 3.73, Gina works through a problem to support her molecular explanation of density. By comparing equal sized blocks of pine and ebony, the weight of a block of ebony would be greater than the block of pine, therefore suggesting that the molecules are denser or more compacted in the ebony. In line 3.75, she expresses her uncertainty as to how such a measurement could determine the number of molecules. Again, in line 3.87, she runs into another point of confusion when she tries to determine molecular density by the size of the blocks. By using both weight and size (volume), she runs into difficulty in trying to figure out a way of determining the number of molecules in a substance.

The problem Gina encounters relates to her model of molecules, which appears to be shared among all of the students who continue to adopt a molecular explanation (some have the added notion of the volume–pressure explanation). This molecular model is based on an interpretive framework of uniformity of molecules. The proportionality of weight to number of molecules (line 3.73) and the proportionality of volume to the number of molecules (line 3.87) suggest that molecules are uniform in weight and size across substances (in the excerpts, these two substances are blocks of pine and ebony). Thus, density has to do with the number of molecules in a particular volume regardless of the substance. As opposed to the unidirectional notion of pressure, uniformity of molecules is more of an image or model, rather than a *p*-prim. The image of molecules, although it guides children's inferences, is not based on personal experiences (i.e., it is not phenomenological) in the same way as "pressure" as a phenomenological primitive (where everyday interactions with the world provide the experiences). However, such an interpretive framework acts in much the same way as a *p*-prim, in that it acts as a guide for making inferences. Such a model of molecules is sufficient for explanations within a single substance composed of the same molecules, but the model does not work across different substances or within objects containing a variety of molecules.

DISCUSSION

The following discussion will look at the four questions posited earlier in this article and their implications for teaching and learning. The first section looks at issue of emergent organization as characteristics of chaotic systems and the implications for its theoretical applications to classroom arguments and for instruction (i.e., the first research question). The second section examines the implications of prior and emerging conceptual understandings and interpretive frameworks on learning and for instruction (i.e., the last three research questions).

The Argument as a Chaotic System and Its Implications for Instruction

Traditionally, instructional claims have focused on linear approaches to instruction and on predictable outcomes. However, the unique contributions of a chaotic systems framework provide a perspective that values nonlinearity and unpredictability. As evident in this study, such a perspective provided the basis for students to engage in an on-going argument, which led to unpredictable, yet increased conceptual complexity.

The contention here is that student-to-student discourse needs to be embedded in situational and cognitive contexts (a) that are conducive to and promote engagement in classroom arguments (i.e., a safe classroom atmosphere, etc. as suggested by Gallas [1995]); (b) that draw on students' prior understandings, experiences, emotional connections, and so forth; and (c) that address the nature of science. These contexts involve establishing functional classroom communities (Bloom, 1998; Roth, 1998), connecting to students' contexts of meaning (Bloom, 1990, 1992a, 1992b), and establishing Perkins and Simmons' (1988) four frames of understanding. Within such contexts, students are encouraged to engage actively in discussing their work and taking on more authoritative roles (Cazden, 1988; Cortazzi, 1993; Gallas, 1995).

Within such classroom contexts, where the teacher becomes another player in student dominated discourse and argument, the nature of the discourse can take on the characteristics of chaotic and autopoietic systems. As seen in Figure 1, the feedback loops of student arguments produced bifurcation points, which led to new conceptual strands of the argument. Like the prototypical chaotic and autopoietic system of a tornado, the argument, as represented in the figure, takes on the characteristics of spiraling, while generating new assertions, and leading to increasing conceptual complexity. In other words, as the students argued about specific claims, new avenues of thought spun off into more complex conceptual themes.

As the teacher, my conflict of whether to control or not to control the, at times, heated discussion was a critical point in what seems at this point to have been an intertwined chaotic system of my own thinking. Had I decided to place constraints on the students' argument, either through confining the limits of the conceptual material or by limiting the behavior of the students, the effect may have been vastly different. Rather than a spiraling, self-generating, self-amplifying, and self-maintaining argument, the results of teacher control may lead to a more typical linear and sequential classroom event. The suggestion here is that teacher control has the potential to limit or negate student ownership over the ideas generated.

Predicting that this particular argument would have arisen did not occur and would have been difficult, if not impossible, to do. However, by creating the context in which such an argument can arise and by providing the types of activities where dissonance can occur, the stimulation of such arguments are more likely to occur. In this particular study, the intent of the activity was to provide the students with an event, which had an unanticipated result (for the students)—that is, the block of ebony sinks. This particular event happened to provide the initial attractor. This initial attractor stimulated a move from relative equilibrium (i.e., students in agreement) to a position of increasing distance from equilibrium. Once the positions of the two primary "camps" of the argument became evident, the relationships between the students changed. The division into two competing camps took on the characteristics of Bateson's (1979) complementary (competitive) relationships. Such types of relationships, although potentially unhealthy and destructive, appear to be essential in providing the initiating and fundamental pattern of organization for arguments. This fundamental pattern of organization is autopoietic. Although seemingly contradictory, the divisiveness of complementary relationships provides the ground for self-amplifying arguments. This pattern of organization along with the processes provided by the students' thinking produce a dissipative structure, characterized by the feedback loops of the students' back and forth argument.

Although the need for the relationships within the classroom to take on some degree of complementarity (i.e., where students are competing with one another to assert the validity of their claims), the ideal is to move toward reciprocal relationships (i.e., where students engage in a give and take process of knowledge claim negotiation). This study fell short of reaching this goal. The complementarity led to a continual increase in complexity with no particular agreement by the end of the argument. Even though agreement may not always be possible, some sense of mutual understanding of and respect for the particular positions held by other students may be possible. However, such an autopoietic model of classroom discourse, as suggested by Barab et al. (1999), "potentiates the learner–facilitator interaction" and provides a "fully contextualized experience in which there is no artificial separation between the act of learning, of participation, and the context in which it arises" (p. 353).

Prior and Emerging Conceptual Understandings and Interpretive Frameworks

The results of this study unraveled several underlying principles or *p*-prims of students' understandings of the relations between pressure, volume, and density, as well as a model of students' understandings of molecules. The following discussion will examine the implications of these results for our understandings of student learning, followed by an exploration of the implications for instruction.

The particular emergent understandings evident in this argument arose from a variety of attractors and bifurcation points, as discussed in the previous section. Some of these emergent understandings relate to previous studies of density and related phenomena where the focus was on identifying students' alternative conceptions and difficulties in developing accurate understandings. Gennaro (1981) questioned whether student difficulty was one of conservation of volume or of confusing units of mass and volume. Hewson's (1986) research found that accurate scientific conceptions of volume and mass were not present. In addition, Hewson, as well as Driver (1989), found that a common conception of density involved the notion of "packing of particles" (Hewson, 1986, p. 167). However, none of these studies identified the underlying mechanisms or frameworks that guided student thinking.

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 can easily be attributed to pre-operational thinking. Such statements are easy to pigeonhole without fully understanding what is taking place. However, as we saw, Greg's thinking and understandings were much more complex than were initially evident.

From the subsection Emergent Understandings and Underlying Principles, in the Results section, we have seen how the two positions of Greg and Gina unfold, the underlying meanings and understandings become more apparent. 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 Greg's and Gina's contentions are based on interpretive frameworks at a fundamental level (Bloom, 1992a, 1992b). Several interpretive frameworks or *p*-prims are at play in Greg's notions of pressure: (a) pressure affects density, (b) pressure is directional, (c) external forces affect pressure, and (d) surface area affects the degree to which external forces affect pressure. Gina's position is characterized by a model of 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). These underlying understandings provided the guiding framework, through which examples and new information were sought out and brought to bear in the argument. In fact, in Greg's case, the "pressure is unidirectional" *p*-prim appeared to bring about the link to the "surface area…" and "external forces (e.g., gravity)" *p*-prims. In turn, these *p*-prims led to the claim that pressure can increase the density of water.

Part of the problem of interpretive frameworks or *p*-prims is recognizing when they are at play. During direct instruction, teachers may never have the opportunity to see them, because most of the talking is being done by the teachers. During classroom discussions, the opportunity is there, but how do you spot interpretive frameworks at work? If we look back through the transcripts, we notice that certain key terms keep occurring during the argument, such as pressure, compressurized, and molecules. Both Bateson (1979) and Bruner (1986) suggested an approach to uncovering underlying mechanisms and meanings. Bateson referred to "context markers" as certain terms or phrases, which point to underlying cognitive or epistemic contexts of meaning. Bruner discussed the notion of "triggers" as certain terms or events that point to underlying meanings and which may evoke certain responses. The recurring terms (i.e., pressure, compressurized, and molecules) marked or pointed to the types of underlying problematic understandings or interpretive frameworks suggested by Gee (1994). They also triggered further explanations, counterarguments, and so forth based on the interpretive frameworks.

Classroom discussions and arguments allow teachers to see the recurring markers during the emerging development of understandings. When such markers are identified, the teacher can begin to probe more deeply for a more complete understanding of the students' interpretive frameworks. Although *p*-prims, as diSessa (1993) contended, can be difficult to address in formal teaching situations, it may be possible to do so once such an understanding of the underlying frameworks are developed. The teacher can develop activities and instruction, which address the interpretive frameworks or *p*-prims. Such activities can either be implemented within the unit or at a later time. In the case of this study, had I been the regular classroom teacher, discovering the interpretive frameworks after the completion of the unit could have led to smaller units of instruction on molecules and molecular structure and the dynamics of pressure. However, such a direct approach may not be sufficient without addressing student metacognition (i.e., assessment of their own thinking) and epistemic knowledge (i.e., understanding how their knowledge is structured and how it can be supported or justified). If we consider Vygotsky's (1978) notion of progression from argument to reflection, it is at the point of reflection that teachers can take advantage of opportunities to address the subtleties of student interpretive frameworks and *p*-prims. At such a point, students can be encouraged to analyze and evaluate the strengths and weaknesses of their own frameworks, keeping in mind the key point of being able to justify one's claims.

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APPENDIX

Teacher's talk is boldfaced; UV = unidentified voice; underlined words indicate spoken emphasis.

2.582	JB	Why do you think ebony sinks?
2.583	Fred	Because it doesn't float.
2.584	JB	What's that?
2.585	Frank	Because it's water-logged.
2.586	Fred	Because it doesn't float.
2.587	Gina	Because of the oils that are in the wood.
2.588	Gina	Ebony is dense.
2.589	Fred	Because the tree over-ate.
2.590	JB	Interesting ideas here. So we have ... Oils in the wood ... It's heavy ...
2.591	Gina	It's petrified!
2.592	JB	So, what if I put a great big piece of one of these other pieces of wood that was much heavier than that little piece, and put it in the water?
2.593	Frank	It would float.
2.594	Fred	It would float.
2.595	Greg	Not in ... maybe not in this water. but ...
2.596	Gina	Denser!
2.597	Gina	It's a denser wood.
2.598	Gina	That's what I just said. Denser.
2.599	JB	Denser ...
2.600	Greg	But then ... uh, Jeff? Then
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 ...
2.602	Tchr	Yeah, you'd have to make (???).
2.603	Greg	So, then it would float.
2.604	**Tchr**	**But even if we took one out into the lake, that little piece, and put it in the lake** ...
2.606	Frank	It would sink.
2.607	Tchr	**It would sink.**
2.608	Greg	Yeah, Yeah.
2.609	Fred	But if you put it in a (???)
2.610	Greg	No, it wouldn't. It would go along to the bottom.
2.612	**Tchr**	**[To class.] ... What does dense mean? What does density ... mean?**
2.613	Frank	Density?
2.614	Graham	[Not quite loud enough for the whole class.] Like someone next to me has a dense head. Ha, ha, ha.

2.615	Frank	It means the …
2.616	Greg	Pushed together!
2.617	Gina	[Interrupting Frank.] It means the amount of molecules that are in the … thing. Like the molecules are closer together and they …
2.618	UV	… they compress!
2.619	Fred	Dense.
2.620	**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?**
2.621	UV	It's put together tighter … it's like … squeezed
2.622	Greg	Yeah.
2.623	**Tchr**	**If you take these two pieces of wood, that are about the same size … what are we saying?**
2.624	Gina	There's more molecules per …
2.625	UV	… per s-
2.626	Gina	… centimeter.
2.627	UV	… per square millimeter.
2.640	**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?**
2.641	Gina	Uh, we …
2.642	UV	Weigh it.
2.643	Frank	Measure it then weigh it. And how much …
2.644	Gina	Does all water have the same amount of molecules in it?
2.645	Gina	Like, if you just …
2.646	Gina	… took water from the tap and …
2.648	Gina	No, because water has salt in it. Never mind.
2.649	Frank	Uh, H2O. No, that's the molecule. Uh, water … I'm not sure.
2.650	Fred	Uh, zero …
2.651	Frank	Well, it can be a lot. It can be a little.
2.652	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.
2.653	Tchr	**The volume is smaller?**
2.654	Greg	If you put it in a smaller container. Then the volume will be smaller …
2.655	Tchr	**D'you agree with that?**
2.656	Greg	… and there's more weight in …

2.657	Tchr	**So if you just took the same amount of water and put it into another container** ...
2.658	Greg	Smaller container.
2.659	Tchr	... **smaller container.**
2.660	Greg	The volume would be smaller, that means ...
2.661	Tchr	**Would you** ...
2.662	Greg	... the weight ...
2663	Tchr	... **agree with that?**
2.664	Greg	... but it'd be the same weight.
3.10	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
3.11	Greg	... because it wouldn't be as dense.
3.12	Fred	No. That's not right.
3.13	Tchr	**Now, okay, what was that again?**
3.14	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.
3.15	Tchr	**Does everybody agree with that?**
3.16	[Fred and Frank.] Yeah.	
3.17	UV	No.
3.18	Tchr	**Okay, say it again. So, you're saying** ...
3.19	Greg	Well, the theory of volume is that objects are as dense as they are compacted, so ...
3.50	Greg	Also the smallest thing <u>could</u> float, if it was in a larger volume, because it was the same small thing ...
3.55	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.
3.66	Greg	No ... the density is the larger the volume the larger the ...
3.67	Gina	No ... the thickening molecules. The amount of molecules per square ... the volume.
3.68	Tchr	**How can we** ... **How do we measure density?**
3.69	Gina	Um, by weighing.
3.70	Tchr	**By weighing?**
3.71	Gina	Like if you compared, like if you compared one piece of ebony to one piece of pine that were the same size ...
3.72	Tchr	**Right.**

3.73	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.
3.74	Greg	Right.
3.75	Gina	But I don't know how they could find out how much denser, like how many molecules ...
3.76	Greg	You can measure ...
3.77	Gina	Like I know on a penny ...
3.78	Greg	You can measure ...
3.79	Tchr	**[To Greg.] Go ahead.**
3.80	Greg	... density by length times width times height, because that's volume.
3.81	Tchr	**Volume** ...
3.82	Gina	Yeah, but that doesn't show how many molecules there is, because ...
3.83	Greg	No, it doesn't show how many ...
3.84	Gina	... because ... because look!
3.85	Greg	But if you could ...
3.86	Gloria	You take the height ... I don't want to get into this argument.
3.87	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.
3.88	Greg	I agree. You're right there and I'm wrong.
4.158	Tchr	**... Last week we talked about density, and Fred mentioned something about the blocks ... how we get the ebony to float. Do you remember what we said?**
4.160	Gina	Rubbing alcohol.
4.161	Frank	Surface tension!
4.161	Gloria	Dense up the water.
4.162	George	Drill a hole.
4.163	Eric	Drill a hole and ...
4.164	Fred	I just have to say, I said ...
4.165	Tchr	**Let Fred talk. Gina, you can stay and help me clean up, okay? Thank you.**
4.166	Fred	... density of the water.
4.167	Tchr	**[To Fred.] Okay, go ahead.**
4.168	Fred	I said, density of the water ...
4.169	Tchr	**Would everyone be quiet?**
4.170	Fred	Density of the water. That's what I said.

4.171	Tchr	**But you said ebony ... the piece of ebony, how could you get it to float? You don't remember.**
4.172	Fred	Put floats on it.
4.173	Gai	II remember.
4.174	Tchr	**Hollow it out?**
4.175	Fred	Yeah, you hollow it out.
4.176	Eric	Hollow it out put scotch tape ...
4.177	Fred	And put scotch tape on it.
4.178	Gail	[Laughs.] And put scotch tape on it.
4.179	Frank	You don't need scotch tape.
4.180	George	So the water won't get in the holes, silly.
4.181	Tchr	**Now that idea ... how does that relate to boats floating?**
4.182	Greg	'Cause there's air in the hull.
4.183	Tchr	**What does that do to the density of the object?**
4.184	Gina	It's hollowed out, the thing that ... the boat is hollowed out.
4.185	Greg	Less molecules ...
4.186	Tchr	**Can you think of anything that ...**
4.188	Tchr	**What about the ships in the harbor?**
4.189	George	They float.
4.190	Tchr	**What are they made out of?**
4.191	George	Metal.
4.192	Gloria	Metal.
4.193	Eric	aluminum.
4.194	Greg	Wood.
4.195	Frank	No, metal. There's air in the hull. There's air in the hull ...
4.196	George	They sink like rocks when they (have accidents???).
4.197	Gail	They're made out of tin-foil and pipe-cleaners.
4.198	Gina	They're made out of metal, but they have a wooden frame.
4.199	Fred	They do.
4.200	Tchr	**Some do and some don't. Some are all metal, some have (???)...**
4.201	Gloria	They're made out of metal with no holes in it.
4.202	Frank	It's the shape of ... it's the shape of the hull ...
4.203	Tchr	**Yeah ...**
4.204	Frank	... that helps it float.
4.205	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.
4.206	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 ...
4.207	Greg	Yeah, but ...
4.208	Tchr	**Yeah, so the weight, I mean density, is the amount of weight you've got in a particular volume.**
4.209	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.
4.210	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 *hollow* 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 beside [or, "to the side."], and there's less density. [Rather remarkable stillness in the room as Gina and Greg speak.]
4.211	Tchr	**Yeah, that's actually called the displacement.**
4.212	Greg	Yeah.
4.213	Tchr	**When you put an object into water, it displaces it, pushes it away.**
4.214	Gina	Like with these things, with these on it?
4.215	Fred	I hate those things.
4.216	Gina	You squeeze on them, they go down ...
4.217	Tchr	**Unh hunh.**
4.218	Gina	... because some of the air is like taken away ...
4.219	Tchr	**We're gonna figure that one out.**
4.220	George	I want the really hard one.
4.221	Tchr	**Okay, let's ... okay, Frank, yeah.**
4.222	Frank	And also, you know, when you blow bubbles under water, the bubbles come up to the surface.
4.223	George?	And when you fart.
4.224	Tchr	**Now what happens when you get into the bathtub?**
4.225	Greg	Water rises.
4.226	Gail	I fart.
4.227	Tchr	**The water rises. You're displacing the water, and it rises, right? Okay.**

4.228	Gloria	When the weight is spread out more, it's easier to stay afloat.
4.229	Tchr	**When the ... water's ...**
4.230	Gloria	When the weight of the boat, is spread out more ...
4.231	Tchr	... **spread out more?**
4.232	George	Yeah.
4.233	Gloria	... then it tends to float.
4.234	Tchr	**So the surface area has something to do with it.**
4.235	George	Yup. It does.
4.236	Gloria	And if there's a hole in one end and it fills with water, that end's gonna go down faster because it weighs more with the water in it.
5.256	Tchr	**What's the density of water?**
5.257	Eric	Depends!
5.258	Tchr	**Depends on** ...
5.259	Eric	The, uh, density of water. (???)
5.260	Frank	[To SB.] What will a pole do?
5.261	Fred	It'll do lots. It'll help it to not tip over, or anything.
5.262	Gina	No, how much water there is in it.
5.263	Tchr	**[Directed primarily at Group 1.] But if you change the volume, it's going to (weigh the same???).**
5.267	Tchr	**But if you've got a bucket of water (???) weigh the same as a little cup of water.**
5.268	Gina	No, (???) little cup of water, and you pour a little cup of water into a big bucket it still weighs the same.
5.270	George	It's true.
5.271	Gina	If you pour a little cup of water ...
5.273	Gina	... into a big basin, you'll have the same amount of water in the big basin ...
5.275	Gina	... than in the little cup of water.
5.277	Tchr	**Yeah, but is the density the same?**
5.278	Gina	
Yes.		
5.279		[Other voices saying, "Yes."]
5.280	Greg	Yes, because it changes in a smaller volume, because the density gets ...
5.282	Gina	Well, I'm sorry ...
5.283	Tchr	... **but, if you change the volume, you change the weight, too.**
5.284	UV	Yeah, so (???)

5.285	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 thicken than when I take a big bucket of water and drink it. [spoken with some indignation]
5.287	Greg	That's because the water comes out ... [with adamant emphasis on "out"]
5.289	Greg	It's different when you drink a cup of water ...
5.290	Gina	See, see, he just said the density's gonna be the same, no matter what you do.
5.295	Gina	But you're wrong, Greg. You're wrong. [assuredly]
5.296	Greg	No, what we said is ... density ... density changes in a smaller volume. [persuasive emphasis on "changes" and "smaller volume"]
5.297	Gina	That's not true. [equally adamant emphasis on each word]
5.298	Greg	Yes, it is. It's the same ...
5.299	Gina	You're wrong.
5.300	Greg	No, what we said is ... the density ... dense; I don't know ... it changes in a smaller volume.
5.301	Gina	You're wrong.
5.302	Tchr	**[To Greg.] Well ... we're not convinced.**
5.303	Greg	That's what you said.
5.304	Tchr	**Convince us. I'm not convinced, and she's not convinced.**
5.305	Gina	You're wrong, Greg.
5.306	Greg	No, I'm not.
5.307	Gina	O-oh, yes, you are.
5.308	Eric	[To Gina.] He's right, you know.

SEE excerpts in text of article for lines 5.309 to 5.358.

5.359	Eric	We aren't ...
5.360	NB	You're wrong.
5.361	Greg	Yeah, Gina. We just have ... (???)
5.362	Tchr	**Okay, let Greg talk for a minute.**
5.363	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 ...
5.364	Gina	No! If you're not saying they can, then how do they? [raised voice]
5.365	Greg	You can.
5.366	Gina	No, you can't. [raised voice]
5.367	Greg	Yes, you can. [raised voice and smiling]

SEE excerpts in text of article for lines 6.105 to 6.146.

6.147	Gina	But, can I say something? It's not ...
6.148	Greg	No you can't. [emphatic sarcasm]
6.149	Fred	No, of course. Because you're going to be wrong.
6.150	Gina	It's not just ... It's changing its shape. It's not decompressurizing. See, the water, if you have it in a big container, it's not going to just ... and you pour it from this 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 decompressurize, it's just going to flow out ... [drawing diagrams at the blackboard to demonstrate]
6.151	Graham	Without force.
6.152	Greg	No, without force, Gina, but with force <u>it will</u>. [sarcastically]
6.153	Frank	It will.
6.154	Fred	With force, it will.
6.155	Graham	It will compress ...