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ABSTRACT

This pilot study used a lesson plan study to examine the thinking of preservice teachers about the concept of density, part of almost every school science curriculum, and the teaching of that concept to middle grade students. Subjects in the first study year included seven preservice teachers grouped into three clusters to accomplish the lesson planning task. In the second year, a subset of three students worked together to prepare the lesson plan. Data analysis focused on two facets of understanding density, intuitive and mathematical. Findings suggest that preservice teachers may possess discrete understandings about science content that they have not yet connected in a way that makes sense for them. Probing questions may be a tool to enable them to construct more useful holistic concepts for themselves. Study findings also suggest that the lesson plan study method is a promising strategy for examining the understandings of preservice teachers. Two appendixes contain the lesson planning instructions for both study years. (Contains 22 references.) (SLD)

Pre-Service Science Teachers' Pedagogical Content Knowledge Regarding Density

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Density is a concept that is a part of almost every school science curriculum, with ideas about floating and sinking beginning in elementary school and use of a mathematical formula introduced in middle or high school. The concept poses difficulties for both teachers and students, and is, therefore, an appropriate area for consideration among pre-service teachers at the university. This pilot study used a lesson plan study to examine the thinking of pre-service teachers about the concept of density and the teaching of that concept to middle grades students.

Research Issue

The concept of density is a complex one, partly because it is not a direct measurement, but rather the expression of a relationship (ratio) between two measures—mass (or weight) and volume. Piaget (1971, originally 1946) addressed such a difficulty in his study of young children's ideas about movement and speed. Preschoolers were unable to discriminate between the value of speed and the value of distance or time. For example, when two objects traveled paths of different distances in equal times, many children assumed that equal times meant equal speeds. Piaget indicated that such reasoning showed that the children were able to direct their attention to one aspect of the concept at a time, but not both. If they encounter rich experiences, young children may develop some sense of the properties of matter such as mass, volume, and density prior to formal instruction (Klopfer, Champagne, & Chaiklin, 1992); however, those intuitions rarely develop into sophisticated scientific understandings by the time they graduate from high school (Roach, 2001). The continuing difficulties observed in students may be due to lack of conceptual knowledge and/or lack of procedural knowledge (Heyworth, 1999).

The difficulty with conceptual knowledge may involve both the idea of ratios as specifically applied in scientific concepts involving physical quantities (Bar, 1987; Saunders & Jesunathadas, 1988) and also the mathematical concepts of ratio and proportions (Streefland, 1985). The ratio character of science concepts is not intuitively understood by students. For example, Kariotoglou and Psillos (1993) reported on secondary students who compared the pressure at various points on the bottoms of narrow and wide vessels containing liquids with surfaces at the same level. The students reported that more water implied higher pressure. In this way of reasoning, as with the young children unable to separate distance and time in regard to speed, the students appeared to consider only force, not the relationships (ratio) between force and area.

In addition to problems with conceptual knowledge in the science concepts themselves, there are also common difficulties in procedural knowledge related to proportional reasoning. The problems may occur in a mathematical context (Tourniaire & Pulos, 1953) as well as in a science context. (Akatugba & Wallace, 1999; Krajcik & Haney, 1987). In some cases, at least, students tend to avoid proportional reasoning when solving science problems. For example, Anamuah-Mensah (1986) found that secondary school students preferred to use algorithms (formulas) when solving acid-base titration problems, often choosing the wrong mathematical operations because they did not understand the relationship. Frazer and Servant (1987) showed that students attempted to calculate the concentration of a solution using a formula by multiplying the amount of solute by the volume of the solution. Their answers provided no evidence of reasoning about the meaning of concentration in terms of the given measurements. It is important for educators to understand that, even when students can cite definitions and formulas of science ratio concepts, they do not necessarily understand their meanings or know how to handle calculations involving such relationships.

Because both intuitive understandings and mathematically based scientific understandings support each other in the development of profound and useful conceptions about density, it is probably appropriate to incorporate both into the process of teaching (Smith, Maclin, Grosslight, and Davis, 1997). To clarify, intuitions about density may involve concepts about quantities, though not necessarily in a formal mathematical relationship; therefore, when the term "intuitive understanding" is used in this paper, it refers to ideas that children may develop through their experiences with materials apart from a formal mathematical relationship (as in $D=m/V$). References to "mathematically based scientific understandings" refer to applications of precise numerical relationships. In practice, instruction of young children often focuses on the notions of "floating and sinking" or "heaviness" without attention to the finer points of equal masses and different volumes or vice versa, ideas that could easily extend children's inferences about density without involving calculations (Kohn, 1993). In older students, the intuitive aspects are often ignored, giving way to a focus on two factors: (1) memorizing a definition and (2) solving problems using the algorithm, $D = m/V$, which students can usually perform—even if they have little conceptual understanding of density. The connections between the experience-based understandings developed in elementary schools and the mathematical relationships presented through formulas to secondary students may be ignored, creating a cognitive gap that prevents a rich understanding of complex concepts such as density.

The implications for pre-service teachers in science is obvious: if these teachers have a fundamental understanding of the qualitative aspects of density (usually intuitive) as well as the quantitative relationships related to mass and volume, they are more likely to use intuitive understandings along with precise quantitative relationships to facilitate more meaningful learning in their students. This study addressed both issues in asking these questions:

(1) What understandings do pre-service science teachers hold in regard to density?

(2) How do their conceptions influence their teaching practice in regard to density?

An investigation of these two factors is in essence an exploration of the teachers' pedagogical content knowledge (PCK), the point at which the nature of the content is inseparable from the development of appropriate pedagogy. Although many contextual constraints inform the instructional practice of teachers, "the public knowledge portrayed to students is filtered through the lens of teacher knowledge . . ." (Gess-Newsome, 1999, p. 88).

Methodology

The researchers chose a methodology—lesson plan study—that would allow them to examine the pre-service teachers' ideas about the content (density) and about appropriate teaching strategies (pedagogy) related to density. This research tool has been used previously as an interview technique by both mathematics and science education researchers (Berenson, 2001; Dawkins, 2000, 2001; De Jong, 2000). The prospective teachers' initial knowledge base was explored in the context of preparing lessons, primarily because in the short-term planning of new lessons, the content appears to be the most important issue for teachers (Sanchez & Valcarel,1999). In this two-year study, pre-service science teachers (middle grades level) participated in a lesson-planning task and interview during their sophomore year, when they were enrolled in their first science education course, and again in the following year when they were involved more intensely in lesson planning and field-based experiences. Because the sample is very small, the authors make no claims to generalize beyond this study; however, findings cited in this paper are consistent with aspects of other studies, reinforcing ideas about difficulties with conceptual understandings about complex ideas such as density.

The methodology was considered to be an instrumental case study, the case being the group of pre-service teachers involved in the two-year study. It is instrumental in the sense that it focuses on a well-defined issue, the matter of the teachers' pedagogical content knowledge regarding a very specific concept, density (Creswell, 1998).

Subjects, Data Sources, and Method of Analysis

Year 1. The subjects in Year 1 included 7 pre-service teachers who were preparing to teach science at the middle grades level, grouped into three clusters (2 or 3 persons per cluster) to accomplish the lesson planning task. They prepared plans for two lessons during a regular one-hour class period (see task in appendix 1). Within a week of the lesson planning session, all seven students met to participate in a videotaped post-interview to explain their lessons. The data sources included lesson plan documents prepared by the pre-service teachers in small groups and transcripts of videotaped interviews conducted post-task.

Year 2. In Year 2, a sub-set of Year 1 students, including one person from each of the lesson planning groups, worked as a single team to accomplish the task. Those three students were selected based on convenience; they were able to schedule time for the Year 2 process. The process was very similar in both years, with the exception that in Year 2 the researcher asked probing questions in the pre-interview about the relationship of density to the idea of a ratio and the possibility of using a graph to illustrate the ratio. The information from Year 1 informed the Year 2 process. The researchers were able to identify areas of confusion and to plan probing questions intended to prompt the students to think about density as a ratio. In Year 1, the lesson plans focused very little on the concept of density apart from the formula. Because the researchers had a special interest in exploring the pre-service teachers' intuitive understandings as well as their application of formal mathematical relationships, the lesson planning task required that they plan a lesson for Day 1 that would address the concept of density without any reference to the formula, $D = m/V$. For the second lesson (Day 2), the teachers were to introduce the formula and include problems for students to solve. (See table 1 for a summary of Year 1 and Year 2 subjects and data sources.)

Table 1
Subjects and Data Sources

Year 1		Year 2	
Subjects	Data Sources	Subjects	Data Sources
7 pre-service science teachers (middle grades), working in three groups	• Lesson plan documents • Transcript of videotaped post-interview	3 pre-service science teachers (middle grades), each representing a different group from year 1	• Personal data provided by each student • Transcript of videotaped pre-interview • Lesson plan document • Transcript of videotaped post-interview

The analysis of the data focused primarily, though not entirely, on the two facets of understanding density (intuitive and mathematical). It was an iterative process of examining the written lesson plans and interview transcripts to probe both facets in regard to the pre-service teachers' conceptual understandings and their choices of pedagogies to facilitate understandings in their students through their lesson plans. An informal system for organizing information took a form illustrated in Table 2 below. Although the grid was helpful in organizing information, in reality the categories were not necessarily so clean; for example, evidence found in the lesson plan documents also related to the teachers' conceptual understandings.

Table 2
Organizational Scheme for Analysis

	Evidence of Intuitive Understanding	Evidence of Mathematical Understanding
Teachers' conceptual understandings (as indicated in interview responses)	*Example: ideas about "stacking" liquids of different densities*	*Example: indication of understanding of m/V relationship as a direct proportion*
Teachers' choices of pedagogies (as indicated in lesson plan documents)	*Example: use of comparisons of different objects in lesson plan (w/o measuring)*	*Example: use of a graph in lesson plan to show direct relationship between m and V*

Findings and Evidence

Using both the lesson plan documents and the interview transcripts from both years, the researchers identified several areas of interest.

Intuitive understanding. In regard to understanding the concept of density apart from the formula, the students relied heavily on the idea of floating and sinking, or layering of liquids of different densities. When asked how floating and sinking relate to density, this comment was typical: "Objects less dense than water will float on water; objects more dense will sink." Upon further questioning, none of the students could explain buoyancy:

Interviewer: "What are boats made of?"
Student: "I think some are made of steel."
Interviewer: "Is steel less dense than water?"
Student (smiling): "Hmm, that's a problem, isn't it?"

During the ensuing discussion, however, one student said, "Even if the boat is made of steel, the steel is spread out over the water—not in a big solid glob." There was an intuitive notion about the relationship between density and buoyancy, but the interviewer did not take the conversation in the direction of a more sophisticated understanding involving displacement of water and other factors. In fact, a student said she would probably "hold off on water displacement until after they [students] have a good grasp on density."

Density as a property of substances. In Year 1 students made no references to density as a property of substances. Most of the examples and demonstrations they cited in their lesson plans involved solid objects floating in water or layered liquids. Materials cited either in discussion or in lab instructions included the following: bricks, feathers, wood blocks, salad dressing, oil, and colored water. If you exclude the water present in the sinking and floating examples, no elements or compounds were mentioned in any lesson. The absence of such a reference in Year 1 prompted the researchers to introduce indirectly the idea to the teachers in Year 2 for their consideration. The responses will be noted later in this discussion.

Focus on direct measurements. In Year 1 the problems posed by the students focused primarily on the measuring of mass and volume of solid objects and then the substitution of those values into the density formula. A great deal of attention was given to measuring the volume of irregularly shaped objects by means of water displacement. All three groups proposed labs in which students measured mass and volume before calculating density. As seen in the literature regarding young children's inability to concentrate on a complex concept like speed, these pre-service teachers seemed much more comfortable focusing on the quantities that could be directly measured, rather than the relationship between those quantities.

Dependence on textbooks or former teachers. Both directly and indirectly the students in the Year 1 project indicated their reliance on textbook examples and on the examples provided for them by their teachers. During the post-interview, one student ended an explanation with this phrase: "like in the textbook." In discussing buoyancy, the same student said, "I had to constantly refer back to the book." During the post-interview, the question was posed: "Where did you get the idea for this activity?" Two out of three groups cited demonstrations they had observed during their middle or high school years. Asked where they thought their teachers got their ideas, one student said, "Probably from the textbook just like us." Gess-Newsome cites a prospective science teacher who, after presenting a micro-lesson in class, explained:

You know, I'm a biology major. I took all the required course work for my degree, and did quite well. But no one has ever explained to me what it is that I am expected to teach about biology. In micro-teaching, I selected lessons that I had seen in workshops or that *other instructors had taught. I wasn't trying to be unique. I just didn't know what else to do.* (p. 51)

Pre-service teachers do not know what they are supposed to teach; it is reasonable for them to default to what they have read or seen—unless an intervention provides better ideas.

Influence of prompts on developing understanding. After analyzing the data from Year 1, the researchers identified two areas to address with questions during the pre-interview of Year 2: density as a property of substances and use of a graph to represent the relationship between mass and volume of substances. Their contention was that these students had the ingredients to develop a much more sophisticated understanding of density; they just had never had any guidance in connecting the ideas they already had. Thus, in the pre-interview of Year 2 (with 3 students), the researcher asked this question: "How could you represent the density of a material on a graph?" One student immediately drew horizontal and vertical axes and after a very brief discussion among the three, she labeled the horizontal axis as "volume" and the vertical axis as "mass." It took only a very small amount of prompting to suggest that they graph a material whose density they already knew—water. At least one student stated that water's density was one gram per milliliter. They used those units to label intervals on the graph and plotted the first point. It took no prompting for them to plot additional points (proportional reasoning) and draw a line representing the density of water. Upon questioning, they were able to conclude that there was a direct mathematical relationship between mass and volume for each substance. Further discussion led them to find a chemistry book that had a table with the densities of common substances. They chose one less dense than water and one more dense than water and plotted points on the same graph. Their spontaneous discussion included the observation that the slopes of the lines showed a comparison among the densities and that steeper slopes represented greater densities. The interviewer decided not to make explicit the idea that the chemistry table listed substances (not objects with non-uniform densities) but rather to wait until later to determine if students incorporated that concept into their plans.

Influence of prompts on developing lessons. The lesson plans submitted by the Year 2 students reflected in some respects the pre-interview discussion. They introduced their first lesson with the layering of liquids of different densities and then had students determine masses and volumes of various objects (no substances). Instead of asking students to determine the density of the objects (as the Year 1 lessons had done), they asked them to show the mathematical relationship by using a graph. The plans did not address the problem of having only one point to plot. Perhaps it can be inferred that they would lead their students to determine other points just as they themselves derived additional points. The idea of density as a characteristic property of substances was not addressed at all. Even though the graphing idea incorporated the table of substance densities in the pre-interview, the idea about substances was not explicitly discussed. The ideas that were developed fully in the interview were developed fully in the lessons. Those that were subtly introduced were not addressed in the lessons.

Discussion

The findings have practical implications for pre-service science teacher educators. First, it appears that pre-service teachers may possess discrete understandings about science content that they have not yet connected in a way that makes sense for them; probing questions may be a tool to enable them to construct more useful holistic concepts for themselves. They have the disconnected components, but a masterful facilitator can effectively prompt the combining of the parts into a product that makes sense. In a concept such as density, they may have developed intuitive understandings that are quite reasonable, but may not have been encouraged to connect those understandings to mathematical relationships explored at higher grade levels. In regard to the concept of density, introducing the idea of density as a ratio that can be represented graphically encourages students to visualize the relationship between mass and volume and to make comparisons among different substances. In some cases, ideas must be expressed explicitly. For example, the notion that density is, in at least one sense, a distinguishing property of substances was not reflected in the plans even though the students used a table that suggested such an idea.

Second, the lesson plan study method is a promising strategy for examining the understandings of pre-service teachers and providing an opportunity to facilitate deeper consideration of the science content and of ways to present that content through instruction. For example, lesson plans in this study showed the common use of floating and sinking demonstrations as well as the confusion often associated with those processes. They also showed the frequent use of objects in determining density, with little attention to the idea that such materials (i.e., shoe boxes) do not have a uniform density. If lesson plans are judged only on the use of strategies such as inquiry activities or a prescribed format, problems with conceptual understandings may go unchallenged. However carefully a lesson is constructed, superficial attention to the underlying scientific concepts will perpetuate the types of incomplete understandings demonstrated in this study and many others. If university science teacher educators use lesson plans as a window to their students' understanding of science, perhaps the cycle of misconceptions can be broken.

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Appendix 1

Year 1 Lesson Planning Instructions:

Please work together as a group to prepare plans for two lessons to introduce the topic "Density" to a middle school science class.

Assume you have a class of mixed-ability students and assume that the students have not previously addressed the concept of density.

You may refer in your lesson to any materials you need that would normally be found in a middle school science classroom and/or lab

Because of the fact that this project is a part of a larger research study related to ratio and proportion, we would as that you be particularly aware of any aspects of your lesson that involve ratios or proportions and how they apply to your lesson on density.

Write down an outline of two lesson plans (about 50 minutes each). Include as many details as possible. Include these elements (plus any others that you choose):

(a) how to start both lessons
(b) What are the most important teaching and learning activities (what the teacher does and what the students do)
(c) Two problems (as classwork or homework) in which students determine the density of materials in which the mass and volume are known (or can be measured in lab). Show the solutions to the problems as you would illustrate for your students—how you would work the problems as examples.

Appendix 2

Year 2 Lesson Planning Instructions:

Please work together as a group to prepare plans for two lessons to introduce the topic "Density" to a middle school earth science class.

Assume you have a class of mixed-ability students and assume that the students have not previously addressed the concept of density.

You may refer in your lesson to any materials you need that would be normally found in a middle school science classroom and/or lab.

1. Plan a 2-day lesson for middle school students, introducing the concept of density. Assume that you have about 50 minutes for each lesson.
2. For the first lesson, address the concept of density without any reference to the formula ($D = m/V$). (This doesn't mean you can't talk about the mathematical relationship—but not in terms of the formula.)
3. For the second lesson, introduce the formula. Include in the second lesson at least two problems to solve (either for classwork or homework) that ask students to determine density of materials in which the mass and volume are known (or can be measured in the lab). Show the solutions to the problems.

Write down as many details of the lessons as you have time to do (including things you might say or questions you might ask).

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