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The complexity of teaching density in middle school

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Background: Density is difficult to learn and teach in middle schools. This study, hypothesizing that the density concept develops as part of a conceptual system, used a conceptual change approach to teaching density. The approach emphasized the use of multiple strategies to teach the density concept and the associated concepts in the conceptual system.

Purpose: This study assessed post-instructional understanding of different aspects of density in a sample of seventh grade students, examined the effectiveness of the multi-dimensional approach in teaching density, investigated the relations between prior student characteristics and their post-instructional understanding, and investigated if the concept of density develops as part of a conceptual system.

Program description: In the first part of the study, student understanding of density was assessed in regular classrooms. In the second part, the investigator and a science teacher co-taught the density unit over a two-week period emphasizing relations between density, mass, volume, part-whole relations, and a scientific particulate conception of matter. A conceptual change approach was used which emphasized multiple representations of knowledge and the use of analogies.

Sample: The sample in regular classes consisted of 1645 seventh graders in 51 schools in the West Bank, Palestine. The intervention group consisted of 29 students in one school.

Design and methods: The post-instructional understanding of density in 51 regularly taught classrooms was assessed in the first part of the study using a pencil-and paper test. In the second part, a pre-test was used with the intervention group. Students in both parts of the study took the same post-test. Descriptive statistics were calculated to describe student performance. Comparison between pre-test and post-test performance of students in the intervention group was conducted using *t*-test and ANOVA. Correlations between pre-test sub-scores and post-test scores for students in the intervention class also were calculated. X^2 was used to test for co-development of the density concept and other concepts using the different items of the post-test for all groups.

Results: Student understanding of density was found poor after instruction, while the intervention had a moderate effect on understanding. Students who started with a basic understanding of some aspects of density gained more from the intervention. The density concept co-developed with the concept of volume and a particulate conception of matter.

Conclusions: Teaching density as part of a conceptual system helps promote understanding of the concept. This requires the continuous development and refinement of a learning progression of density, volume, and the particulate nature of matter on the one hand, and an in-depth treatment while teaching the concept on the other hand.

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Keywords: density concept; conceptual change; science instruction; middle schools

Introduction and theoretical background

Density is a difficult concept to understand by middle school children (see, for example, Yeend, Loverude, and Gonzales 2001), and efforts to foster students' understanding are not very successful (Smith and Unger 1997). This study attempts to explore the reasons for the difficulties, to identify the specific difficulties that students encounter when learning about density, and to understand the complexity of teaching density at the middle school level.

In this section, a historical account of the development of the density concept is presented in order to show the difficulties in its development within the scientific community, and hence its complexity. This is followed by introducing the theoretical background which underpins the study, the Piagetian and neo-Piagetian perspective, which best explains the complexity of learning the density concept. Later sections describe two studies which attempted to document and understand the difficulties associated with learning and teaching about density.

Density appears to be a simple concept, a ratio of mass to volume, which we often use in everyday life in the modern world. Yet, the history of science shows that density is a recent concept dating back to Leonhard Euler, the Swiss mathematician and physicist who lived in the eighteenth century. While Archimedes implicitly used the concept of specific gravity, it was not used explicitly except by Moslem scholars in the eleventh century and later in Europe in the thirteenth century. Moreover, the conception of quantity of matter (mass) was absent in ancient thought. The conception of mass can be attributed to Kepler, who used the density concept before defining mass. Descartes, however, rejected Kepler's notion, and thought of volume as the quantity of matter, and considered weight and gravity as merely accidental features of matter.

It was Newton who systemized the conception of mass, but not without trouble. 'The quantity of matter [mass] is a measure of the same, arising from its density and bulk [volume]' (cited in Jammer 1997, 64). Newton added at another point that bodies of the same density are those 'whose inertias are in proportion to their bulk.' Historians and philosophers of science have argued about this seemingly circular definition of mass and density, but it is significant to point out that at that time it was density, and not mass, that was considered a fundamental dimension of physics. According to Jammer (1997), Newton seemed to have thought of matter in an atomistic manner that considers density as the number of corpuscles per unit volume. Jammer explains that Newton considered inertial mass as a reducible property of physical bodies which depends on their quantity of matter. Bodies of equal volumes possess different inertial forces as Newton had found out, so their 'quantities of matter' also have to be different. An intensive factor has to be identified to account for differences in quantities of matter in bodies of equal volumes. This is density. Newton also showed that the ratio between weight and quantity of matter is constant. However, it was a little bit later that scientists considered mass and weight as two different concepts.

Three points can be concluded from this brief historical summary of the development of the scientific concept of density. Firstly, density as a formal scientific concept is a new concept, and it took centuries for it to be conceived in its present form and to become differentiated from other concepts such as weight or volume. Secondly, the concept itself is part of conceptual system that includes many interconnected concepts. The concepts co-developed over time, and gained their meanings from the interrelations between them. These include the concepts of mass (inertial and as a quantity of matter), weight, volume, and the relations between mass and motion (Newton's First and Second Laws). Thirdly, the concepts of density and mass are related, even if implicitly, to some conception of the nature of matter. Newton's atomistic conception of matter was involved in his thinking about density and mass. More generally, any intensive property, such as density, includes some assumptions about the nature of matter, specifically assumptions about the continuity and homogeneity of matter, and the associated assumption that the intensive property is invariant under repeated divisions of the whole into parts.

Piaget (Piaget and Inhelder 1974) is credited with the first meticulous investigations of children's understanding of density. However, the education literature neglects important aspects of his studies, especially his consideration of density as part of a conceptual system. Piaget studied children's understanding of density as part of his investigations of children's construction of quantities, and the conservation of matter, weight, and volume in particular, and the relation of conservation to children's conceptions of matter, or what he termed as atomism. For example, in his explanation of the children's ability to conserve volume, he writes that 'children … no longer treat such substances such as sugar, stones, clay, etc. as simple conglomerates of fused (=solids) or separated grains (=powder, dust, etc.), but as differing in compactness, hardness, resistance or density thanks to the underlying schema of compression ("tight") or decomposition ("loose")' (Piaget and Inhelder 1974). Consequently, they distinguish between global volume and the total corpuscular volume, and Piaget explains that it is the confusion between the two that leads to non-conservation.

In his investigation of conservation of weight, Piaget again asserted that in advanced stages of development, the child relates weight to the quantity of matter (fullness), and matter is conceived as composed of corpuscles. The child 'spacializes' the internal quantity of matter with the schema of compression and decompression, that is, the corpuscular conception of volume. In investigating density, Piaget claimed the child finally develops an understanding based on the idea of relative 'fullness' (more packed with corpuscular matter) and conceives matter as granular in structure with different packing (the compression schema). Consequently, what the education literature neglects is Piaget's emphasis on the interrelations between the conservation of weight, the conservation of volume, and the concept of density. All co-develop and require an atomistic theory of matter, cognizance that the sum of parts is equal to the whole, and a schema of compression and decompression.

While this early work of Piaget emphasized the content of children's thinking, later work stressed the structure of their thinking. Consequently, many researchers attributed the difficulty in students understanding of density to the fact that most children cannot understand this abstract concept before reaching the formal operational stage. However, in the 1980s of the last century science educators paid attention again to the substance of children's thinking. The pioneering and influential work of Driver (Driver 1981; Driver and Erickson 1983) on alternative frameworks treated individual student alternative conceptions as part of alternative frameworks. At the same time, other researchers studied children's naïve science ideas, and proposed teaching strategies that take these ideas into consideration (Osborne, Bell, and

Gilbert 1983; Osborne and Freyberg 1985). These works initiated the conceptual change paradigm in science education research.

Recently, the most sustained research program which built on Piaget's work has been conducted by Carey (2009) and her colleagues (Smith, Carey, and Wiser 1985; Smith, Solomon, and Carey 2005). Borrowing from investigations of historical conceptual change in the development of science, Carey proposed that discontinuities occur in the course of conceptual development, and that new conceptual systems come to replace older ones with which they are incommensurable. Most importantly, she emphasized the need to look at a certain concept as part of a conceptual system and not alone. Amount, volume, weight, and the differentiation of weight from density are part of children's underlying theory of matter, according to Carey. Of particular importance to our purposes, Carey showed that children have an undifferentiated concept of weight/density rather than a lack of a representation of density. This differentiation accompanies conceptual change involving seeing weight as a property of matter and seeing matter as continuous, hence weight comes to be seen as the sum of all small parts of a body. Smith, Carey, and Wiser (1985) claimed that this concept of matter supports differentiating weight from density.

While the work is exemplary in its emphasis on conceptual systems rather than individual concepts and in its attention to the relations between students' conceptions of matter and the development of the concept of density, it neglects two important claims made by Piaget – that there is a need to differentiate density from volume as well (or that they co-develop at the same time) and that a particulate conception of matter (along with the compression/decompression schema) are needed for the development of the density concept. Piaget offers a powerful explanatory frame that can explain, for example, why changes in density result from an increase in temperature or a change in state, while Carey's cannot. (But even Piaget's frame is not enough to explain differences in densities of different substances or elements, such as lead and aluminum. For that, we need the scientific corpuscular theory including the concept of atomic mass.) In any case, the historical studies of science and Piaget's and Carey's works indicate that concepts grow together and gain their meaning from the interrelations between them. New concepts, not expressible in term of previous concepts and terms, arise, and this process of conceptual change, whether in the community of scientists or within an individual child, is not sudden, and takes years to occur. In the case of density, the child has also to co-develop the concepts of weight, mass, volume, force, structure of matter, vacuum, and geometrical space to be occupied by mass/objects, hence the complexity of teaching and learning about density.

Review of related studies

Descriptive studies of the concept of density

Students' understanding of density has been thoroughly investigated from the preschool level to the university level (see, for example, Kohn 1993; Kohn and Landau 1987). Curiously, in investigating children's understanding of density or in interventions which try to foster this understanding, tasks involving predictions about sinking and floating are often used. While these tasks might tap children's implicit understanding of specific gravity, explanations of these predications by the children would involve the concept of relative density which is a highly abstract concept. Although such tasks show that young children can sometime succeed in making predictions about buoyancy, these predictions are found to depend on a combination of weight and substance, and not density, even among college students. Density is often confused with weight and size. Yeend, Loverude, and Gonzales (2001) found similar results indicating students, including college students, do not differentiate between density, weight, and volume, thus supporting Piaget's work and contradicting Carey's work which deemphasizes the density/volume confusion which students face. This also seems to contradict with other findings (Smith, Carey, and Wiser 1985) which report that 8 to 9 years old children have developed a conceptual system in which weight and density are found as two distinct concepts. Examination of different studies, however, indicates that different tasks were used to assess understanding of density, and that performance is often task-dependent and affected by small changes in the task (Fassoulopoulos, Kariotoglou, and Koumaras 2003; Kloos 2008).

Although Smith, Carey, and Wiser (1985) explain that the difficulty with density arises mainly from undifferentiated conceptions that become differentiated within a new conceptual system, other explanations have been offered. Tirosh and Stavy (1999) observed that children use intuitive rules, such as 'Same A – same B' which is used when two systems are equal with respect to a certain quantity A but differ in another quantity B. Kloos (2007), on the other hand, showed that children are more likely to believe that mass and volume have similar effects on density (an increase in any of the two leads to an increase in density), while in reality they have opposite effects. Kloos argues that it is this inherent logical incongruence of the concept of density that leads children to make mistakes, and not the undifferentiated weight (mass)/density concept.

These descriptive studies which assess student understanding reveal that density is a difficult concept to learn, and identify some of the sources of these difficulties. What is lacking in the literature, however, are studies which describe teaching and learning of density in actual classrooms to allow us to gain understanding of contextual factors which constrain or enhance the development of students' understanding of density. The few studies that exist show that student understanding is shaped by ineffectual classroom discussion and ambiguities associated with teacher demonstrations and student practical work (Xu and Clarke 2012), or that that teachers do not effectively use formative assessment (Tomanek, Talanquer, and Novodvorsky 2008). In some cases it seems that teachers' subject matter knowledge about density (Dawkins et al. 2008; Valanides 2000) or their density-specific pedagogical content knowledge (Author in preparation) are lacking, which contributes to poor understanding of the density concepts by their students.

Studies of the development of students' conceptions of matter

Since students' conceptions of matter seem to influence the development of the density concept, there is a need to examine these conceptions. There is strong evidence in the literature that students' conceptions of matter develop from an undifferentiated object/matter concept to a view of matter as homogeneous and continuous, followed by a view of matter as constituted from small units (cells) to a modern view that considers atoms as the basic units of matter (Krnel, Watson, and Glazar 1998). The development from a macroscopic view of matter to microscopic view has been documented by various investigators (Johnson 1998; Liu and Lesniak 2006). Other intermediate beliefs exist, such as the belief that matter is continuous and yet consists of particles or that the particles possess the macroscopic properties of the substance (Tsaparlis and Sevian 2013). Smith, Solomon, and Carey (2005) found an interesting relation between students' understanding of the infinite divisibility of number and matter, a result which supports a conceptual change account of development involving conceptual systems and not a specific concept. The robust findings about students' conceptions of matter support recommendations to teach a simple scientific model of the structure of matter by grade eight (Smith et al. 2006; Stevens, Delgado, and Krajcik 2010). Since density is usually taught around that grade level, and previous results show that the concept of density develops as part of the development of a new conceptual system, it seems appropriate to teach gravity in middle schools as part of a conceptual system that includes the particulate nature of matter. However, it is well known that students have difficulties in making micro-macro connections, that is, in explaining macro phenomena using micro models. Although complicated (Talanquer 2011), this approach can enhance student understanding of density (Hitt 2005).

Intervention studies of the concept of density

Many studies which investigated the effects of different interventions on enhancing students' understanding of density exist, most of them indicating moderate effects. All studies emphasize a qualitative understanding of density in contrasts to the quantitative approach found in many school textbooks. At the elementary level of schooling, some studies used model-based approaches (Zoupidis et al. 2011) or emphasized proportional reasoning (Dole et al. 2009, 2013). The developments in understandings, when examined over a long term, were transient (Rappolt-Schlichtmann et al. 2007).

More studies are found at the middle school level using a variety of approaches. Models in the form of visual analogs for the structure of matter were not very successful in some cases (Smith and Unger 1997) and more successful in other cases (Snir, Smith, and Grosslight 1993). Specific instruction in the atomistic schema, as proposed by Piaget, was attempted in only one study, and the results showed a strong effect on understanding the concept of density (Strauss, Globerson, and Mintz 1983). Smith et al. (1997), however, explicitly faced students' theories of matter without introducing the particulate model. They found that instruction that supports qualitative understanding of density is better. Additionally, students who thought matter has weight, no matter how small it is, were more likely to differentiate between weight and density. Socio-cognitive and cognitive conflict and other conceptual change approaches were utilized in many studies with mixed results (Herrenkohl et al. 1999; Kang, Scharmann, and Noh 2004; Kang et al. 2010; Skoumios 2009; Smith, Snir, and Grosslight 1992). Metacognitive training (Mittlefehldt and Grotzer 2003) and improved formative assessment approaches (Furtak and Ruiz-Primo 2008; Kennedy et al. 2005; Shavelson et al. 2008) were also used with some success.

In conclusion, improved instruction can lead to better understanding of density. However, intervention studies have mostly investigated the use of one approach at a time. There is a need to combine approaches in an attempt to achieve larger effects on student understanding of density. In the present study, such an attempt is made.

Purpose of the study

The study aimed to depict the complexity of teaching and learning the concept of density at the seventh grade level through documenting student understanding of density and describing a specific approach to teaching density at the seventh grade level and its effects on student learning. Specifically, the study aimed to answer the following research questions:

(1) How do students understand the different aspects of density?
(2) Can a multidimensional approach to teaching density facilitate the development of the concept among middle school students?
(3) Are there any relations between certain student prior understandings and post-instructional understanding of density?
(4) What patterns, if any, exist in the development of the density concept and some associated concepts?

Design and methods

In order to answer the first research question, in the first part of the study the post instructional understanding of density was assessed in seventh grade in 51 'regular' schools that were taught in a traditional manner. The results of the first part of the study showed that students have a poor understanding of density. Consequently, the investigator decided to co-teach the unit in one classroom to investigate the effectiveness of a multi-dimensional approach to teaching density, and to better understand the difficulties in teaching and learning about it. That is, to answer the second research question, a multidimensional approach to teaching density was used in one 'intervention' class in one school in the second part of the study. Additionally, the prior understanding of students in the intervention school was also assessed to answer the second and third research questions. Data from both parts of the study was used to answer the fourth research question.

Sample and location

A sample of 1645 seventh grade students in 51 schools was chosen from private, government, and UNRWA (United Nations Relief and Welfare Agency) schools in the central area of the West Bank, Palestine. Schools in the districts of Hebron, Bethlehem, Jerusalem, Jericho, Ramallah, and Nablus were included. Twenty-nine seventh grade students in a private school in Ramallah served as the intervention group in the second part of the study. All schools were non-selective schools serving urban and rural populations as well as Palestinian refugees. Student achievement in the intervention school, as indicated by assessments conducted in previous years, was not different from the average student achievement in the control schools. The intervention class included three special education students.

Instruments

A written pre-test and a post-test of student understanding of density were developed grounded in the literature about student understanding of density and guided by previously developed instruments. The post-test, used in both parts of the study – namely, in the regular classes and the intervention class, assessed the following aspects of density: spontaneous use of the density concept in an everyday context, qualitative understanding of density, quantitative understanding of density, effect of temperature change on density at the macro level, concept of displacement volume, conservation of density, conservation of volume, buoyancy of simple/homogenous and complex/heterogeneous objects in water, and the use of a particulate conception of matter in explaining density-related phenomena. A translation of the post-test is found in Appendix 1. The post-test consisted of 19 items, 11 of which were shared by the pre-test, most of them requiring explanations for the choices. The quantitative understanding items included spaces for making the calculations. Three items assessing micro/macro relations required short written answers. Figures were provided, as necessary, with many of the questions. The reliability (Cronbach's alpha) of the post-test was .81.

The pre-test, used only in the second part of the study in the intervention class, assessed all of these aspects except the quantitative understanding because it was expected that students would know very little about this aspect before instruction. The pre-test assessed, instead, student understanding of part-whole relations, that is, students beliefs about the weight of microscopically small pieces of an object and the relation between the weights of these parts and the weight of the whole object. The pre-test consisted of 17 multiple choice items, followed in most cases by requests for explaining the choice. The reliability of the test was .82.

Description of the intervention

In Palestine, only one official science textbook is used in all seventh grade classrooms, and teachers usually follow the textbook closely. The textbook emphasizes a quantitative approach, introduces density as a ratio of mass to volume, and includes an activity to calculate the density of blocks made of the same material and with different volumes. Other activities include finding the volume of an irregular object through displacement of water and then its density, and finding the density by calculating the slope of a mass-volume function. End-of-unit questions emphasize mathematical word problems.

The investigator and the science teacher in the intervention class co-taught the unit over a period of two weeks, consisting of 10 periods, two of which were used for the pre- and post-tests. This is about equal to the average time spent on teaching the unit in regular classes. We believed a conceptual change approach was needed, and consequently gave students the chance to express and discuss their prior ideas. Conceptual change strategies, such as 'Predict, Observe, Explain' (White and Gunstone 1992) were employed. We tried to provide multiple representations of the new knowledge through the use of analogies, manipulatives, models, and investigative activities in addition to short presentations by the teacher or the investigator. We started with the assumption that the density concept needs to develop as part of a conceptual system that also includes conceptions of mass, volume, and the nature of matter. Consequently, we started with concepts related to density rather than density itself – differentiating material from immaterial entities (Carey 2009); properties of matter; whole/part relations using rice, sugar, and Styrofoam activities/demonstrations (Smith 2007); and Piagetian conservation of weight and volume tasks (Piaget and Inhelder 1974). This was followed by introducing students to a simple scientific model of the structure of matter using physical models and charts, and relating it to the states of matter.

Density was first introduced through mapping and analogies from everyday situations: population density differences in Gaza and the West Bank, body weight/height ratios of students in the class, student densities in the classrooms, hair density. Care was taken to differentiate between the components of the ratio relation and the product; for example, between number of hairs and number of hairs per unit area, or between amount of sugar added and the concentration of the solution. The concept of density was first introduced as weight per unit length when students had to identify rods that were made from the same material given a set of rods of different lengths made from plastic, aluminum, copper, and steel. This was followed by a modification of the dots-per-square activity (Smith and Unger 1997), which we thought would introduce the idea of density in two dimensions. Students were given seven cards with dots drawn on squares, and they had to determine which cards had similar average dots per square and to categorize them accordingly into two categories. Explicit mapping to density of materials being affected by particles per unit volume was made. Other activities requiring the concept of density in three dimensions were then introduced. These included finding the densities of cubes of the same volume made from different substances, and comparing the volumes of one-kilogram items of food, such as one-kilogram packages of sugar and popcorn. Students also had to calculate the density of plastic given a set of cubes of different volumes. They were also shown a demonstration comparing the weights of two 400 ml glass beakers, one of which was filled with small glass marbles and the other with bigger wooden balls. During the discussion, it was concluded that both the mass of the particle as well as the distance between particles (or the number of particles per unit volume) affect density. While we had planned for most activities to be conducted in small groups, in many cases the teacher used demonstrations and short presentations. The teacher was particularly concerned about teaching the unit within the two-week period so that she can ‘cover’ the rest of the topics in the textbook.

Analysis

The post-test was scored by assigning one point to the correct choice on multiple-choice items, and one point to the correct explanation, thus a student could receive a score of 0, 1, or 2 on each item. A rubric was developed for correcting each explanation or open-ended item. In the everyday context and the qualitative understanding multiple-choice items, the point was assigned when an explicit mention of the term density was made, and when it was used in a meaningful manner. In the buoyancy tasks, correct explanations were considered those that employed the concepts of relative density, that is, compared the density of the object to the density of water. In complex objects, the correct explanations additionally had to use the idea of the average density of the object. In the items assessing micro-macro relations, correct explanations, given a score of 2, entailed using the ideas of particles (atoms or molecules), distances between particles, and mass or weight of the particles. Incomplete answers, mentioning inter-particle distances or the mass of the particle, were given a score of 1. In the quantitative tasks, correct answers required doing the correct calculations, but simple errors in division or multiplication were ignored. In multiple-choice items where no explanation was required, the student could get scores of 0 or 1, but the score was multiplied by two when calculating the total score on the test to ensure that a maximum of 2 could be achieved on each item in the test. Consequently, the maximum score on the post-test was 38.

The pre-test was scored similarly. In the two multiple-choice items with explanations that assessed student understanding of whole-part relations, correct explanations were those that showed awareness that a single grain of rice or a microscopically small piece of rice still has weight, and that the sum of the weights of the small parts or of individual grains equals the weight of the whole. The maximum score on the pre-test was 34.

Percentages of students choosing each alternative in multiple-choice items were calculated. These percentages were used to describe students' understandings of different aspect of density, the first research question.

To answer the second research question about the efficacy of the intervention, scores of students in the intervention group on the items which were shared by the pre-test and post-test only were considered. As stated previously, these were 11 items, seven of which required a judgment and an explanation, making the total number of responses on this test 18. The reliability of the pre-test was 0.75 while the reliability of the post-test was 0.73. A paired samples *t*-test was used to compare the means of the intervention group on the pre-test and the post-test, and the effect size was also calculated. To detect the specific aspects of students' understanding that significantly differed between the pre-test and the post-test, a one-way ANOVA was performed.

To answer the third research question about relations between prior understandings or conceptions and post-instructional understanding of density, the Pearson correlation coefficient between student scores on the pre-test and the post-test was calculated. Although a correlation between prior performance and later performance does not indicate a causal relationship, a high positive correlation would indicate that students who did well on the pre-test, or some of its components, also did well on the post-test. Based on the theoretical background and review of related studies, the prior variables of interest were prior understanding of density, holding a particulate conception of matter, and understanding part-whole relations. Prior understanding of density was divided into two sub-scores: qualitative understanding (the tasks involving qualitative judgments about two cylinders) and use in everyday context. Consequently, four sub-scores were created by adding the scores of items in each sub-category. Correlations between these four sub-scores on the pre-test and the total scores on the post-test were calculated. Additionally, and to corroborate the previous analysis, the means on the post-test of students who scored in the highest quartile were compared to the means of those who scored in the lowest quartile in each subcategory, and the *t*-test was employed to test the significance of the differences in means.

In order to answer the final research question that explores if the concept of density develops alone or if it co-develops with other concepts, such as volume and the 'atomistic schema' as suggested by Piaget, correlations between the total score on the post-test and its various items were calculated. While all correlations were significant, some correlations were particularly high. These were associated with the cylinder comparison tasks assessing students' qualitative understanding of density, the micro-macro relations tasks, and the task about displacement volume. Composite sub-scores for each of the qualitative understanding and the micro-macro (conceptions of the particulate nature of matter) were calculated. Three contingency tables were created showing the relations between prior student qualitative understandings of density, volume, and conceptions of matter on the one hand, and the total score on the test indicating student understanding of density. X^2 test was used to test the significance of the three relations.

Results

Understanding of density after traditional instruction

Student performance on the post-test after they had studied a unit on density was very low (M = 9.68 out of a possible maximum of 38, SD = 5.39). As evident from Table 1, only in a few cases did about two thirds of the students answer an item correctly. These are instances requiring students to use simple division to calculate the density of an object when given its mass and volume, to make the correct judgment about the comparative densities of two cylinders when the intuitive conceptions of density lead to the correct answer, and to spontaneously use their intuitive conception of density in an everyday context. The intuitive conception of density which explains many of the patterns in students' responses to the test is that density is a specific property of a substance which is an extensive, rather than an intensive, quantity, not completely differentiated from size (and not 'spatialized' volume) and from 'heaviness' (and not mass). A few detailed responses to some items in the test can substantiate this claim.

When students were asked to compare the densities of two cylinders of different volumes with the same mass (Task 1, Table 1), only 26% chose the correct option, the smaller cylinder. Twelve percent thought they had the same density, that is, equated mass with density, while 44% chose the larger cylinder, equating size with density. A high percentage of student judgments was correct on Tasks 2 and 3; on Task 2, confusion of density with either mass or volume will lead to choosing the correct option, that the densities are equal, and in Task 3 confusion of size with density will also lead to the correct option. The very low rate of students who were able to explain their choices on these tasks shown in Table 1 indicates that the choice of the correct response on both items does not reflect an understanding of density but, rather, a confusion of density with size and, to a lesser extent, with mass or 'heaviness.' Student responses to Tasks 4 and 5 show that about half the students thought of density as a property associated with specific substances. When students were asked about a real-life context, choosing the material with which to build an extra second floor room on an old house, about two thirds chose wood over concrete, indicating that they thought of wood as lighter than concrete, thus also associating certain densities with specific substances. However, only 19% of the students chose wood because they thought it has smaller density, that is, indicated that they hold an explicit acceptable conception of density which they use in everyday contexts. Responses to quantitative tasks typical of those used in classrooms, such as the one in the post-test requiring the use of simple division to calculate density, show that many students can master such skills, but this does not indicate they understand density. Tasks in the post-test probing qualitative understanding reveal a lack of deep understanding of density despite good performance on tasks requiring simple calculations of density.

In contrast to these items on which about two thirds of the students did well, there were several items which were answered correctly by less than one third of the students. When shown an object that was cut into two pieces of unequal size, only 36% conserved density, that is, thought the density of the two pieces was equal. In fact, 41% thought that the density of the larger piece was bigger, again confusing size with density. About half the students had not conceptualized volume as a space occupied by objects, and could not find the volume of an object by finding the volume of water it displaces when immersed in water. Consequently, only a third could

Table 1. Percentages of students in regular classes answering the different post-test items correctly.

Item	Percentage (N = 1645)
Qualitative understanding	
Judgments	
Task 1 (two cylinders, equal mass, different volumes; compare densities)	.26
Task 2 (two cylinders, equal mass, equal volume; compare densities)	.75
Task 3 (two cylinders, different volumes, same substance; compare masses)	.65
Task 4 (two cylinders, different volumes, different substances; compare masses)	.49
Task 5 (two substances, same volume, different substances; compare masses)	.46
Explanations	
Task 1 (two cylinders, equal mass, different volumes; compare densities)	.09
Task 2 (two cylinders, equal mass, equal volume; compare densities)	.36
Task 3 (two cylinders, different volumes, same substance; compare masses)	.05
Task 4 (two cylinders, different volumes, different substances; compare masses)	.24
Task 5 (two substances, same volume, different substances; compare masses)	.19
Effect of temperature on density at the macro level	*.49*
Quantitative understanding	
Simple calculation of density given mass and volume	.66
Calculation of density requiring finding volume by displacement	.32
Calculation of density using the slope of a graph	.40
Calculation of density to identify an unknown substance	.34
Conservation of density	.36
Volume	
Displacement volume	.53
Conservation of volume	.25
Buoyancy	
Requiring relative density only	.46
Requiring relative density of a heterogeneous object (average density)	.38
Requiring relative density of a heterogeneous object containing air: Judgment	.06
Requiring relative density of a heterogeneous object containing air: Explanation	.00
Use in everyday context	
Spontaneous use of density at macro level in everyday context	.64
Explicit use of the density concept at macro level in everyday context	.14
Micro/macro connections	
Spontaneous use of micro model to explain density differences of two substances	.11
Use of micro model to explain density differences with prompt	.14
Use of micro model to explain effect of temperature change on density with prompt	.08

calculate the density of an object using the concept of displacement volume. Much less understood that the volume of displaced water depends on the volume of the immersed object and not its mass, and accordingly were not able to conserve volume.

Students had considerable difficulties with the buoyancy tasks; while about a half understood relative density, they had difficulties when the objects in the liquids were heterogeneous and they needed to think of the average density of the object and then of its relative density or specific gravity. If the object contained air, students, almost unanimously, thought it would float, and did not think about its average density.

Finally, as shown in Table 1, students could not use micro models about the structure of matter to explain differences in density of different materials or to explain the effect of temperature change on density. Even when given direct hints, the percentage of students increased from 11 to 14%, indicating that the problem might be with an underdeveloped atomistic schema for these students and not difficulties in connecting the micro and the macro levels.

In conclusion, student performance indicates poor understanding of density after instruction in seventh grade. Although many do well on tasks requiring simple calculations of density, at least two thirds of the students still hold a conception of density as an extensive property of substances which is undifferentiated from size and 'heaviness.' Most students still do not conserve volume or density in operations where these two quantities remain invariant. They do not understand the concept of average density of complex objects to be able to use in buoyancy tasks, and believe that object containing air always float. Finally, the great majority has not developed a particulate model about the structure of matter, and/or cannot use it to explain macro phenomena associated with density.

Understanding of density after the intervention

Student performance on the post-test in the intervention class was significantly higher than their performance on the pre-test ($M_{post\text{-}test} = 8.50$, $SD = 3.54$; $M_{pre\text{-}test} = 6.68$, $SD = 3.51$), $t(27) = 3.18$, $p = .004$. The effect size was 0.52, which is medium. To detect the specific aspects of students' understanding that significantly differed between the students in the experimental and control classrooms, a one-way ANOVA was performed. Table 2 shows the percentages of students answering correctly on each item in the tests and the items on which there was a significant difference between the two tests. An alpha level of .05 was used.

Examination of Table 2 shows that, although students' performance increased on the vast majority of the items, students in the intervention classroom mainly developed a deeper understanding of three aspects of density. Firstly, their qualitative understanding of density significantly improved. These students also could better use their qualitative understanding of density in an everyday context. Finally, these students could use micro models of matter to explain phenomena associated with density much better than they could before the intervention.

Table 2, however, shows that although the effect of the intervention on students' understanding of density was of a medium size, the effect in non-comparative terms was modest, and the understanding of these students was still lacking. While at least two thirds of the students made correct judgments on qualitative density tasks and explicitly used the concept in an everyday context, only about half of them correctly answered buoyancy tasks involving complex objects or used micro models to explain macro density facts. Additionally, less than one third provided adequate explanations for judgments on qualitative tasks, conserved density or volume, or understood the buoyancy of objects which contained air.

Comparison of the post-instructional performance of students in the intervention classroom and in regular classrooms was not attempted in detail because we could not clearly establish that the student prior understanding of the two groups was similar (no pre-test was used in the regular classrooms). However, since student achievement in the intervention school on a different science test conducted in a previous year was not different from the average performance of students in the

Table 2. Percentages of students in the intervention class answering the different items on the pre-test and the post-test correctly.

Item	Pre-test	Post-test
Qualitative understanding		
Judgments		
Task 1 (two cylinders, equal mass, different volumes; compare densities)	.46	.75*
Task 2 (two cylinders, equal mass, equal volume; compare densities)	.86	.93
Task 3 (two cylinders, different volumes, same substance; compare masses)	.79	.61
Task 4 (two cylinders, different volumes, different substances; compare masses)	.61	.64
Task 5 (two substances, same volume, different substances; compare masses)	.79	.71
Explanations		
Task 1 (two cylinders, equal mass, different volumes; compare densities)	.29	.39
Task 2 (two cylinders, equal mass, equal volume; compare densities)	.25	.50*
Task 3 (two cylinders, different volumes, same substance; compare masses)	.14	.18
Task 4 (two cylinders, different volumes, different substances; compare masses)	.36	.29
Task 5 (two substances, same volume, different substances; compare masses)	.50	.46
Conservation of density	.11	.29
Conservation of volume	.14	.25
Buoyancy		
Requiring relative density of a heterogeneous object (average density)	.32	.46
Requiring relative density of a heterogeneous object containing air: Judgment	.04	.04
Requiring relative density of a heterogeneous object containing air: Explanation	.00	.04
Use in everyday context		
Spontaneous use of density at macro level in everyday context	.61	.93*
Explicit use of the density concept at macro level in everyday context	.14	.61*
Micro/macro connections		
Spontaneous use of micro model to explain density differences of two substances	.14	.46*

Note: Number of usable student responses in the intervention class was 28.
*significant difference, $p < .05$.

Table 3. Correlations between some sub-scores on the pre-test and the post-test.

Sub-score	*r*
Use of the density concept in an everyday context	.61
Qualitative understanding of density	.71
Understanding of whole/part relations	.42
Holding a micro particulate conception of matter	.43

Note: Number of usable student responses in the intervention class was 28.

regularly taught schools, a comparison of the post-test performance of both groups was conducted. The comparison yielded corroborating evidence for the above-shown conclusion – students in the intervention class developed significantly deeper understanding, compared to students in regular classrooms, in the same three aspects of the concept of density. These were a qualitative understanding of density, use of the concept in an everyday context, and the use of a micro model to explain macro phenomena.

Relations between student prior characteristics and post-instructional understanding

The Pearson correlation coefficient between student scores on the pre-test and the post-test was 0.66 indicating that students in the intervention group who started with a deeper understanding of density developed a deeper post-instructional understanding. Correlations between four sub-scores on the pre-test and the total scores on the post-test were calculated and are presented in Table 3.

To corroborate these findings, students who scored in the upper third and lower third on each of these sub-scores were identified, and the average scores on the post-test were calculated for students with high scores and low scores. Comparison of the average on the post test of high and low performance students in each of these pre-test sub-scores showed that the differences in the four cases were significant at the .05 level using the *t*-test. Evidently, students who started to learn about density with a more developed qualitative understanding of density, an explicit concept which they could use in everyday situations, awareness that the sum of the weights of microscopically small pieces of an object equals the weight of an object, and holding a particulate conception of matter, better developed their conception of density as a result of the intervention used in the study.

Development of the density concept or of a conceptual system?

Relations between the total score on the post-test and some of its components were investigated. Table 4 shows the relation between students' understanding of density as measured by the total score on the Test and of volume. Table 5 shows the relation between students' understanding of density and their qualitative understanding of density, while Table 6 shows the relation between students' understanding of density and their conceptions of matter.

A chi-square test of independence was performed to examine the relation between students' understanding of displacement volume and understanding of density as measured by the total score on the post-test. The relation was significant; X^2 $(30, N = 1699) = 512.28$, $p < .001$. Students who had a good understanding of displacement volume were much more likely to understand the concept of density.

A chi-square test was performed to test the relation between students' qualitative understanding of density in the cylinder comparison tasks and their understanding of density and was found to be significant; X^2 $(300, N = 1699) = 2860.41$, $p < .001$. Students who had a good qualitative understanding of density were much more likely to understand the concept of density.

A chi-square test was performed to test the relation between students' conceptions of matter and their understanding of density and was found significant; X^2 $(180, N = 1699) = 1555.90$, $p < .001$. Students who had a good understanding of density were more likely to have a particulate conception of matter and to use it in explaining phenomena associated with density.

These preliminary results indicate that the concept of density develops as part of a conceptual system in which other concepts, particularly the concept of volume and students' conceptions of matter, also develop simultaneously.

Table 4. The relation between patterns of performance on the displacement volume task and total score on the post-test.

	Displacement volume task (number of students)		
Score on post-test	Incorrect	Correct	Total*
Low	709	459	1168
Middle	67	394	461
High	0	40	40
Total	776	893	1669

*Five cases out of 1674 were excluded from the analysis because of missing answers to many items.

Table 5. The relation between patterns of performance on the qualitative understanding tasks and total score on the post-test.

	Qualitative understanding tasks (number of students)			
Score on the post-test	Low	Middle	High	Total
Low	823	315	30	1168
Middle	58	284	119	461
High	0	14	26	40
Total	881	613	175	1669

Table 6. The relation between patterns of performance on the particulate nature of matter tasks and total score on the post-test.

	Particulate nature of matter tasks (number of students)			
Score on post-test	Low	Middle	High	Total
Low	1149	19	0	1168
Middle	340	95	26	461
High	2	10	28	40
Total	1491	124	54	1669

Discussion and conclusions

The study revealed that traditional instruction in Palestine, in agreement with studies conducted elsewhere (Kohn and Landau 1987; Yeend, Loverude, and Gonzales 2001), is largely ineffectual in fostering the development of the concept of density in middle school. However, the present study showed new results about how different aspects of understanding density develop – the relative difficulty of buoyancy, especially when the object contains air, and of the conservation of volume and density. It also showed that students have not developed a particulate model of matter that can help them in interpreting macro facts related to density.

Traditional instruction that does not take student preconceptions into consideration, textbooks that treat density separately from other related student conceptions, and a school system which pushes teachers to closely follow the textbook on one hand and to ‘cover’ all the units in a crowded curriculum on the other hand, do not facilitate deep understanding of the concept of density.

The study also showed that a complex and multidimensional approach, which emphasizes conceptual change and co-development of density and volume, mass, and the particulate nature of matter, fosters a relatively sound understanding of density in middle schools. This corroborates previous studies which treated density as part of a conceptual system (Carey 2009; Smith et al. 1997), or which introduced the modern particulate model of matter (Strauss, Globerson, and Mintz 1983). The results in the present study which show that the density concept simultaneously develops with other concepts (a qualitative understanding of density, volume, and a particulate conception of matter) corroborate findings from previous studies which showed the development of a conceptual system (e.g., Carey 2009). However, the relations between co-development of density on the one hand and volume and the particulate conception of matter on the other hand were previously discussed only by Piaget (Piaget and Inhelder 1974).

The new instructional method was moderately successful in that only half of the students understood displacement volume and buoyancy or were able to use micro models to explain density-related facts, and less than one third conserved volume or density and gave acceptable explanations for their judgments on qualitative density tasks. If learning density entails conceptual change, then we expect the process to be gradual (Carey 2009). On the other hand, the time taken during the intervention was definitely not sufficient; teaching density as part of a conceptual system requires much longer periods of time. Certain limitations, however, should be mentioned. Most important among those was the limited time for the intervention caused by the self-imposed time constraint by the teacher. This meant that many of the activities were given as demonstrations and as part of short lectures. Another important limitation is that the intervention was conducted in one class only. These limitations necessitate recommending replicating the present study in many classes, and using a design research methods approach (Kelly, Lesh, and Baek 2008) that allows development and refinement of the teaching approach.

The moderate success in teaching density achieved in this study, however, cannot be completely explained by these factors. Clearly, there is need for more research in order to better understand the reasons for the poor understanding of density by middle school children. Research that combines investigating student understanding of density and related conceptual frameworks on the one hand and teaching strategies on the other hand is needed. Additionally, and more generally, science education research needs more investigative work focused on the learning and teaching of specific concepts or topics. The results of such investigations can be used to enrich the topic-specific pedagogical content knowledge of science teachers, while work that documents the 'wisdom of practice.' that is, the pedagogical content knowledge or 'pedagogical constructions' (Hashweh 2005) of expert teachers can tap into research on the learning and teaching of specific topics.

The following implications of the study for teaching density in middle schools can be provided. Density has to be taught as part of a modern scientific conceptual system which also includes the modern notions about mass, volume, and matter. There is a need for continued development and testing of a learning progression for matter (Smith et al. 2006) that includes the concepts of weight, mass, volume, and density, a progression which can guide curriculum development. Additionally, textbooks and teaching practices which acknowledge students' prior ideas about these concepts are needed. Lastly, the crowded science textbooks found in Palestine, and in many other countries, place big constraints on providing the needed time and effort to foster students' understanding of density.

Finally, the fact that students who started with some specific ideas gained more from the new instruction than other students is worth discussing. The fact that students who had a better overall understanding of density or a better qualitative understanding of density developed a better post-instructional understanding of density corroborates previous results (Snir et al. 1993). Also, the result that students who initially knew that microscopically small parts of a body still have weight (part-whole relations) developed a better post-instructional concept of density confirms an earlier finding (Smith et al. 1997). The fact that, in this study, students who held a particulate conception of matter before instruction were better prepared to gain from instruction is new. The overall results indicate that it would be useful to better prepare all students by providing experiences that help develop students' ideas about density, whole-part relations, and matter at lower grades. Again, there is a need for the development of a specific linear progression to guide curriculum development concerning the concept of density.

Disclosure statement

No potential conflict of interest was reported by the author.

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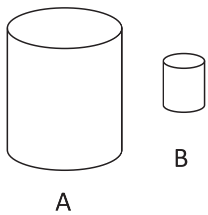
Appendix 1: Student understanding of density test

1. Khalid intended to build a new room on top of his old house. An engineer told him that the house was old and cannot hold an extra heavy weight. Khalid had to choose between building the new room using wood or reinforced concrete. What do you advise Khalid to use:

a. Wood
b. Reinforced concrete
c. He can use either wood or concrete
d. No advice can be given in view of the provided information

Please explain why you chose this answer.

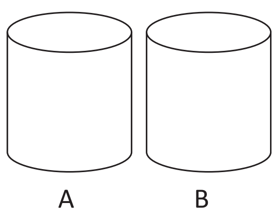
2. Objects A and B have the same mass. Which has greater density?



a. Object A
b. Object B
c. The two objects have the same density
d. I cannot determine which has greater density with the given information

Please explain why you chose this answer.

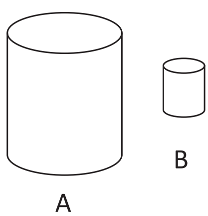
3. Objects A and B have the same mass and the same volume. Which has greater density?



a. Object A
b. Object B
c. The two objects have the same density
d. I cannot determine which has greater density with the given information

Please explain why you chose this answer.

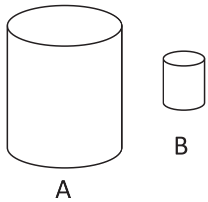
4. Objects A and B are from the same material. Which has greater mass?



a. Object A
b. Object B
c. The two objects have the same density
d. I cannot determine which has greater density with the given information

Please explain why you chose this answer.

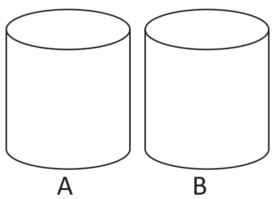
5. Objects A and B are from different materials. Which has greater mass?



a. Object A
b. Object B
c. The two objects have the same density
d. I cannot determine which has greater density with the given information

Please explain why you chose this answer.

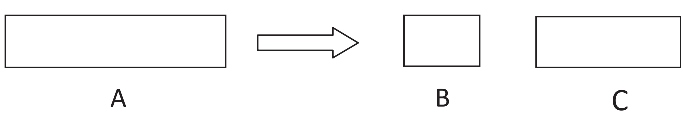
6. Objects A and B are from different materials, and have the same volume. Which has greater mass?



a. Object A
b. Object B
c. The two objects have the same density
d. I cannot determine which has greater density with the given information

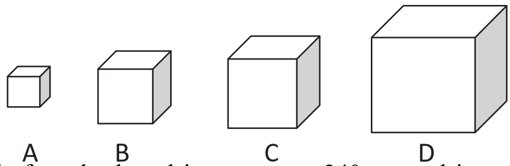
Please explain why you chose this answer.

7. Object A was divided into two pieces B and C as shown in the diagram.



If we compare the densities of objects B and C, we expect that:
a. Object B has greater density
b. Object C has greater density
c. Objects B and C have the same density
d. The question cannot be answered with the provided information.

8. The objects shown in the diagram have different volumes.



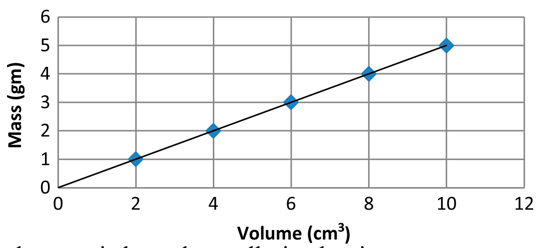
If object A was made from lead, and its mass was 240 gm and its volume was 60 cc., and object B was made from aluminum, and its mass was 160 gm and its volume was 80 cc., and object C was made from iron, and its mass was 300 gm and its volume was 100 cc.

while object D was made from an undetermined substance, and its mass was 300 gm and its volume was 150 cc.

We can conclude that object D was made from:

a. Lead
b. Aluminum
c. Iron
d. No conclusion can be made in light of the provided information

9. The following graph was constructed by measuring the mass and volume of objects made from the same substance with different sizes. Use the graph to calculate the density of the substance.



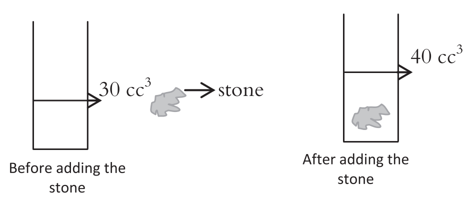
10. When a certain substance is heated, usually its density:

a. Increases
b. Decreases
c. Remains constant
d. It depends on the nature of the substance

11. A solid object has a volume of 30 cc and a mass of 90 gm. Its density is:

a. 3 gm/cc^3
b. 0333 gm/cc^3
c. 2700 gm/cc^3
d. 303 gm/cc^3

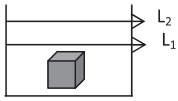
12. An irregularly-shaped stone whose mass was 20 gm was immersed in a large graduated cylinder as shown in the figure. If the level of the water was raised from 30 cc to 40 cc,



a. What is the volume of the stone?
b. What is the density of the stone?

13. Two cubes, one of which was made from lead with a mass of 1412 gm and the other from aluminum with a mass of 337 gm, are of equal volume. The lead cube was immersed in water, and the level of the water was raised from L_1 to L_2 as shown in the figure. What would happen to the water level if the lead cube is replaced by the aluminum cube?

a. It would go up to L_2



b. It would rise above L_2
c. It would rise below L_2
d. It would stay at level L_1

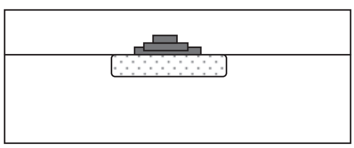
14. Two objects were placed in a water basin (density of water is 1 gm/cc^3). If you know that the density of the object A was 0.5 gm/cc^3 and its mass was 50 gm, while the density of the object B was 1.5 gm/cc^{3}and its mass was 30 gm, what would you expect to happen?

a. Both objects would float
b. Both objects would sink
c. Object A would float while object B would sink
d. Object B would float while the object A would sink.

15. A tightly-closed iron box, filled with air, is put in a water basin. What would you expect to happen?

a. The box will float over water
b. The box will sink to the bottom of the basin
c. The box will be suspended in the middle of the water
d. The provided information does not allow to predict what would happen
Please explain why you chose this answer.

16. The diagram shows a piece of wood that is floating on water. A student added iron pieces above the piece of wood until it sank. Which of the following explains what happened?



a. The weight of the wood and iron pieces became too heavy for the water to hold
b. The density of iron is larger than the density of water
c. The average density of the wood piece and the iron pieces became larger than the density of water
d. The water surface tension could not hold the combined weight of the wood and the iron nails

17. The density of lead is about four times the density of aluminum. How can you explain the fact that the density of lead is so much larger than the density of aluminum?

18. The density of substances usually decreases with an increase in their temperature. Use what you have studied about the structure of matter (matter is composed of particles which vibrate and move, etc…) to explain this phenomenon.

19. You have previously studied that matter is composed of particles (atoms or molecules). Use this to explain the difference between the densities of lead and aluminum if you have not used this in answering question 17.