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Students' Ideas About Changes in Mass Associated With Melting

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Abstract

This paper reports a study on elementary students' ideas regarding changes in mass associated with melting. An open-ended probe was designed and distributed to fifth-grade students (n = 230). In addition, 50 students were asked their reasons behind predictions on mass change. The written responses indicate that, despite conventional teaching, students have difficulty understanding conservation of mass. Although students' predictions were similar, individual reasons for those predictions differed. In some cases, students used similar reasons for different predictions. Finally, the results of the study highlight misconceptions that have not been reported previously.

Research indicates that students have difficulty understanding conservation of mass. The reasons behind this difficulty vary. Driver (1985) points out that students perceive physical change as disappearance of the substance, and evaporation, sublimation, and dissolving are common examples (Andersson, 1990; Bar, 1989; Bar & Galili, 1994; Johnson, 1998; Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; Stavy, 1990). Another reason for the difficulty seems to be related to students' perceptions of the nature and physical state of the matter on change. Studies indicate that students aged 9-13 years tend to regard a gas as having no mass, or less mass compared to the solid or liquid form of the substance (Mulford, 1996; Prieto, Watson, & Rodriquez, 1993; Renstrom, Andersson, & Marton, 1990; Schmidt, 1997; Sere, 1986; Stavy, 1988, 1990). Studies also show that students imagine gases as having the property of negative mass. In other words, they think that the more gas that is added to a container, the lighter the container becomes (Driver, 1985; Renstrom, Andersson, & Marton, 1990). With such misconceptions, students will unlikely conserve mass in physical or chemical change involving gases.

Students' reasoning regarding conservation of mass is also influenced by their atomistic/particulate ideas. Piaget and Inhelder (1974) suggested that the ability to conserve mass develops as students start to construct particulate models of matter. This assertion has not been supported by later research (Adey, 1976; Holding, 1987; Selly, 1979). For instance, Holding (1987) found that some students who imagined sugar dispersed as very small molecules did not conserve mass because they regarded such tiny molecules as having negligible mass or being less dense. Additionally, students also think that atoms do not have mass or that the number of molecules is not conserved during physical changes (Andersson, 1990; Gabel, Samuel, & Huhn, 1987). These particulate ideas clearly do not help students to conserve mass in physical changes.

Even though a substance does not disappear from their sight, students fail to conserve mass on melting (Krnel, Watson, & Glazar, 1998; Stavy, 1990). The majority of students think that solids loose mass on melting (BouJaoude, 1991; Osborne & Cosgrove, 1983; Stavy & Stacher, 1985). Since melting does not involve gases, these students' beliefs seem to be supported either by their conception of substance or their atomistic view of matter. Students might believe that solid substances stick together better than when in a liquid form and are hence heavier (Lee et al., 1993). Also, students do not conserve number or mass of atoms (or molecules) by attaching physical properties to them (Ault, Novak, & Gowin, 1984; Griffiths & Preston, 1992). For example, they think water molecules are largest and the heaviest in the solid state (i.e., when they form ice) (Lee et al., 1993; Krnel et al., 1998; Pereira & Pestana, 1991). Thus, students are likely to believe ice weighs more than water.

It appears that many students do not conserve mass in physical changes, and that their reasoning differs, even if they support a similar view regarding conservation of mass. In the area of the conservation of mass involving physical changes that include evaporation, sublimation, and dissolving, melting seems to have attracted the least research attention. Thus more research would help uncover the origins of student ideas concerning mass changes associated with melting. This study therefore aimed to find out whether elementary students who received conventional teaching on physical changes conserve mass on melting and to uncover their underlying reasoning. In this way, students' incorrect ideas concerning melting that result from science education can be pinpointed and teaching can be redesigned accordingly.

Research Questions and Methodology

The aim of this study was to investigate elementary students' ideas related to change in mass during the melting process. In order to do this, two research questions were addressed: Do students conserve mass during the melting of ice? How do students justify their ideas (correct or incorrect) related to mass change associated with melting?

A total of 230 Turkish elementary students aged 11-12 years took part in the study. Students were chosen from five different state schools. An open-ended probe that asked students to predict whether the mass of an ice cube changes on melting, and to justify their prediction, was used in the study. The probe was distributed to students after their conventional teaching on melting. In Turkey, students meet the concept of melting for the first time in their elementary education (at the age of 11 years) and under the subject "The Effects of Heat on Matter." Conventional teaching of melting involves teaching terminology (definition) and rules (mass is conserved on melting). The teaching method used is mainly teacher-centered, with the teacher explaining, in both macroscopic and submicroscopic terms, what melting is and how it happens. In this sense, the teaching is based on a transmission of knowledge view of learning.

After students responded to the written probe, 50 students were interviewed individually to determine the reasons behind their predictions. Interviewees were chosen so as to represent different reasoning related to mass change on melting. All interviews were audio taped and fully transcribed. Students' open-ended responses were analyzed in an ideographic way (i.e., students' responses were analyzed in their own terms rather than categorizing them according to pre-determined categories). The categories were therefore developed as the data analysis proceeded. After students' responses had been categorized, frequency distributions were calculated. To ensure reliable and valid analysis, random samples of the coding were independently checked by another coder, and 94% reliability was achieved. In analyzing the interview transcripts, particular consideration was given to aspects such as the following: What kind of reasoning do students have for their mass prediction? Do they draw upon the particulate model in order to justify their answers and how do they draw upon it when they were cued to use it? In what ways do they relate the concept of mass to the concepts of volume, density, and heat?

Results

Table 1 shows students' predictions about the change in mass of ice on melting. Less than one half of the students (40%) believed the mass would stay the same during melting, 57% did not conserve mass on melting, and the remaining 3% gave an uncodable response or no response at all. Of the students who did not conserve mass on melting, the majority imagined that the mass of ice would decrease during melting while the rest predicted an increase in mass.

Table 1
Student Responses to the Probe on the Change in Mass of Ice on Melting

Student Response	Number of students (N = 230)
Misconceptions	
The mass **decreases** during melting	74 (32%)
The mass **increases** during melting	57 (25%)
	(Total: 131 [57%])
Scientifically acceptable response	
There is **no change** in mass during melting	93 (40%)
Uncodable/no response	6 (3%)

Students' written and oral responses indicated that although their predictions were similar, the underlying reasons varied. Table 2 presents students' reasoning about mass change on melting. The prediction that ice would have more mass than water was supported by seven underlying reasons. Some students appeared to generalize that the mass of solids is always more than the mass of liquids. Interviews indicated that these students either referred to the position of solids (at the bottom) in water or their feelings of carrying a solid to back up their concept of "heavy solid." Apparently, these students drew their reasoning heavily from perceptual features.

Perceptual cues formed the basis for another line of reasoning. This group of students compared the volume of ice with that of water and believed that the volume of ice is more. They therefore decided that ice would weigh more than water. Some of these students supported their reasoning using the example of volume increase (expansion) during freezing. Apparently this line of reasoning not only stems from perceptual cues concerning volume changes on melting, but also from students' failure to differentiate the concepts of mass and volume. According to these students, bigger volume means more mass. There seems to be a similar relationship between the concepts of mass and density. According to their written responses, some of the students thought that density of ice would be greater than that of water and thereby would weigh more. Upon further probing, they explained that ice is solid and therefore denser than water. When they were asked if this is the case for every solid and its liquid form, some responded to the question positively without any hesitation whereas others were ambivalent.

Table 2
Student Reasoning About the Change in Mass of Ice on Melting

Prediction	Type of reason	Underlying reason
Ice has more mass	Perceptual	Solids are heavier than liquids. Ice is heavier than water, solids sink in water. Volume of ice is more than that of water.
	Conceptual	Density of ice is more than that of water.
	Particulate	Solids are/ice is closely-packed. Ice has more particles than water. Particles of ice are less energetic.
Water has more mass	Perceptual	Density of water is more than that of ice. Water is heavier than ice as ice floats on water. Volume of water is more than that of ice.
	Conceptual	Heat is a substance and has mass/weight.
	Particulate	Particles of water are more energetic.
The mass of ice is the same as the mass of water	Perceptual	No mass is added or removed as ice turns into water.
	Conceptual	Mass does not change during melting. Mass is always conserved.
	Particulate	Particles of ice and water are the same

Another line of reasoning offered by students who predicted a decrease in mass on melting was related to students' ideas concerning the particulate nature of matter. They thought that molecules of a solid weigh more than water. Some of these students assumed ice would have more molecules than water, and thus they predicted the mass of ice would be greater than the mass of water. On the other hand, some students based their reasoning on molecular movement; they thought molecules with more energy weighed less. According to interviews, these students imagined that water molecules move faster, and therefore would have less mass, than ice. Students believed energy made the molecules lighter. Another reason was related to the movement and balance of molecules. Students believed molecules in ice cannot move freely. Thus their molecules are static and have more mass, whereas water molecules are not static and have less mass. These students believed that movement of molecules determines the mass, even if the molecules are from the same substance.

Other students predicted an increase in mass during the melting of ice, using five underlying reasons. According to students' written and verbal responses, the majority of students compared the density of ice with that of water (i.e., they viewed ice as less dense than water). Some based their reasoning on the fact that ice floats in water, while others emphasized the accepted densities of ice and water. Regardless of the nature of reasoning, both groups believed more density meant more mass. Thus they claimed that the mass of water would be greater than that of ice. Another line of reasoning was related to volume change during melting. Some students gave responses like "volume is increased on melting and therefore mass is increased" or "mass of water will be more because volume of water is more than the volume of ice." These students believed larger volume meant more mass, indicating difficulty in differentiating the concepts of mass and volume.

The third line of reasoning was related to the matter, such as the structure of heat. Some students thought heat has mass. Therefore, they expected an increase in mass during melting due to heat being absorbed by the ice cube. When probed further, some explained that heat is energy that is added to the mass of ice. Some, on the other hand, claimed that heat has mass but could not provide further reasoning. The other reasoning of this group was particulate in nature. As can be seen from Table 2, some students believed water molecules to be more energetic than those of ice. This reasoning is familiar, since some students who predicted that mass would decrease during melting predicted such. However, this time the relationship between movement and mass is reversed. Students of this group believed that water molecules move faster, bump into the container, and therefore weigh more.

As with other groups, students who did not expect a change in mass during melting backed up their prediction with different reasons. Some provided conceptual reasoning in explaining the conservation of mass, while others appeared to base their reasoning upon perceptual cues, stressing that nothing was added or removed during melting. According to students using reasoning based on the particulate nature of matter, ice and water molecules are the same, so mass would not change. These students provided acceptable explanations concerning the melting process via the particulate model.

Conclusions

The traditional teaching that students experienced was ineffective because, after instruction, the majority of students in this study did not understand the concept of conservation of mass during melting. This finding is in accord with the literature indicating that traditional instruction, during which the teacher transmits knowledge and points out misunderstandings, is not successful (Driver, 1989; Wandersee, Mintzes, & Novak, 1994).

Students can make the same prediction about mass change on melting but for different reasons (e.g., there were seven ways used to justify the mass of the ice being greater than that of the resulting water). Conversely, some students can use the same reason to support different predictions (e.g., the idea that the energy of particles affects/determines the mass of particles seems to be the common reason behind two different predictions).

Regardless of the prediction of the mass change associated with melting, some of the students supported their ideas via observable features of the melting process. Even those who used the concepts of volume attempted to explain it by perceptual aspects, and this finding is not surprising. Melting is a process that involves apparent volume changes. It is highly likely that students who cannot differentiate mass and volume might use perceptually-bounded volume changes to explain their reasoning. This finding is in line with the findings of other research that indicates students' dependency on perceptual features in their reasoning (Andersson, 1990; Bar, 1989; Bar & Galili, 1994; Johnson, 1998; Stavy, 1990), although these references do not speak for the melting process itself.

This study uncovered students' misconceptions regarding changes in mass during melting. Some of these misconceptions are in line with the findings of previous research, even though most of the latter investigated students' preinstructional ideas. For instance, the idea that solids lose mass on melting (Krnel et al., 1998; Osborne & Cosgrove, 1983; Stavy & Stacher, 1985), and that solids are heavier than liquids (Ault et al., 1984; Lee et al., 1993), are two of these. Similarly, the misconceptions that mass is increased when a substance is heated, and that heat has mass/weight, seem supported by previous research findings that also indicate the underlying reasoning behind these misconceptions to be the idea that heat is a substance or that it has the properties of matter (Schmidt, 1997; Thomaz, Valente, Maliquias, & Aritanes, 1995). The misconception that greater density means more mass/weight also seems to be in line with the findings of previous research (Kind, 2004; Mulford, 1996; Schmidt, 1997). The idea that more volume means more mass also seems to have been reported in the literature, albeit in the context of dissolving rather than melting (Çalık & Ayas, 2007; Holding, 1987; Kabapınar, 2001).

At the same time, this research identifies some misconceptions that have not been reported in the literature previously. These comprise the ideas of molecules being less energetic in ice than in water and therefore weighing more or less, the mass of molecules changing in accord with their movement, and ice being closely-packed and having more molecules than water. It should be noted that these misconceptions were not detected in students' written responses, but rather were uncovered during the interviews. Thus, face-to-face interviews that follow up students' written responses, or an interview-about-instances approach (Osborne & Gilbert, 1980), seem to be preferred methods for studying the origins of students' ideas and the reasoning behind them.

This study reinforces the need to recognize the existence of students' ideas prior to teaching. Specifically, while teaching the concept of melting, teachers will raise the issue of the relationship between heat and mass only if they become aware of the existence of the misconception that heat has mass. It is also important for teachers to be aware of the effects of instruction on students' ideas. As the findings of this study indicate, students can make incorrect connections/conclusions about melting and particles that are a result of science instruction. With such knowledge in mind, teachers can take actions or precautions to avoid promoting misconceptions via their teaching. For instance, they might be more careful in presenting the particulate model of matter as a conceptual tool in explaining the melting concept and in observing the interaction between the two.

Being aware of student misconceptions, though, is not in itself adequate for remedying them. Science teachers need to design specific teaching approaches that start from students' existing ideas and develop these towards the accepted ones. For the topic of mass change associated with melting, it is important that the teacher organize teaching activities where students test their mass change predictions, produce their own explanations as to why their predictions might be incorrect or supported, deduce acceptable ways of thinking, and reject the alternative ones. In this respect, the teacher should design teaching activities to illustrate that heat has no mass/weight, that solid substances are not heavier than their liquid counterparts, and that there is not a linear relationship between mass and volume or mass and density. However, the teacher must invite students to carry out activities, to observe, and to interpret the findings of the activities. Only then can they come to understand the phenomenon in a different, but scientifically acceptable, way.

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