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ABSTRACT

Trying to change the predictive rule for the sinking and floating phenomena, students have a great difficulty in understanding density and they are insensitive to empirical counter-examples designed to challenge their own rule. The purpose of this study is to examine the process whereby students from sixth and seventh grades relinquish their predictive rule in the face of counter-examples and to examine two variables that might affect their interpretation of counter-examples: the use of a computer simulation as conceptual referent, and prior awareness of an alternative concept of density. Two computer programs, "Weight and Density" and "Sink the Raft," were used as the treatment materials. Results show two main effects from the two variables. However, none of the differences in the groups remained by a posttest administered six to seven weeks after the experimental sessions. Appendices include 13 figures; 35 tables; scripts for introduction, model guided observation, and observation without the computer model; outline of treatments; a paper and pencil test, and scoring criteria. (YP)

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PROMOTING CHANGES IN CHILDREN'S PREDICTIVE RULES ABOUT NATURAL PHENOMENA: THE ROLE OF COMPUTER-BASED MODELLING STRATEGIES

Technical Report

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Harvard University

PROMOTING CHANGES IN CHILDREN'S PREDICTIVE RULES ABOUT NATURAL PHENOMENA: THE ROLE OF COMPUTER-BASED MODELLING STRATEGIES

by

Micheline Frenette

Weight and Density
Technical Report

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Chapter 1

INTRODUCTION

Children are familiar with sinking and floating phenomena from a very young age and develop an intuitive feel for which objects sink or float. However, the development of an accurate predictive rule (based on the density of the object's material relative to that of the liquid) represents a challenging intellectual problem in part because it is contingent upon the child's prior understanding of the concept of density. The density of a material is derived from an object's mass relative to its volume and this ratio (mass per unit volume) defines a constant for different material kinds under standard conditions. Although children in the upper elementary grades do not yet have abstract concepts of mass and volume, they do already have distinct concepts of weight, size and material kind and are in the process of developing an intuitive concept of density (Smith, Carey & Wiser, 1985). Some children still combine multiple senses of weight (e.g., "heavy," "heavy for size," "heavy for me") in the same undifferentiated weight/density concept while others have made a clear distinction between the weight of an object and the heaviness of the kind of material it is made of. This latter attribute, however, is thought of qualitatively as an invariant property of material kinds rather than as a new type of quantity expressing the ratio weight/size. In this report, I will be working with the quantities weight and size rather than mass and volume and defining density as an explicit ratio of weight/size. This terminology is in keeping with the learning strategy adhered to in the study: helping students to see density as an intensive quantity distinct from weight by building on their existing conceptions.

Given that children do not have a clear concept of density as a quantity, it is not surprising that many children between 8 and 14 years of age tend to base their predictions of which objects will sink or float on other variables that are easily observable, such as the weight of the object, its size or its shape (Biddulph, 1983; Smith et al., 1986; Inhelder & Piaget, 1958). At most, some children in this age group (likely those who possess an intuitive precursor concept) may realize that flotation is linked to the relative weight of an object by saying that flotation has to do with the "material an object is made of" or "how compact it is" (Biddulph, 1983; Smith et al., 1986) but their incomplete conceptual repertoire does not yet allow them to formulate a specific predictive rule based on the relative density of the two materials, (that of the object and that of the liquid).

Children's ideas about density and flotation were first investigated in the context of Piaget's stage theory of logical development. Piaget & Inhelder (1941/1974) maintained that the concept of density develops at adolescence when the child becomes capable of formal operational thought. Until then, the child has a clear concept of weight but cannot integrate it with volume because he/she does not yet conserve volume (i.e., understand the constancy of the volume of a substance despite external transformations). Further, the relationship between weight and volume is a mathematical ratio which calls upon proportional reasoning, a formal operational ability within Piagetian theory.

Inhelder & Piaget (1955/1958) also maintained that the child cannot develop a predictive rule for sinking and floating phenomena in terms of density until the onset of formal operations. Formal operations are assumed to be required not only for the construction of a distinct concept of density, but also for the control of variables and reasoning from counter-examples necessary for designing and interpreting sinking and floating experiments. Hence, within this model, density is construed as a formal operational concept and the modification of a predictive rule is assumed to derive from a logical analysis of counter-evidence, both achievements being judged out of reach of elementary school children until the development of formal operational thought.

In contrast to Piaget's stage theory of logical development, the "conceptual frameworks" viewpoint in science education stresses that an individual's reasoning about natural phenomena is ultimately constrained by their implicit causal theories rather than their ability for logical argumentation (Carey, 1985; Champagne & Klopfer, 1984; Driver & Erikson, 1983). Since they assume all children have some basic abilities to modify their existing theories in the face of new evidence, the development of children's conceptual repertoire is charted to identify the domain specific ideas children bring to bear in their reasoning about natural phenomena.

For instance, recent research (Smith, Carey & Wiser, 1985) has begun to characterize children's alternative conceptions that block their understanding of weight and density as distinct quantities. Smith et al. argue that the core of young children's concept of weight is the notion of *felt weight* and that this concept includes some components that are precursors of a concept of density (e.g., *heavy for size*) as well as some that will remain part of a concept of weight (e.g, *absolutely heavy*). It makes sense for students to unite these two components in one concept because an object's felt weight is a function of its density as well as its absolute weight and because the notion of how heavy something feels is an inherently comparative one. It is not clear a priori that the relativization *heavy for size* is different in principle from other relativizations such as *heavy for me* or *heavy for objects of its type*. However, as the child comes to reconceptualize weight within a matter theory, in which the weight of an object is analyzed as a function of the amount and kind of matter it is composed, it becomes more important to distinguish the variables of weight and density. Thus, developing a concept of density involves both making conceptual differentiations (e.g., differentiating weight and density) and changing the framework concepts are embedded in.

Most models of cognitive development are built on the assumption that change will occur when a mental schema, defined as an organized pattern of reaction to the environment, is seen to be repeatedly ineffective. Hence, there is general agreement on the importance of motivating cognitive change by showing the advantage of one concept over another in solving a series of problems. Teaching strategies based on cognitive conflict have been designed to create the need for cognitive change in the student. However, these strategies have encountered only limited success thus far. A review of studies on the effect of these intervention strategies concludes: "The overall results of these studies on cognitive conflict are generally mixed. There do appear to be genuine shifts in some aspects of students' frameworks but also a number of student ideas remain resistant to this type of instructional strategy" (Driver & Erickson, 1983, p. 51).

Consider, for example, the effectiveness of such a teaching strategy in challenging students' predictive rules for sinking and floating. Such strategies were found to be only moderately effective at the high school level (e.g., Hewson, 1982; Rowell & Dawson, 1977 a, b; Cole & Raven, 1969) and totally ineffective with 7th graders (Cole, 1968). In related work, Emerick (1982) found that no subject from her sample of 12 to 15 year-olds discovered density by controlling weight or volume when presented with a set of real-world materials designed to facilitate the comparison of these variables in relation to floating.

There are two contrasting explanations for why a cognitive teaching strategy is not more effective in teaching about flotation. On the one hand, lack of success with the cognitive conflict strategy may reflect the student's limited logical resources and accompanying lack of interest in the scientific method. In Emerick's study, for example, she reports that students were not bothered with inconsistencies between their predictions and their observations. Frequently, they showed a lack of concern with the counter-examples on the grounds that they were irrelevant (e.g., "this piece must be hollow inside") or they compartmentalized their knowledge to avoid revising their theory ("maybe this heavy object floats but other heavy objects will sink").

On the other hand, the problem may be that students do not have the domain specific conceptual resources to benefit from counter-examples rather than a general inability to acknowledge them (see Hewson, 1981; Posner & Strike, 1986). If children do not yet have a concept of density which they can use to organize their understanding of sinking & floating, then they may prefer to hold on to a weight theory (which works some of the time) rather than move to having no theory at all. This tendency to hold on to a flawed theory until a better theory was available was observed in younger children's reasoning about the phenomena of balancing blocks (see Karmiloff-Smith & Inhelder, 1974)

The importance of making children aware of more adequate competing theories in order to bring about conceptual change is supported by work from the philosophy of science and the process of theory change among scientists as well. Kuhn (1970) suggests that theories are never defeated by contrary evidence but only by better theories. Just as a powerful theory is necessary for the recognition of a conflict with reality so the availability of an alternative powerful theory is necessary to solve the problem quickly and effectively. This would lend some support to the following statement: "If it is true that old theories are never defeated by contrary evidence but only by better theories as claimed by Kuhn children having both available to them are in the best possible situation to accept the new one" (Rowell & Dawson, 1983, p. 214).

In keeping with this view, Posner & Strike (1986) believe that the presentation of counter-evidence is only the first step in a process of conceptual change: making the student aware that something is wrong with their conceptions that may need to be changed. In addition, however, students need to be presented with alternatives that are both *intelligible* (i.e., understandable) and *plausible* (i.e., appears to have the capacity to solve the problem). "Only an intelligible theory can become a candidate for a new conception in conceptual change" (Posner et al., 1982, p.217).

The issue of how to provide information to guide the formulation of a new concept is a complex endeavor. Consider the case of developing a concept of density which is differentiated from weight through interaction with real world materials. One could explore the phenomenon of flotation. However, one major source of difficulty in inferring the relevance of density to flotation is that the irrelevant features (volume and weight taken singly) are the most obvious while the relevant feature (the density of the material) is concealed. Indeed, for many children it is not yet even a distinct concept. In addition, children have to grapple with the problems posed by the size-weight illusion (where smaller objects made of dense material appear to be heavier than larger objects that actually weigh the same), a difficulty which has been found to hinder students from clearly differentiating weight from density (e.g., Halford & al., 1986). Researchers may deliberately restrain handling of materials in order not to activate such kinesthetic feelings about the influence of weight (e.g., Emerick, 1982). Another frequently used approach to understanding density is to show that density defines a constant for different materials by having students plot the weight of objects of a given material against their respective volumes. This has proven to be difficult to understand even at the high school level (e.g., Rowell & Dawson, 1983) probably because it is an abstract procedure and it does not provide an intuitive grasp of density. A more qualitative understanding of density may be achieved by comparing the weights of equal volumes of the material and of the liquid.

Children's difficulties with the concept of density were assumed to be linked to the fact that children's concepts of weight and size are embedded in an alternative framework which does not analyze each in compositional terms. Further, density is an intensive quantity which is not directly perceptible. Many researchers (e.g., Karplus et al., 1983) have shown that up through early adolescence some children have difficulty with the concept of ratio. However, Quintero (1980) has shown that children grasp perceptible intensive quantities before more abstract ones. Building on this strength, ongoing research of the "Weight and Density" group at the Educational Technology Center (Smith, 1984; 1985; Smith et al., 1986) has developed computer-based models to complement real-world materials, in order to provide students with conceptually relevant information that is accessible to them and that they can then apply to a problem.

One of the programs, entitled *Weight and Density* (to be described more at length in Chapter 2), provided students with an interactive visual representation of density, where its intensive nature (i.e., the fact that it is a local property of the material and therefore not affected by variations in the size of the object) could be visualized and thus grasped more easily. In these computer analogs, objects were constructed of squares which stood for size units and dots were used to represent weight units. Hence, the density of the material was conveyed by the number of dots in a square, (i.e., number of weight units per size unit). An interactive data display updated information as objects of different sizes and made of different materials were constructed on the screen. Thus, the use of this explicit conceptual model should make the concept of density more intelligible to students.

In addition, this explicit conceptual model was embedded in a flotation simulation called *Sink the Raft* (described at more length in Chapter 2). This program should contribute to making a flotation rule based on density more intelligible and plausible because it clearly identifies the competing variables of weight and density. Further, the size (and consequently, the weight) of an object may be altered and re-set instantaneously. With real-world exemplars, one needs to switch back and forth between objects since few materials can be readily cut and re-assembled. This feature of the simulated experiment allows students to isolate variables more easily and provides immediate feedback on a wider spectrum of instances for a given variable. When the child is allowed to experiment with this visual analog of the density concept which is shown for both objects and liquids, he/she is in a better position to infer that the density of the object in relation to the liquid is the critical predictive factor. The theoretical and pedagogical principles guiding the design of these programs are discussed more fully in another report (see Snir et al., 1988).

These programs have been found to facilitate conceptual change in 6th and 7th graders when used in the context of teaching units which also included lectures, demonstrations and experimentation with real-world materials (see Smith et al., 1986, 1987). These units, designed for classroom teaching, involved groups of students over a number of weeks. In contrast, the present study involved students in an individual tutoring situation for a brief period of time in order to focus on one phase of the process of conceptual change and to highlight the respective contribution of each program to this process. Cognitive conflict is an important factor that can lead to conceptual change to the extent that students can acknowledge counter-examples to their own rule as disconfirming evidence and act upon that knowledge to revise their rule. Such a change is more likely if students have the conceptual resources to build alternatives to their former rule. The study tested two variables that were expected to help students benefit from the observation of such counter-examples, the use of a simulation as a conceptual referent and prior awareness of an alternative concept.

The first hypothesis is that the presentation of counter-examples to one's flotation rule will be more effective when it is coupled with information about the competing concepts. More specifically, using a conceptual simulation of flotation should result in greater shifts in children's hypotheses about flotation than exploring sinking and floating phenomena without the support of such a simulation. The assumption is that the opportunity to interact with simulated models of the variables that are being examined (e.g., weight, density) makes the competing variables more salient, thus allowing students to judge the role of these variables in sinking and floating phenomena more easily (i.e., evaluate the plausibility of different predictive theories more efficiently). To test this first hypothesis, some subjects will be presented with counter-examples to a predictive rule based on the weight of the object, using real-world materials only while other subjects will also have access to conceptual information about the materials through an interactive computer representation.

The second hypothesis is that the importance of counter-examples to one's flotation rule will be better acknowledged if the student is already in possession of the conceptual resources needed to make sense of the counter-examples, that is, children will be more likely to change an ineffective theory of flotation based on weight when they already have been introduced to the concept of density. The prediction is that the opportunity to learn about density before exploring its relevance to sinking and floating phenomena (using conceptual models) will result in greater shifts in children's flotation theories because children will be able to judge the import of the counter-evidence while being aware of an alternative concept. To test the second hypothesis, some subjects will be introduced to the concept of density prior to examining sinking and floating phenomena while others will be introduced to the concept of density only after having been confronted with counter-evidence. All children, however, will be taught about density using computer-based models, given its demonstrated effectiveness for children of this age (Smith et al., 1987).

Interaction effects between the two variables, or at the very least, cumulative effects of the two variables, are also expected to occur. For example, the subjects who benefit from both variables (i.e, they are introduced to density first and they have the opportunity of making models of sinking and floating phenomena) are likely to be advantaged relative to the other three groups of subjects in changing their predictive rule. The subjects who benefit from neither variable (i.e., they are introduced to density afterward and have to rely on the observation of real-world materials only) are expected to have the most difficulty in changing their predictive rule.

Chapter 2
METHODS

2.1. The Overall Research Design

The study followed a randomized control group pretest posttest design (Campbell & Stanley,1966) in order to test the effect of two independent variables on students' rules for predicting whether an object will sink or float. The first independent variable was the mode of exploration of sinking and floating phenomena (i.e., with or without the support of a computer model) while the second independent variable was the order of introduction to the concept of density (i.e., prior to or following the exploration of sinking and floating phenomena). These two variables were organized into a 2 X 2 factorial design which yielded four different treatment conditions (see Table 1 in Appendix H). A fifth experimental group which received no treatment served as a control group. (Students in this group were given a make-up session after all the data for the study had been collected.) Each treatment consisted of two individual sessions that will be described in more detail in section 2.3. One of the sessions involved the presentation of the cor pt of density while the other session involved the exploration of sinking and floating phenomer.a. The dependent measures that were used in the design will be described in Chapter 3.

The study involved one hundred 6th and 7th graders from two public schools in Cambridge, Massachusetts. Fifty subjects from each grade level were randomly selected from a pool of 117 subjects who had volunteered for the study and who had also obtained a written consent from their parents to participate. The mean age of the 6th graders was 11.5 years while the mean age of the 7th graders was 12.2 years. The percentage of boys in the sample was 51% and the percentage of students from different racial/ethnic groups was as follows: 44% White, 34% Black, 16% Hispanic and 6% Asian.

The subjects were distributed among the five experimental groups (i.e., the four treatment groups and the control group) following a blocked random assignment procedure based on their grade level and on their answers on the pretest. First, sixth graders were divided into two groups, according to whether they had justified some of their predictions of sinking and floating phenomena on the basis of the weight of the object or whether they had based all of their predictions on the kind of material the object was made of. A median split was then used to subdivide these two groups further, based on whether they had obtained a low score or a high score on the items of the pretest pertaining to the concept of density. The subjects in the resulting four groups were then randomly assigned to one of the five experimental conditions. The same assignment procedure was repeated for the seventh graders.

The distribution of subjects among the five experimental conditions by gender and ethnic origin is displayed in Figure 1 (Appendix A). Male and female students were evenly distributed among the experimental conditions but the students from the various ethnic groups were not equally represented in all five conditions. Among the subjects who used the simulation of sinking and floating phenomena (Groups A), twice as many white students were introduced to density first in comparison with students from the other ethnic groups. Also, among the subjects who explored sinking and floating phenomena without the support of the computer model (Groups B), a greater number of white students followed the second sequence of introduction to density in comparison with students from the other ethnic groups. However, later analyses showed that this discrepancy in the final assignment of subjects did not influence the results of the study.

The experimental sessions were conducted individually by the author and another graduate student in education who was also involved in the development of the sessions. The first experimenter was responsible for 59% of the total number of sessions. The two experimenters each carried out half the sessions involving exploration of sinking and floating phenomena without the computer model but the first experimenter carried out 65% of the sessions which involved the exploration of sinking and floating phenomena with the support of the computer model. As will be described in section 2.3, each treatment consisted of two sessions and the subjects underwent both of their respective sessions with the same experimenter. The sessions always took place in a separate locale within the school.

2.2. Materials: Computer programs and concrete artefacts

The experimental sessions made use of two computer programs that were developed at the Educational Technology Center. The Center's mandate was to explore innovative ways of using the computer in the mathematics and science curricula and to ensure that the computer served as a tool to further children's understanding of real-world phenomena. Research projects were organized around "targets of difficulty," that is, topics toward which students traditionally showed a great deal of resistance. One of the difficulties reported by science teachers in teaching about matter was to find clear and meaningful ways for students to grasp the conceptual distinction between weight (an extensive property of the object) and density (an intensive property of the material).

Hence the goal of the "Weight and Density" research group was to investigate children's conceptual development in this area and to develop software that would help children understand the difference between weight and density.

The software designed by the group provides a symbolic environment that can be used to represent physical objects in a way that visually highlights the numerical relationship between their size, their weight and the density of the material they are made of. Objects are represented on the screen by means of a grid and dot structure (see Figure 2 in Appendix A). In this model, the square stands for a size unit and the dot stands for a weight unit. Hence, for a given object, the size is determined by the total number of squares (i.e., number of size units) and the weight is determined by the total number of dots enclosed in the object's perimeter (i.e, number of weight units). For a given material, the density is expressed as the number of dots within a square (i.e., number of weight units per size unit). One program is used exclusively to build bulky objects made of homogeneous material while a second program enables the user to represent liquids in addition to objects and to conduct sinking and floating experiments.

The first program, entitled *Weight and Density* offers five symbolic materials, each one identified by a different color. Once a material has been chosen, a unit of that material appears in the building window. The size of the object may then be increased and subsequently decreased by pressing the appropriate arrow keys. The material of a given object may also be altered, in which case the dot ratio specific to that material overlays the previous model, while the size of the object remains unchanged. Data on the size, weight and density of the object, expressed in the symbolic units, may be requested at any point in the building process and may be displayed separately or jointly. Once in the data mode, any change in one variable brings on corresponding adjustments in the data reading. When the objects are colored in, the squares and dots are no longer visible but the data display is always in reference to the underlying grid and dot structure.

The *Sink the Raft* program makes use of the visual analogs of size, weight and density described above to represent an object and a fixed amount of liquid, thus enabling the subject to conduct sinking and floating experiments. However, instead of seeing the full grid and dot structure (which would be visually confusing when the object is immersed in the liquid) the user has the option of viewing a sample of the material and may then scan the object and the liquid by moving this window around (see Figure 3). When the object is lowered into the container, one of three outcomes is possible, depending on the relationship between the respective densities of the object and the liquid : 1) the object floats when its density is *less* than the density of the liquid; 2) the object sinks when its density is *greater* than the density of the liquid; 3) when the two densities are equal, the object remains suspended between the surface of the liquid and the bottom of the container. For each experiment, the level of the liquid is seen to rise and the object submerges to a depth that takes into account the relative densities of the two entities. As in the other program, the user may change the size and the material of the object and the data display adjusts accordingly. The liquid is also available in five different kinds of materials but the amount of liquid is constant.The programs were run on an Apple IIc computer coupled with an Amdek Color-I monitor (8" by 11").

2.3. Procedure: The experimental treatment

Three different learning sessions were designed, two of which made use of one of the computer programs described above. This section will describe the general procedure that was followed within each session. The detailed scripts that were adhered to by the experimenters in carrying out these sessions may be found in Appendices B, C and D. Each session lasted between 35 and 45 minutes (i.e., approximately one class period). An overview of each treatment, which consisted of two of the individual teaching sessions to be described next, may be found in Appendix E.

2.4.1. <u>The session on the concept of density</u>

The goal of the session on density was to help students articulate the distinction between the concepts of weight and density. The activities consisted in representing the size, weight and density of a set of steel and aluminum cylinders by means of the *Weight & Density* program described above. The metal cylinders that were used are illustrated in Figure 3 while their respective computer representations may be observed in Figures 4 through 6 . Students were handed the materials and asked to comment on the fact that the cylinders of identical size weighed different amounts and that inversely, the cylinders of identical weight were different in size. To expand upon students' intuitive understanding that steel is a heavier kind of material than aluminum, the numerical relationship between the two metals was demonstrated by equilibrating a steel cube with three aluminum cubes on a balance scale. It was explained that the density of a material is a measure of how much weight is crowded into one unit of that material and that this quantity is independent of the amount of material.

The computer model was introduced as a means of representing data from real objects in order to help us understand some features of these objects. The experimenters guided the subjects in putting up appropriate representations of the size, weight and density of the metal cylinders on the computer screen, pointing out the relationship between these three parameters. To conclude the session, the meaning of density and the procedure for inferring the relative densities of materials were reviewed. During the session, explanations were repeated when necessary and the experimenter was free to answer queries except those that concerned sinking and floating phenomena. This session on density was conducted in an identical manner for all the subjects in the study.

2.4.2. The sessions on sinking and floating phenomena

Two different sessions were designed to explore sinking and floating phenomena, one of which made use of the *Sink the Raft* computer program to guide subjects' observations of the phenomena, while the second kind of session relied only on direct observation of the phenomena without the support of the computer model. Nonetheless, both kinds of sessions shared a common goal and followed the same general structure, centering around the presentation of counter-examples to a predictive rule based on the weight of the object. The phenomena consisted of bulky objects made of homogeneous material (disregarding the role of shape as in boats) and were also limited to instances that float partly immersed in the water (excluding cases that float on top of the water due to surface tension). Cases of suspension were also excluded.

The goal of the sessions was to provide students the opportunity to reflect on the role of different variables in sinking and floating phenomena without attempting to teach a predictive rule as such. Instead, the role of the experimenter in these sessions was that of a facilitator; he or she asked for clarification when necessary without implying that the subject's answer was wrong (e.g., "I'd like to be sure of what you mean by that"). When a subject sought approval for their answers, the experimenters reflected the question back to the student (e.g., "What do *you* think?" or "I'd like to know what *you* think about it"). Students' responses to these real-world phenomena were also recorded to be later compared with their responses to similar phenomena depicted on the written test.

The sessions consisted in the presentation of four different kinds of counter-examples to a predictive rule based on the weight of the object. In other words, subjects could observe that variations in weight of an object did not affect the outcome (i.e., a "Light Floater" versus a "Heavy Floater" and a "Light Sinker" versus a "Heavy Sinker") or that the same weight led to two different outcomes (i.e., a "Light Floater" versus a "Light Sinker" and a "Heavy Floater" versus a "Heavy Sinker"). Wax and wood (pine and oak) were used as floating materials while clay and metal (steel and aluminum) were used as sinking materials. For each object, students were asked to predict whether the object would sink or float, to state the reasons for their predictions and then to observe whether their prediction was confirmed or disconfirmed when the object was immersed in water. At this point, the sessions differed according to whether the subject was in the group which used the computer simulation or not.

2.4.2.1. The session on sinking and floating phenomena *with* the computer model

After a brief introduction to the symbol system used in the *Sink the Raft* program, subjects were guided in making a computer representation of the phenomenon they were observing. The set of materials used in these sessions and their respective representations by means of the computer model are illustrated in Figures 7 through 10. The white liquid was arbitrarily designated as representing the water and the task consisted in making a model of the object that would reflect its behavior in water. The procedure for making a model of the object was similar to the procedure used with the *Weight & Density* program. In order to choose a material for the object, subjects used a balance scale to compare the weight of a unit of water (i.e., a small container) with the weight of a unit of that material (i.e., wax or clay pre-packed into an identical container). When the objects to be modelled were made of wood or metal, students compared the weight of a given quantity of the material with an equal quantity of wax or clay molded into the same shape. Hence, students had the opportunity to observe that, given the appropriate relationship between the two densities, the computer model replicated the behavior of the real objects irrespective of their absolute weight. After the replication of each experiment in the simulated mode, students were asked again to interpret the phenomenon they had just observed.

2.4.2.2. The session on sinking and floating phenomena *without* the computer model

Subjects who explored sinking and floating phenomena without the support of the computer model used the same set of real-world counter-examples to a weight rule but did not use (nor see) the *Sink the Raft* program at any time. After they had predicted whether the objects would sink or float, stated the basis for that prediction and tested the result of their prediction, subjects' attention was drawn to the size, the weight and the density of the objects at hand. Subjects in this group followed the same comparative procedure with the balance scale as the students in the computer group to infer the relative density of the object and of the liquid. However, contrary to their peers in the other treatment group, they did not have available the visual model nor the data display provided by the computer program to help them compare the role of these different variables. Immediately after the measurement procedure, subjects were asked to comment a second time on the phenomenon they were observing. To equate the time spent in the exploration of sinking and floating phenomena by subjects undergoing different treatments, students in this group had the opportunity to make another prediction for the same type of counter-example (and to observe the result of that prediction) with a different set of materials in lieu of the modelling activity with the computer program.

2.4. Validation of the experimental treatment

2.4.1. Development of the experimental sessions

The final design of the experimental sessions described above was the result of a developmental procedure which included trial runs of the sessions with eight students from a public school in Watertown, Massachusetts. In the process of fine-tuning the sessions, several minor adjustments were made, either in the interest of saving time, of making the transitions smoother or of ensuring a more natural interaction between the student and the experimenter. More importantly, the trial sessions brought about some significant changes in the basic design of the learning activities as compared with the initial plan.

At the outset, one whole session was meant to test the implications of a flotation rule based on the weight of the object while a second session was intended to test a flotation rule based on the density of the material. However, time constraints did not allow the experimenters to articulate the concept of density and to explore sinking and floating phenomena within a single session; moreover, it became apparent that subjects could not evaluate the relevance of variables such as weight and density for predicting phenomena sequentially but that, instead, the comparison between these two rules was taking place simultaneously. Further, when the goal of the session was explicitly stated as a test of a specific rule, students readily deduced that the rule based on density was the favored one which made it difficult to know if they personally found the rule plausible. Therefore, the two sessions retained in the final design of the study took on a more specialized function. During the first session, the experimenter was to play an active role in helping subjects articulate the difference between the concepts of weight and density. In contrast, during the second session devoted to the exploration of sinking and floating phenomena, the role of the experimenter was to present a series of counter-examples to a weight rule (without describing them as such) and to allow the student to judge for himself the value of different predictive rules.

These trial sessions also led to a more constructive use of the sinking and floating simulation as a modelling tool. Originally, students first conducted experiments within the simulation, deduced a rule and then applied this rule to real-world cases. Thus, sinking and floating phenomena were being represented on the screen before the subject was aware of the variables that were being tested. However, it was felt that this sequence did not make appropriate use of the program as a modelling tool and lent a false credibility to the computer as dictating our observations. Hence, the final design of the study followed the reverse sequence. The session began with observations of real-world sinking and floating phenomena which posed a puzzle. The computer program was introduced afterward as a means of representing information about the phenomena at hand which might provide clues as to what was happening. We believed this sequence would allow a more efficient exploration of the role of different variables in sinking and floating phenomena since the outcome of the simulated experiment could be perceived more clearly as the result of having manipulated a specific variable. Finally, the two experimenters participated in several training sessions in order to master the script of the experimental sessions while interacting naturally with the subject.

2.4.2. Reliability of the experimental sessions

Given the constraints of the school setting and the limited number of experimenters, it was impossible to keep the time intervals between the tests and the treatment sessions exactly equal for all the subjects. In order to avoid bias in favor of one treatment over another as much as possible, the different types of sessions were scheduled on a rotating basis. Thus, following the administration of the pretest to a classroom, the experimenters alternated between a session on the concept of density and each one of the two sessions on sinking and floating phenomena until all the subjects in the classroom had been seen. The posttest was then administered to that classroom as soon as it was convenient to do so. This rotating schedule also served to minimize the possibility of bias toward any treatment due to novelty or fatigue on the part of the experimenters.

For the treatment groups as a whole, the average number of days between the different phases of the study was as follows: 39 days between the pretest and the first session, 6 days between the first and second session, 6 days between the second session and the first posttest and 53 days between the immediate posttest and the delayed posttest. The exact time intervals between these events for each of the four treatment groups are reported in Table 2. It can be seen that the rotating schedule was relatively successful in keeping interval differences between the experimental groups to a minimum. Indeed, there was no significant difference among the experimental groups with respect to the average number of days that elapsed between the adjacent events (i.e., the pretest, the first session, the second session, the immediate posttest and the delayed posttest). However, since the treatment groups differed considerably from one another with regard to the variance of these time intervals, the analyses to be presented later on will test for possible confounding effects of this factor on the results.

In order to ascertain the possibility of experimenter bias in the administration of the treatments and to ensure the reliability of the data recorded during the sessions, eight experimental sessions (four from each one of the experimenters) were audio-taped and subsequently evaluated by two independent judges. The sample of sessions represented five percent of the total number of sessions in proportion to their respective frequency of occurrence in the study, that is, four sessions on the introduction to density, two sessions on sinking and floating phenomena with the computer model and two sessions on sinking and floating phenomena without the computer model. This sample of taped sessions was also equally divided between 6th and 7th graders.

The two judges were graduate students in education working on research projects related to science and computers. A training session with both judges served first to explain the design and the purpose of the study and included a demonstration of the modelling activities using the computer programs and the real-world materials. The importance of validating the sessions was then discussed and the judges were given explicit instructions on how to evaluate whether the treatment was carried out in a manner consistent with the goals of each session. They were asked to note, for each session, on a copy of the experimental script, significant omissions, deviations or additions from the script on the part of the experimenter and to verify whether the experimenters gave adequate guidance and clarification when handling student replies and queries. Finally, judges were asked to assign a global rating indicating how well the experimenter followed the instructions on the following three-point scale: 1) Excellent, 2) Adequate, 3) Unsatisfactory.

During the sessions, the experimenters also recorded the justifications that students provided for their predictions of sinking and floating phenomena. Since these responses were intended to serve as one of the dependent measures, a second major task entrusted to the judges was to ascertain the reliability of these data. They were asked to record the predictions and the corresponding justifications provided by subjects and to classify the type of justification in one of three categories: 1) Weight/Other, 2) Material kind, 3) Density. This scoring system is the same one that was developed for the paper and pencil test and is described more in detail in the next chapter. Judges were unaware of the experimenters' scoring of these responses. At the end of the training session, the judges were handed written instructions that outlined the tasks they had to carry out. Each judge then listened to all eight tapes independently.

The ratings provided by the judges for the overall consistency between the sessions and the experimental instructions may be found in Table 3. On the average, experimenters were rated as adequate or excellent in adhering to the prescribed procedure, although a few sessions conducted by the second experimenter were judged to be unsatisfactory. Comments on the variations between the two instructors pertained to the rate of progression through the script, adequate acknowledgment of student replies and appropriate emphasis on the relationship between the computer model and the real-world materials.

With regard to the responses from subjects that were collected during the sessions and subsequently scored by the two experimenters, 96% of the first experimenter's scoring and 77% of the second experimenter's scoring were in agreement with at least one of the judges' scoring. Thus, the spoken explanations that students provided during the sessions were considered a sufficiently reliable source of data on their ideas about real-world sinking and floating phenomena to be used as one of the dependent measures. The next chapter will be devoted to the lengthier validation procedure involved in the development of the paper and pencil test which served as the major dependent measure.

Chapter 3

VALIDATION OF THE PAPER AND PENCIL TEST

3.1. Introduction

This chapter will report the validation procedure related to the paper and pencil test which was used as a pretest, as an immediate posttest and as a delayed posttest. The test, entitled "*Ideas about Sinking and Floating,*" was developed to assess students' thinking in three areas: 1) the conceptual distinction between weight and density; 2) the conceptual basis for the prediction of sinking and floating phenomena; 3) the role of the computer model as a conceptual aid. The test included open-ended items as well as true-false and multiple-choice formats. Some of the tasks were strictly verbal while others used illustrations. The structure of the test showing the breakdown of items by content area, type of task and format is outlined in Table 4. An annotated version of the test indicating the correct predictions for the sinking and floating phenomena and the appropriate answers to the multiple-choice items may be found in Appendix F.

The content validity of the items was ascertained initially by judgments from experts in the field, one a physicist and the other, a cognitive psychologist. A preliminary version of the test was then administered to a 6th grade and a 7th grade classroom. Overall, the wording of the test proved to be comprehensible to students of this age group. However, some items were subsequently eliminated as a result of this trial. For instance, in the preliminary version, students were asked to formulate a rule to predict whether an object would float and a rule to predict whether an object would sink. However, it was found that students were consistent in formulating a rule for sinking that also applied to floating; therefore, the two questions were merged into one. Students also tended to be consistent in their justifications for each type of sinking and floating phenomena, whether it was presented in a multiple-choice or an open-ended format; hence, duplication of problems was avoided in the final version of the test. Further, the true-false format was not used with counter-examples to a weight rule to avoid gratuitous selection of verbal statements that included the word "density."

The test was administered to each classroom involved in the study during students' science periods by one of the experimenters. In general, students were motivated to cooperate since they had volunteered to participate in the study. Nonetheless, to reduce potential anxiety associated with any form of testing, students were reminded immediately before taking the test that the results did not count toward their grade. However, to avoid undue carelessness in writing the test, the subjects were also reminded of their contribution to the study and the importance of assessing changes in their ideas. The purpose of the control group was also explained and students who had been assigned to this group were assured they would participate in the experimental sessions at a later date. To facilitate understanding of the items, the test was read aloud during the first testing session; for the second and third administrations, queries about wording and procedure were handled individually. The test results of eleven additional subjects who were randomly excluded from the study in order to have equal numbers of students in the experimental groups were combined with those of the 20 subjects in the control group to provide estimates of test-retest reliability. Although results will be presented for only some of the items about to be described, this chapter will report the validation process for the entire paper and pencil test. The reliability data and the validity data will be used to support the exclusion of some items from the final analyses.

3.2. Measure of the density concept

Two dimensions widely used in the measurement of concepts are verbal or propositional knowledge and practical knowledge or "knowledge-in-action" (i.e., Gagné & White,1978; Driver & Erkikson, 1973). On a verbal level, possessing a concept of density may be defined as the verbal ability to distinguish between weight as an extensive quantity that varies with the total amount of material and density as an intensive quantity that is locally defined for a particular kind of material. This distinction between the two concepts is also reflected on a practical level in a subject's judgments about the effects of physical transformations upon an object's weight and the density of its material, in a subject's knowledge of procedures for inferring the relative density of objects made of different materials and a subject's ability to order objects by the density of their material when the respective weights of the objects do not covary with the density of the material they are made of. These types of tasks have been developed in previous studies on children's understanding of density (Hewson, 1982; Smith et al.,1986; Smith et al.,1987) and were adapted for the present study. In an attempt to enhance the validity of the section on density, items using illustrations to tap subjects' judgments about concrete cases were used in combination with strictly verbal items.

3.2.1. Strictly verbal items

The verbal tasks on density included a true-false item (Q17) consisting of six statements about weight and density. These statements dealt with procedures for deriving the relative densities of two objects (a, d), the relationship between weight and density (b, e, f) and density as a property of material kind (c). The first posttest was used to establish the internal consistency of this sort of item instead of the pretest because most students were not familiar with the word "density" at the time of pretesting. Subjects showed a fairly consistent pattern of response to this item on the first posttest (Alpha = .69).

The major verbal task (Q18) required students to formulate in their own words the difference between weight and density. The open-ended definitions of density provided by subjects were then judged as inadequate or appropriate. A definition was judged to be inadequate when it failed to clearly establish the difference between the weight of an object and the density of its material (e.g., "weight is how heavy something is and density is how much something contains"). An appropriate definition of density could reflect either a qualitative precursor concept in which the intensive nature of density was acknowledged in an intuitive way as crowdedness or compactness (e.g., "density means how closely something is packed together") or a more formal concept that defined density more explicitly as the amount of weight allocated to a given space (e.g., "density means like 5 ounces per square inch") (Smith, 1984, 1985). Additional examples of definitions provided by subjects may be found in Appendix G.

The criteria by which a definition of density was judged to be adequate are different from the commonly accepted scientific view in two respects. A scientifically acceptable definition of density may be expressed as a ratio between a mass unit and a volume unit for a given material under standard conditions. However, mass, unlike weight, is not a familiar concept to 6th and 7th graders. The approach favored by Smith et al. (1986, 1987) to develop young students' understanding of density is to first lead them to distinguish between two meanings they ascribe to weight, *heavy* and *heavy for size*, by conceptualizing the second sense as a property of material kind. Given this developmental goal, it is not imperative for students to distinguish between weight and mass at this point. In addition, these same pedagogical concerns of building upon students' existing notions and stressing an intuitive grasp of concepts in lieu of overloading the student with a formal, but potentially less meaningful, definition of a concept has led us to temporarily overlook the accuracy of children's notions of volume while they are gradually paving their way to a more complete understanding of density. In keeping with this approach, the computer model used in the present study deliberately simplifies the representation of volume by means of an area unit (see Snir et al., 1988).

These open-ended definitions of density were scored by two judges who were blind to the treatment group of the subjects. The reliability of this scoring was checked by having a third person independently score 10% of the tests from each judge. Initial agreement between the two scorers was 94% on the pretest, 83% on the first posttest and 82% on the second posttest. After discussion of these discrepancies, the tests were scored once more and consistency between the two scorers, assessed by the same method, increased to 100% on the pretest and to 90% on the two posttests.

3.2.2. Illustrated tasks

In the tasks where illustrations were used, subjects were asked to choose the correct answers regarding the relative density of different materials (Q13 and Q14) and the potential effects of physical transformations such as cutting on the weight of objects and on the density of the material they were made of (Q15 and Q16). All the choices involved in these tasks were initially scored as right or wrong. This procedure led to poor internal consistency on the first posttest among the questions calling for judgments about weight and density (Q13 through Q16) (Alpha = .38). The problematic questions were the ones that dealt with the effects of transformations on weight and density (Q15 and Q16).

Both theory and research (Piaget, 1941/1974) predicted that students of this age could conserve weight and therefore would understand that cutting an object will decrease its weight and combining it with another object will increase its weight. Judging whether such transformations would have any effect on the density of a material, however, is more difficult. Such a judgment calls for an understanding of density as a property of material kind, unrelated to the amount of material. On these two items, 38% and 48% of the subjects, respectively, misjudged the effects of simple physical transformations on weight; nonetheless, at least half of these subjects answered the more difficult question about density correctly. Given this pattern of response, the validity of these items as a measure of students' understanding of density was very doubtful.

Other paper and pencil measures of conservation have also been noted for their unreliability (e.g., Good, 1977). Given the difficulty of arriving at a this study, pending the development of a more complete test. A prudent approach to the data analysis based on a partial but valid indication of subjects' understanding of density, and one that is consistent with their verbal explanations of sinking and floating phenomena, was judged to be more useful than a potentially misleading approach based on more exhaustive but invalid measures.

3.3. Measure of ideas about sinking and floating phenomena

3.3.1. Rationale for the tasks on sinking and floating phenomena

The construct validity for the measurement of students' ideas about sinking and floating phenomena is based on the hypothesis that individuals develop a set of ideas or beliefs that guide their approach to specific phenomena in the physical world as expressed in the following definition. "By the construct 'conceptual framework' we shall mean the mental organization imposed by an individual on sensory inputs as indicated by regularities in an individual's responses to particular problem settings" (Driver & Erickson, 1983, p.39). Techniques for eliciting such aspects of students' thinking range from strictly verbal methods to contextual methods involving actual phenomena. One technique of the latter type consists in presenting a phenomenon (or a graphical representation thereof) for which the student must formulate a prediction and an interpretation. These responses are then categorized into response types that reflect the subject's conceptual framework vis-à-vis that particular phenomenon. The test developed for the present study includes both kinds of methods.

On the one hand, subjects' comprehension of sinking and floating phenomena was tested by exclusively verbal items which elicited their predictive rule about such phenomena. In one task, subjects were asked to explain in their own words, how one goes about predicting whether a given object will sink or float (Q6). A second item required subjects to indicate their agreement or disagreement with some statements about sinking and floating phenomena (Q7). Of interest was whether subjects would simultaneously acknowledge the importance of the density of materials as a predictive factor (c & f), resist statements that stressed instead the weight of the object (a & d) and acknowledge sinking and floating as a phenomenon involving a relationship between two materials rather than one linked to an intrinsic property of a single material (b & e).

In another part of the test, a series of items asked subjects to make predictions about sinking and floating phenomena and to justify the basis for their predictions. The phenomena were counter-examples to a predictive rule based on the weight of the object. Subjects had to decide whether variations in weight of the same material would affect its behavior in water and explain why they thought so (Q1 and Q2) and whether objects made of different materials but similar in weight would sink or float and why (Q3 and Q4). The last prediction problem (Q5) presented an object made of floating material that was heavier than the object made of sinking material. For each object whose outcome was to be predicted, the problem showed an object of like material immersed in water. The items presented fictitious materials to avoid reliance on prior familiarity with some kinds of materials as a means of prediction and to draw attention to the variables of weight and density. Likewise, in the paired comparisons, only qualitative information about the parameters (i.e., "both objects are very light") was provided to engage judgments about the conceptual relevance of these variables without being detracted by specific numbers.

Subjects were also asked to interpret various sinking and floating phenomena for which they did not have to make predictions. Two items (Q10 and Q11) presented situations where a rule based on the weight of the object is apparently confirmed (i.e., the light objects float and the heavy objects sink) while two items (Q8 and Q12) showed situations where such a rule did not apply (the floating object weighs more than the sinking object or both objects weigh the same). Finally, another task (Q9) involved the same object alternately floating and sinking in two different liquids.

3.3.2. Validation of the open-ended questions

Most of the items described above required subjects to formulate answers in their own words. The validation of a procedure to analyze these open-ended responses involved two phases: 1) finding descriptors that could reliably be used by different scorers; 2) establishing whether the descriptors showed some stability across a variety of sinking and floating phenomena (i.e., internal consistency) as well as over time (i.e., test-retest reliability).

A content analysis of students' responses unveiled a variety of reasons that subjects relied upon to interpret sinking and floating phenomena. Some superficial answers could not be considered as explanatory (e.g., "because it will float") but the majority of the responses could be classified into three main types. First, there were *alternate* responses which appealed to variables such as the weight of the object that do not systematically lead to reliable predictions (e.g., "heavy objects will sink"). Two other types of responses appealed to *material kind* as a predictive factor (e.g., "it's made of the same material so it will float," "it sinks because it's made of a heavy kind of material") or more specifically to the *density* of the material (e.g., "it floats because it's less dense than the liquid"). Responses that showed a confusion between the concepts of weight and density were not credited as "density" responses but as "weight" responses. In addition, credit for a response based on material kind or density was contingent upon having made a correct prediction where relevant. When the subject appealed to material kind or density but made an incorrect prediction, the response was classified into the "alternate" category unless the subject also confused material kind or density with weight, in which case it was considered a weight response. A distinction was also made between responses which simply used the word "density" and those which also indicated what was meant by density. When subjects only used the word "density," they were only given credit for their answer if they had provided an acceptable definition of density elsewhere on the test. Detailed criteria for scoring these answers as well as verbatim examples for all of these categories may be found in Appendix G.

One indication of the validity of these categories as descriptors of an individual's framework for thinking about sinking and floating phenomena is the extent to which subjects are reasonably consistent in giving the same interpretation across a range of situations. Overall, students did tend to provide explanations throughout the test that were positively related to each other (Alpha = .81). However, Question 9 correlated negatively with the other items on sinking and floating phenomena. When Question 9 was removed, the internal consistency of the open-ended items on sinking and floating increased slightly (Alpha = .85).

It will be recalled that this particular item depicted an object that alternately floats and sinks in two unidentified liquids whereas all the other items used water as a given. A high rate of missing data (40%) was also observed with regard to Question 9 and the item was not included in the main analyses.

Agreement between the two scorers for judging the type of reason was 87% on the pretest, 94% on the posttest and 97% on the delayed posttest. The stability of students' answers to the open-ended questions 7 weeks later was moderately good (Spearman r = .65, ***p < .001). Hence, the descriptors for the open-ended answers proved to be fairly valid and reliable indicators of student's ideas about sinking and floating phenomena. The next section will, in contrast, show how the multiple-choice items did not serve this purpose as well as the open-ended questions and were subsequently dropped from the analysis of results.

3.3.3. Validation of the multiple-choice questions

In addition to formulating answers in their own words, children also had to indicate whether they agreed or disagreed with a number of predictive statements about sinking and floating phenomena. Three different scoring procedures were tried in the process of validating the multiple-choice questions that: 1) Tabulating *right or wrong* answers across all the items; 2) Tabulating the answers according to the *type of rule* across all the items; 3) Determining the type of rule on the basis of the *pattern of response* within sets of items. This section will present the results obtained with each of these methods.

The first method tabulated the total number of right answers across all the true-false statements about sinking and floating. Subjects were credited with a correct answer when they agreed with statements that supported predictions based on material kind or the density of a material and also when they disagreed with statements appealing to the weight of the object. The internal consistency of both sets of items combined was rather low on the pretest (Alpha = .40), in comparison with that part of the density measure which also used multiple-choice items. The word "density" may have clued some subjects to the correct answer in the statements about sinking and floating. The consistency of response within the sets of verbal statements was also poor: Alpha = .29 for statements relative to a general predictive rule for sinking and floating phenomena and Alpha = .37 for statements about specific sinking and floating phenomena. In terms of the predictions alone, however, students were rather consistent in getting them right or wrong (Alpha = .75), suggesting that they were not randomly circling answers for this set of items. The reliability of the items was assessed by correlating scores on the pretest with scores on the posttest for the 31 students who were not in the treatment groups. The result was rather poor (Spearman r = .29, p = .08) although it was somewhat better for the predictions alone, independently of the justifications provided in support of the predictions (Spearman r = .45, p < .01). Thus, answers to the multiple-choice items on sinking and floating problems showed considerably more variation over a period of seven weeks than answers to the open-ended questions. Furthermore, even if students had answered the true-false items more consistently, the sum of the correct answers would not, in the end, have provided a very informative measure of the content of children's ideas (i.e., the same sum could have been obtained through different patterns of response). Given the poor consistency and the low reliability yielded by the first method of scoring, the potential usefulness of the true-false items about sinking and floating was explored with a second scoring procedure. Instead of pooling right or wrong answers, the internal consistency of the items was tested by grouping the answers that indicated agreement with a particular approach to sinking and floating phenomena across all the items. Each statement had been designed to tap one of three possible predictive rules based on either the *weight* of the object, the kind of *material* it is made of or the *density* of its material. When the answers were thus grouped by type of rule, it was observed that students answered items tapping a rule based on weight rather consistently (Alpha = .69) as well as items tapping a rule based on material kind (Alpha = .61). However, answers to items tapping a rule based on density were much less consistent (Alpha = .31).

Since it was not entirely surprising that few students really had a consistent approach to sinking and floating phenomena based on density on the *pretest*, the items tapping a rule based on density were also checked on the first posttest which provided a slightly higher index of consistency (Alpha = .44). Thus, it appears that a number of students indicated circumstantial agreement with some of the statements involving density because they were clued by the word "density" which was used in some items but not in others that nonetheless tapped a rule based on density. As a consequence, the true-false items were not reliably discriminating between students who were convinced that the density of a material was relevant to sinking and floating phenomena and students who held different ideas even when the items were scored according to the type of predictive rule.

Finally, a third scoring method was tried in an attempt to improve the validity of the true-false items. This time, the whole set of statements which applied to a given phenomenon yielded a single score in favor of a particular type of rule based on the pattern of responses within the set. The scoring procedure that determined the assignment of a subject's pattern to a predictive rule based on weight, a mixed rule or a rule based on material kind or density is shown in Table 5. However, when the items were scored in this way, the consistency of response to items tapping a rule based on the density of a material remained the same as before (Alpha = .30). Although the consistency of rules based on material kind was improved somewhat (Alpha = .74), the consistency of rules based on the weight of the object was diminished considerably (Alpha =. 30). Finally, the consistency of mixed rules involving a combination of the above reasons was only fair (Alpha = .52). In short, the multiple-choice items did not discriminate well between competing rules in comparison with the open-ended questions, whatever the scoring procedure used. Given the poor validity and low reliability of questions that called for students to agree or disagree with verbal statements about sinking and floating phenomena, it was decided to drop this kind of item from the final analyses.

3.4. Models of sinking and floating phenomena

One question was the extent to which subjects would adopt the computer model as a mental representation in support of their reasoning about sinking and floating phenomena. One item (Q12) was designed to address this issue. Students were shown two objects similar in weight behaving differently in water; subjects were asked to interpret the phenomenon, to make a model to illustrate their interpretation and to comment on the model for the reader. The drawings were judged on two counts, according to the type of model depicted and according to the information provided by the model. The verbal explanation that subjects provided about their model was also scored separately. The same categories that were developed to describe children's open-ended answers to sinking and floating phenomena (i.e., ranging from no explanation to an explanation based on relative density) were used to characterize both the verbal explanation and the information provided by the drawing. The following categories were used to distinguish the types of models drawn by subjects : 1) Computer model (grid and dots); 2) Shading/line (variations in intensity); 3) Particulate (crowdedness of individual elements); 4) Hollow-full (containers); 5) Figurative (descriptive); 6) Other types. Illustrations of these different kinds of models may be found in Figure 13 in Appendix A.

In the initial scoring, computer models were scored as either appropriate or inappropriate. Criteria for drawing an appropriate computer model included the following: using distinct symbols for size units and weight units, making size units and total weights approximately equal (allowing for drawing ability and time factors), depicting density as a constant for a given material and the correct relationship between the density of the two objects and/or the liquid. However, since a perfect correlation was found to exist between the appropriateness of the grid and dot model and the level of information provided by the drawing, the relationship between these two scores may also be used as an index of whether the computer model was appropriately used. In other words, a grid and dots drawing that only provides information about the weight of the objects (and thus receives an information score of 1) reflects an inappropriate use of the computer model. Agreement between the two judges for identifying the kinds of models drawn by subjects was 77% on the pretest, 83% on the immediate posttest and 85% on the delayed posttest.

Chapter 4
RESULTS

4.1. Introduction

The analyses presented in this chapter will assess the extent to which sixth and seventh graders were more likely to change the basis for their predictions of sinking and floating phenomena from the weight of the object to the density of the material when either or both of the following independent variables were present: first, the availability of an interactive computer model representing the size, weight and density of objects and liquids to guide their observations of sinking and floating phenomena and second, prior introduction to the concept of density.

Given the poor validity of the multiple-choice questions on the test, only data from the open-ended questions will be presented. These consist of the justifications that students provided in support of their predictions of sinking and floating phenomena and their formulation of a predictive rule. These answers were classified into three main categories of reasons: *alternate* reasons (i.e., that do not lead to reliable predictions), reasons based on *material kind* and reasons based on the *density* of the material. These categories are defined in more detail and illustrated by verbatim responses from subjects in Appendix C Since the hypotheses of the study were concerned with the relinquishing of a predictive rule based on an extensive property, the weight of the object, and since the experimental (teaching) sessions were designed as counter-examples to such a rule, responses based on *weight* were selected among the alternate reasons and retained for analysis.

The analyses of students' ideas about sinking and floating phenomena will be presented in two parts which each correspond to a different set of data. The first set of data is comprised of the justifications offered by subjects to justify their predictions of *real-world* sinking and floating phenomena during the experimental (teaching) sessions. These responses were expressed orally in a one-on-one learning situation. The second set of data consists of responses to similar phenomena depicted on the *paper and pencil test* which subjects wrote along with their classmates at three times during the study: before the experimental sessions, closely following the sessions and six to seven weeks later. Two series of analyses were then performed on each set of data.

The first kind of measure was designed to evaluate *group trends* and was based on the frequency of occurrence of the different types of response in the various experimental groups. Thus, the mean number of responses falling each of the three categories, "weight," "material kind" and "density" were tabulated for each experimental group. These data pro ided three continuous measures for which parametric statistics were appropr.ate. A significantly greater occurrence of justificat s that appeal to the density of a material following the experimental sessions can reveal gradual changes that are taking place in students' interpretations of sinking and floating phenomena as a group, but this level of analysis leaves aside the issue of conceptual integration of density at an individual level.

To obtain a measure of how consistently *individual* students appealed to the concept of density to justify their predictions of sinking and floating phenomena, each subject's set of answers was classified into one of three *patterns* reflecting increasing degrees *of integration*. The first pattern, symptomatic of a low level of integration, involved students who justified one or more of their predictions by alluding to the weight of the object, thereby indicating a superficial understanding of the role of intensive properties in sinking and floating phenomena. The second pattern reflects an intermediate degree of integration in that subjects consistently referred to an intensive property of the object, its material kind, but without systematically acknowledging the specific role of the density of the material. Finally the third pattern indicates a high degree of integration and involved students who consistently interpreted sinking and floating phenomena as a function of the density of the material. Subjects had to respond to at least 60% of the problems to be attributed a pattern. This measure provided categorical data which consisted of the number of subjects displaying different patterns of response and thus were analyzed using non-parametric statistics.

The main effects of the independent variables were ascertained by collapsing the results of the appropriate treatment groups in two successive ways. First, the influence of the sinking and floating simulation involved the contrast between students whose observations of sinking and floating phenomena were supported by the simulation (i.e., those in the first and second groups) and students whose observations of the same phenomena were unaided by the simulation (i.e, those in the third and fourth groups). The reader is referred to Table 1 for a complete identification of the experimental groups. Secondly, the influence of the order of presentation of the concept of density was based on the contrast between students who were introduced to the concept prior to the sinking and floating tasks (i.e., those in the first and third groups) and those for whom the session on density followed the observation of sinking and floating phenomena (i.e., those in the second and fourth groups). In addition, the interaction effects between these two independent variables were examined. When relevant, the general effect of having participated in some mode of treatment as opposed to none at all was also evaluated by comparing the results of subjects in the treatment groups with those of subjects in the control group.

Changes in students' understanding of density will be reported first followed by the presentation of results pertaining to students' interpretations of sinking and floating phenomena. These will include subjects' responses to real-world phenomena during the experimental sessions and their responses to similar cases illustrated on the paper and pencil test. Finally, changes in subjects' formulation of a predictive rule for sinking and floating phenomena will be reported, contrasting the rules expressed orally during the experimental sessions with those expressed on the paper and pencil test. Analyses of some additional items from the test will also be reported in a later section to complement the discussion of the major findings.

4.2. Understanding of density on the paper and pencil test

On the pretest, only 13% of the subjects could clearly define density as a concept distinct from weight. On the two posttests, half the students in the overall sample (and two-thirds of those in the treatment groups) were able to explain what density means (see Table 6). While there was no difference between the five experimental groups on the pretest ($X^2(1) = 0.05$, $p = .83$), significantly more students in each of the four treatment groups could provide a definition of density when compared with the control group both on the immediate posttest ($X^2(1) = 9.91$, $^{**}p < .01$) and on the delayed posttest ($X^2(1) = 9.33$, $^{*}p < .05$). Therefore participation in the teaching sessions was a significant factor in helping students verbally distinguish between the concepts of weight and density

This general effect of treatment was independent from having worked with one experimenter as opposed to the other. Subjects who had satisfactorily defined density on the pretest had been assigned in equal proportions to each one of the experimenters ($X^2(1) = 0.19$, $p = .66$) and there was no experimenter effect on students' ability to define what is meant by the density of a material on either of the two posttests, $X^2(1) = 1.67$, $p = .20$ and $X^2(1) = 0.00$, $p = 1.00$, respectively (see Table 7).

Although there was a general effect of treatment, there was no differential effect of the experimental conditions on students' ability to define density. Students who observed sinking and floating phenomena guided by the computer simulation of such phenomena offered appropriate definitions of density as frequently as students who observed the real-world ma..rials only both on the immediate posttest ($X^2(1) = 0.01$, $p = .93$) and on the delayed posttest ($X^2(1) = 0.13$, $p = .71$) (see Table 8). Students who knew the difference between weight and density on the pretest had been assigned to these two conditions in equal proportions ($X^2(1) < 0.00$, $p = 1.00$).

Students' understanding of density was also unrelated to the order in which they had been introduced to the concept. Indeed, the proportions of students who could define density on the two posttests were comparable, irrespective of whether subjects had participated in the session dealing exclusively with density prior to or following their observations of sinking and floating phenomena, $X^2(1) = 0.34$, $p = .56$ and $X^2(1) < 0.00$, $p = 1.00$, respectively (see Table 9). Subjects had been equally assigned to these two conditions on the basis of their definition of density on the pretest ($X^2(1) = 0.02$, $p = .87$). Further, the fact that the four experimental treatment groups were comparable to each other in their ability to define density is not surprising since they all received the same basic instruction in the concept of density.

4.3. Responses to real-world sinking and floating phenomena during the experimental sessions

This section reports the effects of the two independent variables, the use of the sinking and floating simulation and the order of presentation of density, on students' interpretations of real-world instances of sinking and floating phenomena during the experimental sessions. These sessions were described in detail in Chapter 2 and will only be briefly reviewed here. The phenomena that students were given to observe consisted of a series of four counter-examples to a prediction based on the weight of the object; that is, the objects exemplified either a heavy floater or a light sinker. For each case, students first *predicted* whether the object would sink or float in water and explained the basis for their predictions. Subjects then *observed* whether the object in question sank or floated. At this point, treatment consisted in drawing attention to various features of the materials at hand (i.e., their size, their weight and the density of their material), but the mode of teaching varied according to the experimental group (some modeled the objects on the computer while others did not). Finally, on the basis of these observations students were given an opportunity to *revise* their explanations.

Half the students used the *Sink the Raft* program to represent the size, the weight and the density of the material of the objects and of the liquid they were observing in addition to handling the materials. The remaining students did not use the simulation but only handled the real-world materials. Following each observation, subjects were asked if they found any of the information useful for predicting the object's behavior in the water. At the time they participated in this session, half the students had been introduced to the concept of density while the other half had not.

The four justifications of predictions from each student were grouped together and designated as the *justifications offered prior to testing their predictions*. Similarly, the four responses from each student after they had put the object in the water and had their attention drawn to various features of the material were grouped together as the *justifications offered after having tested their predictions*.

In reporting the results, group trends will be considered first followed by the analysis of the individual patterns. As described in detail at the beginning of the chapter, group trends were determined by the mean number of answers falling into the different categories for a given group of subjects. Individual patterns were based on the number of subjects who showed specific combinations of responses across a range of items.

4.3.1. Group trends in response to real-world sinking and floating phenomena

The effects of the mode of observation of sinking and floating phenomena (i.e., with or without the computer model) will be reported first, followed by the effects of the order of introduction to density (i.e., prior to or after the observation of sinking and floating phenomena). The percentage of responses which fell into the categories of *weight*, *material kind* and *density* were computed and each of these three measures was subjected to analysis of variance. The distribution of scores did not depart substantially from normality and the group variances were sufficiently similar to warrant the use of the Anova technique.

There were significant effects of the first independent variable, but only for some *justifications offered after having tested their predictions*. When students initially justified their prediction of whether each object would sink or float, there was no difference in the type of reason given by students who were using the computer-based model and those who were not, whether the initial reason given was "weight," $F(1,76) = 0.39$, $p = .54$, "material kind," $F(1,76) = 0.00$, $p = 1.00$ or "density," $F(1,76) = 0.35$, $p = .56$ (see Table 10). Hence, there was no cumulative effect of the computer simulation on the reasons subjects provided in support of their successive predictions. However, when we consider the responses that subjects gave *after* observing the results of their predictions, we find significantly fewer justifications based on the weight of the object ($F(1,76) = 5.94$, *$p < .05$) and significantly more justifications based on the density of the material ($F(1,76) = 4.12$, *$p < .05$) among students who were interacting with the computer model of sinking and floating phenomena. There was no major difference between these two treatment groups with respect to the proportion of answers based on material kind ($F(1,76) = 0.36$, $p = .55$) at this time.

Looking more closely at the exact patterns of change in both groups, one sees interesting differences in patterns of change for weight and density responses. The number of times "density" was mentioned increased in both groups (those using the computer and those not) as compared to the number of times it was mentioned *before* subjects had tested their predictions, but students who tested their predictions with the computer model provided significantly *more* justifications based on the density of the material than students who only handled the real-world materials. On the other hand, the significant difference in the proportion of "weight" answers between the two groups results from a different pattern. The simulation group *decreased* their weight responses from their initial predictions while the no simulation group actually made more weight answers following experimentation than they had made before! This observation suggests that interaction with a visual-numerical model of sinking and floating made it easier for subjects to perceive the relevance of density to the phenomena at hand and the irrelevance of weight. In contrast, exploration of the phenomena with real-world materials alone was less informative and *sometimes even misleading* (especially about the irrelevance of weight) when students were asked to revise the basis for their predictions. (Note: both groups decreased their number of material kind predictions).

The results of the four treatment groups were then collapsed in order to test the effect of the second independent variable. That is, the predictions and explanations of subjects who had already been introduced to the concept of density at the time they observed the sinking and floating phenomena (i.e., groups 1 and 3) were compared with those from subjects who had not yet been introduced to the concept of density (i.e., groups 2 and 4). It was found that the order in which students had been introduced to the concept of density significantly influenced the frequency of their material kind and density interpretations , both before and after testing their predictions of sinking and floating phenomena (see Table 11). When they first formulated their predictions, students who had already learned about density gave significantly *fewer* initial justifications based on *material kind* ($F(1,76) = 11.83$, ***$p < .001$) and significantly *more* justifications based on the *density* of the material ($F(1,76) = 12.64$, ***$p < .001$) than students who had not yet been introduced to the concept of density. When given the opportunity to revise their justifications after testing their predictions, students who had been introduced to density prior to the sessions on sinking and floating phenomena again gave significantly *fewer* reasons based on *material kind* ($F(1,76) = 8.03$, $^{**}p < .01$) and significantly *more* reasons based on the *density* of the material ($F(1,76) = 6.82$, $^{**}p < .01$). However, the order of introduction to density did not significantly influence the number of justifications based on the weight of the object, neither when subjects initially formulated their predictions ($F(1,76) = 0.01$, $p = .92$) nor when they had the opportunity to revise these justifications

No significant interaction effects between the two independent variables were observed. When students initially formulated their predictions, there was no joint influence of the two variables on the proportion of justifications based either on weight ($F(1,76) = 0.14$, $p = .71$), on material kind ($F(1,76) = 0.24$, $p = .63$) or on density ($F(1,76) = 0.00$, $p = 1.00$). Similarly, there was no interaction effect on the number of justifications based either on weight ($F(1,76) = 0.55$, $p = .46$), on material kind ($F(1,76) = 0.007$, $p = .93$) or on density ($F(1,76) = 0.08$, $p = .77$) when subjects revised their interpretations after observing the results of their predictions.

However, we may note in passing that the *highest* proportion of "density" answers, 76%, was given by the first treatment group in which both factors presumed to be helpful for cognitive change had been implemented (i.e., subjects tested their sinking and floating predictions with the computer model and had already been introduced to the concept of density) (see Table 12). In contrast, the group which had the *lowest* proportion of density answers, 35%, was the fourth treatment group in which neither factor was implemented (i.e., subjects did not have the sinking and floating simulation available to test their predictions and had not yet been introduced to the concept of density). In the second and third treatment groups, the proportion of justifications based on density was 62% and 60% respectively.

In summary, the analysis of group trends in students' justifications of their predictions for real-world sinking and floating phenomena during the experimental sessions revealed significant main effects for both of the two independent variables.

When students could test their predictions while interacting with the *Sink the Raft* program, they were significantly more likely to revise their justifications and conclude that the density of the material was relevant to predicting whether an object would sink or float. Also, they relied on the weight of the object as a predictor of sinking and floating phenomena significantly less often than their peers who did not have the simulation available. Although the advantage of the computer simulation was evident in students' justifications made *after testing their predictions*, it did not lead these students to be superior in justifying their predictions *before testing* them.

Introduction to the concept of density by means of the *Weight and Density* program prior to the exploration of sinking and floating phenomena resulted in significantly more justifications based on the density of the material and significantly fewer justifications based only on material kind both *before* and *after* testing predictions. Finally, there were no interaction effects between the two independent variables.

4.3.2. Individual patterns in response to real-world phenomena

The extent to which individual subjects integrated the concept of density into their interpretation of sinking and floating phenomena was determined by the pattern of their responses to the series of predictions. Subjects were assigned to the *low level of integration* when they justified one or more of their predictions on the basis of the weight of the object, to the *intermediate level* when they justified all their predictions on the basis of material kind without alluding to density and to the *high level of integration* when their predictions were based on the density of the material or a combination of material kind and density. The reader is reminded that each response credited as material kind or density was contingent upon having made the correct prediction. This restriction obviously did not apply when students were asked to revise their responses after observing the results of their predictions.

The opportunity to interact with the *Sink the Raft* program did not have any influence on the proportion of students showing low, moderate or high levels of integration of density in their initial predictions of sinking and floating phenomena, $X^2(2) = 1.49$, $p = .47$ (see Table 13) However, when they were given the opportunity to revise the basis for their predictions, students who used the computer simulation to model the sink/float situation were significantly more likely to have high level of integration patterns than students whose observations had been limited to the real-world materials, $X^2(2) = 6.02$, $^*p < .05$. Indeed, a significantly greater number of those students who had tested their predictions *without* the computer model displayed low levels of integration of density to support their predictions.

Prior introduction to the concept of density did not have any influence on the number of subjects displaying low, moderate or high levels of integration of density in their *initial* predictions of sinking and floating phenomena, $X^2(2) =$

2.33, $p = .19$ (see Table 14). However, students who had been introduced to the concept of density prior to the sinking and floating sessions were significantly more likely to display highly integrated patterns based on the density of the material in revised predictions and less likely to show moderate degrees of integration than students who had not yet taken part in the session designed to introduce them to the concept of density, $X^2(2) = 6.14$, $p < .05$.

Since the evaluation of the experimental sessions by two independent judges had revealed some differences in teaching style between the two experimenters, analyses were conducted to assess the possibility of experimenter bias on subjects' level of integration in response to the sinking and floating tasks. When the two experimenters were compared, there were no significant differences in the number of students showing the three types of patterns on the justifications provided before testing their predictions, $X^2(2) = 4.36$, $p = .11$ nor on the justifications provided after they had tested their predictions, $X^2(2) = 3.14$, $p = .21$.

In summary, the hypotheses of the study were only partially supported by the individual pattern analyses. First, using the sinking and floating simulation or being introduced to density beforehand did not have any influence on the patterns of responses provided by subjects *in their initial justifications of sinking and floating phenomena* (i.e., prior to testing their predictions). However, both independent variables were significantly related to a greater frequency of high integration patterns *after students had observed the results of their predictions*. The findings indicated that individual students were significantly more likely to consistently acknowledge the relevance of density as a predictor of sinking and floating phenomena when they could test their predictions with the *Sink the Raft* program and also, when they had already been introduced to the concept of density.

The following section will examine whether the influence of the independent variables was evident in subjects' interpretations of sinking and floating phenomena on the paper and pencil posttests. It will be recalled that the written test required subjects to formulate predictions without the opportunity of observing the results of their predictions. The test situation is therefore most comparable to that point in the exploration of real-world phenomena when subjects initially formulate their predictions — a task which showed the fewest effects of the independent variables in the experimental (teaching) sessions.

4.4. Responses to sinking and floating phenomena on the paper and pencil test

Shortly after the experimental sessions, students were given a paper and pencil test in which they had to make predictions for a series of illustrated sinking and floating phenomena similar to the real-world cases they had observed and to explain the basis for their predictions. These open-ended justifications were classified into the categories of "weight," "material kind" and "density" according to the criteria described in Chapter 2. Data were analyzed in terms of group trends based on the mean number of answers from each group falling into the different categories and also in terms of individual patterns of integration, to be defined further on. The presentation of the results in this section will parallel the sequence in the previous section. Group trends will be examined first followed by the analysis of the individual patterns of integration. In addition to the main effects of the independent variables and the interaction effects between the two, the general effect of treatment will be tested by contrasting the results of subjects in the treatment groups with those of subjects in the control group who wrote the tests but did not participate in any experimental session. In addition, results on the immediate posttest will also be compared with those obtained on the delayed posttest administered seven weeks later.

4.4.1. Group trends in response to sinking and floating phenomena on the paper and pencil test

The mean number of responses falling into the different categories provided continuous data which were subjected to analysis of variance. The assumptions of the Anova technique, that is, normality of distribution and homogeneity of variance within the groups, were satisfied by this set of data. The Neuman-Keuls test ($p = .05$) was used for the post-hoc comparisons when relevant.

4.4.1.1. General effect of treatment on group trends on tests

The general effect of treatment was assessed by comparing the mean number of weight, material and density responses among the five experimental groups (see Table 16). While there were no major differences on the pretest with respect to the number of *weight* responses $F(4,95) = 1.94$, $p = .11$, *material kind* responses $F(4,95) = 0.74$, $p = .56$ or *density* responses $F(4,95) = 1.68$, $p = .15$ that subjects provided for their sinking and floating predictions, some significant differences between the groups emerged on the posttests.

On the **immediate posttest**, the proportion of *weight* answers differed significantly across the five experimental groups, $F(4,95) = 4.97$, $^{***}p < .001$. Each of the four treatment groups provided fewer justifications based on weight than the control group but none of the treatment groups differed from each other. On the average, justifications of sinking and floating predictions based on the weight of the object decreased by 56% from the pretest for subjects in the treatment groups, while the weight responses of subjects in the control group only decreased by 20%. On the **delayed posttest** administered six to seven weeks after the experimental sessions, students in each of the treatment groups still gave significantly fewer justifications based on the *weight* of the object than students in the control group ($F(4,95) = 3.57$, $^{*}p < .05$).

There were no significant differences between the experimental groups with respect to the number of justifications that appealed to *material kind* on the **immediate posttest** $F(4,95) = 2.31$, $p = .06$). On this first posttest written shortly following treatment, the mean number of responses based on material kind had increased by 19% on the average from the pretest, for subjects who participated in the experimental sessions and that same increment was observed for subjects in the control group. These respective proportions remained the same on the delayed posttest ($F(4,95) = 0.58$, $p = .68$).

The proportion of responses making reference to the *density* of the material was, however, significantly influenced by participation in the experimental sessions. On the **immediate posttest**, students who had been assigned to one of the treatment groups justified their sinking and floating predictions by alluding to the density of the material to a significantly greater extent than students in the control group ($F(4,95) = 4.20$, $^{**}p < .01$). While the average number of density answers increased by 34% from the pretest to the immediate posttest for students who had participated in the experimental sessions, there were almost no density answers among students in the control group. This advantage of the treatment groups over the control group was maintained on the delayed posttest ($F(4,95) = 3.18$, $^{*}p < .05$).

In summary, the experimental sessions as a whole had a significant impact on students' interpretations of sinking and floating phenomena as measured by group means in comparison to a situation where students received no treatment. Justifications based on the weight of the object *decreased* significantly while justifications based on the density of the material *increased* significantly as a result of treatment. Furthermore, both of these changes remained stable over a period of six to seven weeks. The increase in responses based simply on material kind, however, was independent from participation in any treatment. All the subjects in the study provided more justifications based on material kind on the two posttests than on the pretest.

4.4.1.2. Main effects and interaction effects of the independent variables on group trends on the paper and pencil test

Following the comparisons between each of the treatment groups and the control group which served to establish a general effect of treatment, analyses were conducted with data from the treatment groups only to determine the differential effects of the independent variables on students' responses to sinking and floating phenomena. The four treatment groups were collapsed to form two sets of data in succession. In the first set of analyses, students were grouped according to whether they had tested their sinking and floating predictions with or without the interactive computer model. For the second set of analyses, the same students were grouped depending on whether or not they had been introduced to the concept of density at the time they made their predictions about sinking and floating phenomena. The analyses related to these two independent variables are summarized jointly in Tables 17 and 18.

The hypothesis relating to the first independent variable was not supported by the data. On the **immediate posttest** shortly following treatment, there was no significant difference between students who tested their sinking and floating predictions with the *Sink the Raft* program and those who worked with real-world materials only with regard to the mean number of justifications based on the *weight* of the object ($F(1,76) = 1.19$, $p = .28$), *material kind* ($F(1,76) = 2.52$, $p = .12$) or the *density* of the material ($F(1,76) = 0.05$, $p = .83$). The proportions of responses falling into these three categories were also very similar for the two treatment groups on the delayed posttest ($F(1,76) = 1.70$ $p = .20$, $F(1,76) = 1.08$ $p = .30$ and $F(1,76) = 0.40$, $p = .53$, respectively). On the pretest, there had been no significant difference in the number of responses falling into the categories of weight, material kind and density ($F(1,76) = 2.21$ $p = .14$, $F(1,76) = 0.12$ $p = .74$ and $F(1,76) = 3.80$, $p = .06$, respectively) between students who were assigned to test their predictions with the sinking and floating simulation and those who were assigned to experiment with the real-world materials only.

Since a significant interaction effect on the pretest resulted from a higher proportion of weight responses given by some of the students in the simulation group, an analysis of covariance was conducted on the posttest data controlling for weight answers on the pretest. This analysis did not reveal any main effects of the independent variables. In short, students who had worked with the sinking and floating simulation to test their predictions were not significantly advantaged when compared to those who had observed the same real-world phenomena without the simulation. Subjects in both treatment groups alluded less frequently to the weight of the object in support of their predictions and provided more responses based on material kind and on density than on the pretest.

When subjects were grouped according to whether they had been introduced to density prior to or following their experimentation with sinking and floating phenomena, there was only partial support of the hypothesis concerning the effects of this variable. There were no significant differences on the **pretest** in the number of justifications based on weight, material kind or density ($F(1,76) = 0.19$ $p = .67$, $F(1,76) = 1.04$ $p = .31$ and $F(1,76) = 0.42$, $p = .59$, respectively). In addition, following the experimental sessions, both treatment groups provided fewer justifications based on the weight of the object. The two groups' number of weight responses were not significantly different either on the **immediate posttest** ($F(1,76) = 0.43$ $p = .52$) nor on the **delayed posttest** ($F(1,76) < 0.00$ $p = 1.00$).

There was, however, a significant effect of order of density presentation on the number of material kind justifications on the immediate posttest. Although the number of material kind answers doubled for both treatment groups, subjects who were already familiar with the concept of density resorted *less* frequently to explanations based simply on material kind ($F(1,78) = 4.29$, *$p < .05$). Thus it seems that students who had *not* been explicitly instructed on the concept of density, upon perceiving the inadequacy of a prediction based on the weight of the object, may have more frequently resorted to another observable feature of the object, that of its material kind. There was also a *tendency* ($p = .10$) for students who learned about density *prior* to the exploration of the sinking and floating problems to explain the phenomena in terms of the density of the material more often than students who had not yet been introduced to the concept of density ($F(1,78) = 2.76$, $p = .10$).

Hence, the sequence in which students had been introduced to the concept of density significantly influenced the frequency of occurrences of justifications based on material kind in support of predictions about sinking and floating phenomena on the immediate posttest. However, the introduction of the concept of density prior to the sinking and floating sessions had only a temporary influence on students' interpretations of sinking and floating phenomena since analysis of the delayed posttest showed no significant difference between the two treatment groups with regard to the number of

4.4.2. Individual patterns in response to sinking and floating phenomena on the written test

Students who justified one or more of their predictions on the basis of the weight of the object were categorized as showing a *low level of integration* of density in their understanding of sinking and floating phenomena. The pattern where students wrote exclusively about material and never mentioned density in any of the tasks was interpreted as showing a *moderate level of integration*. Finally, students were classified as showing a *high level of integration* if they consistently justified their predictions on the basis of density or alternated between "material kind" responses and "density" responses. Given the open-ended nature of the questions and the absence of probes on a written test, it was decided to also credit subjects with a high pattern of integration when they displayed this combination of responses. The reader is reminded that each response credited as material kind or density was contingent upon having made the correct prediction.

4.4.2.1 General effect of treatment on individual patterns on the paper and pencil tests

On the pretest, the majority of students showed a low level of integration of density in their responses to sinking and floating phenomena and there was no difference between the treatment groups and the control group in the number of subjects displaying the different types of patterns ($X^2(2) = 0.57$, $p = .75$). As may be seen from the data presented in Table 19, there was a *tendency* for the experimental sessions as a whole to help subjects integrate the concept of density into their interpretation of sinking and floating phenomena when compared to a situation where no teaching had taken place. Indeed, no student in the control group consistently justified his or her predictions about sinking and floating phenomena on the basis of density. This difference between the treatment groups as a whole and the control group approached but did not reach the accepted level of statistical significance ($X^2(2) = 5.71$, $p = .06$) and ($X^2(2) = 5.13$, $p = .08$) respectively for the immediate posttest and the delayed posttest.

4.4.2.2. Main effects of the independent variables on the patterns of response on the paper and pencil test

There was no difference between the groups who had observed sinking and floating phenomena with the computer model and those who had observed the real-world materials alone in the number of subjects displaying the three levels of integration on the immediate posttest, ($X^2(2) = 3.03$, $p = .22$) nor on the delayed posttest ($X^2(2) = 0.88$, $p = .64$) (see Table 20). Subjects had been assigned to each of these treatment groups in comparable proportions based on their integration pattern on the pretest ($X^2(2) = 1.20$, $p = .55$).

Likewise, there was no difference between the groups who had been introduced to the concept of density prior to their observation of sinking and floating phenomena and those who had been introduced to density afterwards with regard to the number of subjects displaying the different levels of integration on either posttest, $X^2(2) = 3.96$, $p = .14$ and $X^2(2) = 1.31$, $p = .52$ respectively (see Table 21). Subjects had been assigned to each of these treatment groups in comparable proportions based on their integration pattern on the pretest ($X^2(2) = 1.20$, $p = .55$).

There was no experimenter difference on either posttests, $X^2(2) = 1.76$, $p = .42$ and $X^2(2) = 1.46$, $p = .48$ respectively. Students had been assigned to each of the two experimenters in equal proportions with respect to their level of integration on the pretest ($X^2(2) = 1.41$, $p = .49$). Also, there was no difference between boys and girls with regard to their level of integration of density in response to the sinking and floating tasks on the two posttests ($X^2(2) = 4.45$, $p = .11$ and $X^2(2) = 2.09$, $p = .35$) respectively. Male and female subjects had also displayed the different integration patterns in equal proportions on the pretest ($X^2(2) = 1.23$, $p = .54$).

In short, neither independent variable (i.e., the opportunity to observe sinking and floating phenomena with the support of an interactive model and prior instruction in the concept of density) led students to justify their predictions about sinking and floating phenomena more consistently in terms of the density of the material on the paper and pencil test. In other words, the changes that had been observed after students had tested their predictions of real-world phenomena (during the teaching sessions) were not maintained in a situation where students had to make predictions without being able to observe the result of those predictions (during the posttests). Indications that the first independent variable was not leading to lasting differences was already evident in the data from the teaching sessions. The significance of the entire pattern of results will be discussed at greater length further on.

4.5. Changes in the predictive rule for real-world phenomena and illustrated cases on the paper and pencil test

During the experimental sessions, students were asked to consider a variety of sinking and floating phenomena in order to determine the best predictive variable. One question of interest was whether students would see the similarities between the different sinking and floating phenomena and extract a general predictive rule. Presumably, formulating a rule to one's self should help create a suitable mind set to accurately predict similar phenomena in different contexts. At the end of the session on sinking and floating phenomena, students were asked how we can predict whether an object will sink or float. One item on the written test also asked subjects to formulate a predictive rule. This section will report changes in the rules expressed in both situations.

After the exploration of real-world sinking and floating phenomena, half the students in the treatment groups formulated a rule based on the density of the material and one fourth of the subjects expressed a rule in terms of material kind. The remaining subjects still thought the weight of the object was the most useful information to predict whether something will sink or float (see Table 22). There was a tendency for subjects who had observed sinking and floating phenomena guided by the interactive computer model to provide more rules based on the density of the material ($X^2(2) = 4.99$, $p = .08$) but the sequence in which students had learned about density relative to their observation of the phenomena did not have a clear influence on the kind of predictive rule they expressed ($X^2(2) = 3.42$, $p = .18$).

The rules formulated in writing on the tests were examined next. A visual inspection of the frequencies of different types of rules provided by the sample as a whole on the pretest (see Table 23) reveals that half the students formulated a rule based on the weight of the object, fewer than 20% of them provided a rule in terms of material kind while one third of the subjects expressed rules based on other factors (e.g., gravity, pressure (unexplained), etc...). After the experimental sessions, the proportion of rules appealing to factors other than weight or material kind remained the same but there was a major drop in the number of weight rules. Fewer than 20% of the subjects now thought of sinking and floating phenomena as a function of the weight of the object.

Instead, half the students formulated a sinking [illegible] ating rule based on the intensive properties of the object, that is, its materia [illegible] and the density of its material. These students were evenly split in number as to whether they talked about material kind or more specifically, about the density of the material. On the delayed posttest, the number of rules based on density was stable; however there was a slight increase in the number of rules based on material kind and a corresponding decrease in the number of rules appealing to weight and other reasons. Overall, the number of density rules provided on the written posttests is lower (i.e., 25%) than the number of density rules expressed orally during the one-on-one experimental sessions (i.e., 50%), suggesting that students had more difficulty expressing a rule in writing or that the formulation of a rule was a more fragile kind of learning.

While there had been no difference between the treatment groups and the control group with respect to the kind of predictive rule formulated on the pretest ($X^2(2) = 3.15$, $p = .21$), there was a significant impact of experimental treatment as a whole on the formulation of density rules on the immediate posttest, $X^2(2) = 16.02$, $^{***}p < .001$ (see Table 24). Students in the control group could to some extent deduce that sinking and floating was a function of the material the object is made of but participation in any one of the treatment groups was instrumental in bringing about the formulation of a more specific predictive rule based on the density of the material. However, this general effect of the experimental sessions was not maintained on the delayed posttest. Although the number of rules based on the density of the material provided by subjects in the treatment groups remained the same, a greater number of them expressed rules based on material kind, resulting in no significant difference between the treatment groups and the control group ($X^2(20 = 2.79$, $p = .25$). However, we may note that the contrast between the number of material kind rules and the number of density rules was accentuated on the first posttest by a larger amount of missing data.

No main effects of the independent variables on subjects' expression of a predictive rule were observed. First, there was no difference in the kind of predictive rule expressed between the groups who had observed sinking and floating phenomena with the computer model and those who had observed the real-world materials alone, either on the immediate posttest, $X^2(2) = 0.57$, $p = .75$ or on the delayed posttest, $X^2(2) = 2.34$, $p = .31$ (see Table 25). Subjects had been assigned to each of these treatment groups in comparable proportions based on the kind of predictive rule they had formulated on the pretest, $X^2(2) = 1.66$, $p = .44$.

Likewise, there was no difference between the groups who had been introduced to the concept of density prior to their observation of sinking and floating phenomena and those who had been introduced to density afterwards with regard to the kind of predictive rule on either posttest, $X^2(2) = 0.30$, $p = .86$ and $X^2(2) = 0.07$, $p = .97$ respectively (see Table 26). Subjects had been assigned to each of these treatment groups in comparable proportions based on their predictive rule on the pretest, $X^2(2) = 1.19$, $p = .55$.

In short, the analyses did not reveal any influence of the independent variables on subjects' formulation of a predictive rule for sinking and floating phenomena. One might expect that students who worked with the sinking and floating simulation would have been in a better position to formulate a rule based on density because they benefit from illustrations and labeling of the variables each time they interpret a sinking and floating phenomenon. However, this expectation was not borne out on either posttest. Also, contrary to expectations, the simulation (which allowed students to visualize the density of the liquid as well as that of the object) did not influence the frequency of rules based on relative density. The next section will summarize the overall results and highlight the contrast between the findings observed during the experimental sessions and those observed on the paper and pencil test.

4.6. Overview of results

4.6.1. Understanding of the concept of density

A significantly greater number of subjects who participated in the experimental sessions were able to provide an appropriate definition for the concept of density when compared to subjects in the control group both on the immediate posttest and on the delayed posttest. Whether subjects had learned about density before or after the exploration of sinking and floating phenomena did not influence their ability to define the concept. Understanding of density as measured by this open-ended task was also unrelated to additional experience with the computer model of weight and density as it appears in the *Sink the Raft* program. All experimental groups had been introduced to the concept of density in the same way, making use of a computer-based model and real world materials.

4.6.2. General predictive rule for sinking and floating phenomena

There were no differences between the treatment groups with regard to the formulation of a general predictive rule for sinking and floating phenomena at the end of the experimental sessions although there was a tendency for the students who used the sink/float simulation to have more density based rules. On the immediate posttest, subjects in the treatment groups were significantly more likely to formulate a rule based on the density of the material than students in the control group. However, this general effect of treatment was not maintained on the delayed posttest. The type of treatment subjects were involved in did not significantly influence the kind of predictive rule they expressed on the posttests.

4.6.3. Interpretations of real-world sinking and floating phenomena

When subjects initially expressed a reason to support their predictions of sinking and floating phenomena during the experimental sessions, there was no difference between the students who were observing the phenomena guided by the computer model and the subjects who were relying on real-world materials only. On the other hand, the group of subjects who had already been introduced to the concept of density provided significantly fewer justifications based on material kind and a significantly more justifications based on the density of the material.

After they had tested their predictions, subjects were given the opportunity to revise the basis for their future predictions of similar phenomena. The groups who worked with the *Sink the Raft* program saw the weight of the object as relevant to sinking and floating phenomena significantly *less* often and the density of the material as relevant significantly *more* often than their peers, who had had no computer model available to guide their observations. Also, the groups who had been introduced to the concept of density before the exploration of sinking and floating phenomena gave significantly fewer justifications based simply on material kind and significantly more justifications based on the density of the material than students who had yet to be introduced to density when they revised the basis for their predictions.

The effects of both independent variables was also evident in individual pattern analyses of *justifications of predictions made after* testing them, but not for justifications made before. Both students who had used the computer simulation and students who had been introduced to density first had more high level of integration patterns than their counterparts in groups that did not have these experiences.

Although there was a main effect associated with each of the two independent variables on students' responses during the experimental sessions, *no significant interaction effect* between the two variables was observed.

4.6.4. Interpretations of sinking and floating phenomena on the written test

The treatment groups as a whole gave significantly fewer interpretations of sinking and floating phenomena based on the weight of the object, and significantly more interpretations based on the density of the material than the control group both on the immediate posttest and on the delayed posttest.

Also, a greater number of individual subjects in the treatment groups displayed high levels of integration of density when compared to their peers in the control group although this difference approached but did not reach the accepted level of statistical significance on either posttest.

There were not clear effects of the first independent variable on students' performance on the posttest. Whether students had tested their sinking and floating predictions with the support of the interactive **computer model of sinking and floating phenomena** or without this simulation did not have any influence on the mean number of weight, material or density responses nor on the frequency of individual patterns of integration on either posttest.

There were some effects of the second independent variable on posttest performance, but they were somewhat transitory. On the immediate posttest, the groups who had learned about **density prior to the sinking and floating sessions** gave significantly fewer answers based on material kind and were inclined to provide more justifications based on the density of the material than students who learned about density afterwards. However, this effect was not maintained seven weeks later. Neither variable affected individual patterns of integration.

In summary, significant effects of the independent variables (i.e., availability of the computer model during the experimental sessions and prior introduction to the concept of density) were observed in students' responses to real-world phenomena during the experimental sessions when they were given the opportunity to revise the basis for their predictions. However, for the most part, these changes were not maintained when subjects wrote the immediate posttest a short time later. In general, both the mean number of density answers and the number of subjects showing high integration patterns of density were more frequent when subjects revised their predictions of real-world phenomena than on the immediate posttest where they had to make predictions for similar phenomena without observing the results; instead, subjects tended to provide more answers based simply on material kind on the written test. In fact, the pattern of responses provided on the immediate posttest is similar to the pattern of responses observed when subjects first formulated their predictions of real-world phenomena during the teaching session. The next chapter will discuss these findings in more depth and present some complementary analyses to highlight the discussion.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1. Introduction

Changing the basis for one's predictive rule about sinking and floating phenomena from an easily perceived extensive property, the weight of the object, to an unobservable intensive property, the density of the material the object is made of, involves a complex cognitive change for sixth and seventh graders. The subject needs to first understand the new concept and then make a commitment to this new concept as a more effective way of predicting sinking and floating phenomena. Previous research reported in chapter 1 has been pointing to two problems in this area: students have a great deal of difficulty understanding density and they are frequently insensitive to empirical counter-examples designed to challenge their own rule (i.e., Cole, 1969; Emerick,1982).

One explanation put forth is that students lack the conceptual resources to make sense of the counter-evidence and that real- world materials do not provide any explicit information that would help them develop alternative explanations (Strike & Posner, 1986). Work guided by this general assumption has led to the development of computer modelling strategies as means to help students articulate the distinction between weight and density and to apply the newly formed concept to predict sinking and floating phenomena. Students have been involved in teaching units over a number of weeks consisting of lectures, demonstrations, experimentation with real-world materials in conjunction with interactive computer models (see Smith et al., 1986, 1987). A key feature in these studies has been the use of conceptually enhanced computer simulations as a means of making available to students conceptually relevant information that they can grasp visually and manipulate by interacting with the program (see Snir et al., 1988). These studies have found that many 6th and 7th graders make progress in differentiating weight and density and in reformulating their predictive rules for sinking and floating after working with this curriculum. These results contrast with the limited success of other approaches which have relied only on logical analysis and real world experimentation (i.e., Cole & Raven, 1969; Emerick, 1982).

The purpose of the present study was to take a closer look at the process whereby students relinquish their predictive rule in the face of counter-examples and to examine two variables that might affect their interpretation of counter-examples. One variable concerned whether or not students had the conceptual resources to resolve the conflict generated by the counter-examples. The other variables was whether or not students received explicit visual support for applying this conceptual analysis in the context of sinking and floating experiments. Data from the experimental sessions were used to monitor the cognitive process that was taking place during treatment, and changes in students' thinking was measured by a paper and pencil test administered at two tin .s after the treatment.

The first variable was manipulated by varying the order of presentation of the teaching session on density (i.e., before or after the session in which students explored sinking and floating phenomena). It was hypothesized that students who had the teaching session on density prior to the sink/float experimentation would be more likely to have the conceptual resources to resolve the conflict generated by the counter-examples in the sink/float session. Hence, in the face of experimental evidence, these students should be more likely to think their way thr h to a rule based on density (or material kind) rather than weight.

The second independent variable was manipulated by varying whether or not students used a conceptual simulation of sinking and floating in addition to working with real world materials in exploring this phenomena. Again, it was hypothesized that students who worked with the conceptual simulation would be aided in interpreting counter-examples and formulating a predictive rule based on density rather than weight.

5.2. Discussion of results

5.2.1. General effect of treatment

There was a statistically significant effect of treatment as a whole on students' ability to provide a definition of density and to base interpretations of sinking and floating phenomena on density rather than weight as measured by group trends in comparison with the control group. The experimental groups had a 55% increase in numbers of students who could give an adequate definition of density between the pretest and delayed posttest, in contrast with only a 10% increase for the controls. Indeed, by the end of the study, 70% of the experimental group could give an adequate definition of density. Similarly, in their sink/float predictions, the experimental treatment groups decreased the frequency of weight responses by 56% and increased the frequency of density responses by 34% on the immediate posttest changes that were maintained on the delayed posttest six to seven weeks later as well. In contrast, the control group never moved to density based answers and showed a much more modest decline in weight based answers.

Considering the limited success of other approaches which have relied only on logical analysis and real-world experimentation (i.e., Cole & Raven, 1969; Emerick, 1982), this is an important testimony to the potential of computer-based modelling strategies to enhance children's understanding of sinking and floating phenomena. By the same token, these findings lend some credence to the general hypothesis that students can learn from counter-evidence when they have the opportunity to develop the necessary conceptual resources (i.e., Driver & Erikson, 1983; Champagne & Klopfer,1984; Posner & Strike, 1986).

At the same time, several aspects of the data also reveal that this teaching intervention may have been too brief to allow students to achieve a well-integrated understanding of density and sink/float phenomena. First, students who were correct in their verbal definitions of density did not always succeed with the nonverbal problems. Second, only 20% of the students in the experimental group were consistent in using density as the basis for all their sink/float predictions on the posttests. While this number is considerably higher than in the control group, it shows that the majority did not achieve a high level of integration of density. Finally, although more students in the treatment group were able to formulate a general predictive rule based on density than were students in the control group, this advantage was not maintained on the delayed posttest.

Indeed, it seems that many students in the experimental groups did not make a full-scale change to density but were satisfied with a more general interpretation in terms of material kind. Such a step from an extensive property (weight) to an intensive property (material kind) is an important one as such, but students in the control group also improved in this respect, suggesting that simply taking the test allowed them to deduce some information or caused them to draw upon their previous experience with sinking and floating phenomena. It is not clear from the present analyses what proportion of students who did make the move to an interpretation based on density had started out with an approach based on material kind.

5.2.2. <u>Main effect of the order of introduction to density</u>

The order in which subjects had been introduced to density had a partial influence on their interpretation of sinking and floating phenomena. On the immediate posttest, there were significantly fewer justifications based on material kind among the subjects who had been introduced to density first; there was also a tendency for these subjects to provide more density answers. In other words, shortly after the sessions, subjects who had followed the first sequence were more specific than their peers who followed the reverse sequence (i.e., they used density rather than material kind), even though by the time they wrote the test, all the subjects had been introduced to density in an identical manner.

However, this variable did not influence their integration of density as profoundly as was expected. First, the students who received density first did not significantly reduce their number of weight responses. Second, these students did not have a significantly greater number of high integration patterns on the immediate posttest. Third, the group trends were not maintained on the delayed posttest. After the experimental sessions, we observed that the number of density answers on the posttests gradually declined (by 20% and 10% respectively) among subjects who had followed the first sequence (i.e., they revert to more general interpretations based on material kind) whereas the performance of subjects who followed the second sequence remained stable.

These results are in contrast to the data gathered during the experimental sessions. There had been clear indications in the course of treatment that awareness of an alternative concept helped students not only to revise their interpretations to make use of density, but also to make predictions ahead of time based on density. This advantage of prior introduction to density was not only reflected by a higher group mean of density based revisions and predictions but also in a greater number of subjects showing highly integrated patterns of density based revisions.

However, it should also be noted that even in the experimental sessions, the shifts were primarily from material kind answers to density answers. There was no significant difference in weight answers between the group that had density introduced prior to the sink/float session and the group that had density introduced after this session. Thus, there was no evidence that by increasing the accessibility of density, students were more likely to abandon a weight rule in the face of counter-evidence. It should be noted that in the experimental session (in contrast to the written test), the percentage of weight answers was low. Further, it may be that those few subjects who gave weight based answers were ones that had not understood the distinction between weight and density. This hypothesis could be tested with further data analyses relating students patterns of responding on different parts of the test.

In contrast to the present findings, Rowell & Dawson (1983) had observed a positive long-term effect of sensitizing students to alternative conceptions (the efficiency of various experimental designs) before challenging their own approach. This strategy may not have worked as well in the present case, because student conceptions frequently were not really challenged in the experimental sessions (many in fact made correct predictions on the basis of material kind). This possibility will be discussed more fully in a later section. Another possible reason is that the lengthier teaching unit in the Rowell & Dawson (1983) study allowed the students to integrate the alternative conception more fully after being alerted to the range of potential solutions.

5.2.3. Main effect of the sinking and floating simulation

Subjects who had worked with the *Sink the Raft* program as opposed to real-world materials alone to test their predictions about sinking and floating phenomena did not significantly differ in their interpretations of the phenomena on the posttests. This finding was surprising in view of the fact that the simulation was significantly influencing their interpretations in the course of treatment. When students had the opportunity to revise their predictions, those who had the support of the simulation offered significantly fewer weight responses and significantly more density responses than students who had to rely on the observation of real-world materials alone. Indeed, those students who performed the experiment only with real world materials, actually gave more slightly weight based responses after observing the results of their experiment than before! This advantage of the simulation was also reflected in a greater number of subjects showing highly integrated patterns of response based on the density of the material.

However, in spite of this clear influence of the *Sink the Raft* program in helping students revise their interpretations, it was also evident that subjects in the simulation group were not applying these revisions to the successive predictions they had to make. Indeed, there was no main effect of the simulation on the justifications they offered in support of their initial predictions. Subjects were relying on the simulation to re-interpret the phenomena at hand but seemed to approach each instance anew. We did however observe a tendency for students in this group to formulate a general predictive rule based on the density of the material at the end of the session to a greater extent than their peers.

The simulation may have served, then, as a representational support for those in the process of understanding density. However, the intervention appears to have been too brief to lead these students to an integrated understanding of sinking and floating in terms of density, since the advantages were only evident when the representational aid was present.

5.3. The computer models within a strategy for conceptual change

The **model of conceptual change** that guided the design of the experiment (Posner & Strike, 1986) presumed three conditions to be essential for conceptual change to occur: 1) that there be *dissatisfaction* with the existing conception, 2) that the new conception be *intelligible* and 3) that the new conception be *plausible*. The study did not question the role of counter-examples to create dissatisfaction. Instead, it addressed the lack of information in real-world counter-examples as they are usually presented, focusing on meeting the second and third conditions for conceptual change. That is, it helped students to grasp the concept of density and demonstrated its relevance to real-world phenomenon.

The two hypotheses of this study identified factors that should be important in bringing about conceptual change within the context of this general model. In particular, *given a situation where subjects perceived the need to change their rule*, the observation of sinking and floating phenomena guided by an interactive conceptual simulation and prior introduction to density were assumed to be more helpful than the counterpart situation in leading students to change their predictive rule.

To induce this need for conceptual change, a learning situation was designed whereby subjects rules would be empirically contradicted (i.e., phenomena predicted by students were all counter-examples to a rule based on the weight of the object). Why then did so few students (20%) make a major shift in their thinking? One possibility is that Posner and Strike's first condition for conceptual change (dissatisfaction with one's existing conception) was typically not met in the teaching situation. As it turned out, over 70% of the students managed to make correct predictions for five out of the seven items even though few of them thought of this situation in terms of density. Hence, the question arises as to whether the sinking and floating phenomena that students had to predict were too easy and did not pose a real challenge to their former predictive rules. Thus, although many students may have acknowledged the relevance of density to the phenomena at hand during the experimental sessions when they were asked to revise their interpretations, they may not have felt deeply motivated to change the basis for their predictions. In keeping with this hypothesis, we observed that the simulation helped students acknowledge the relevance of density when they could observe the results of their predictions but it did not help them move to being able to predict sinking and floating phenomena in advance on the basis of density to a greater extent than the observation of real- world materials alone.

A further difficulty may have related to student's lack of metaconceptual awareness of what constituted a good predictive rule or law (e.g., one rule which covers all the instances, rather than different rules for different instances). The teaching situation itself was very unstructured: students were simply presented with a series of problems and asked to make sense of them. Perhaps students would have benefited from more structure which made them aware of the kind of rule they were looking for (in the Smith et al. studies, 1986, 1987, such metaconceptual issues had been broached; also more guidance was given in testing rules). In any event, it seemed that many subjects were approaching each phenomenon anew and probably did not have enough time to be convinced of the general applicability of the new rule.

Finally, it should be noted that the sink the raft program was used only in the context of helping students interpret known situations. That is, they modeled the objects on the computer after they witnessed whether they sank or floated. However, it might be more beneficial for students to model the objects on the computer before they witness what happens and have the experience of using the model to aid their making predictions. Subjects would also likely benefit from the exploration of a wider range of each type of counter-example, and the explicit variation of the type of liquid used (again in the Smith et al. study, the use of the simulation had not been as limited as in this study).

One further data analysis was conducted to see if there was a greater effect of the two independent variables for individual items that were especially puzzling for children. In general, children found the case of the heavy floater more perplexing than the case of a light sinker. Indeed, the highest rate of incorrect predictions occurred for the large piece of wax which 60% of the students thought would sink. Students are presumably more familiar with light sinkers because of their play experience with pebbles and the like but find heavy floaters more counter-intuitive.

In keeping with the analysis of the items pooled together, analysis of the individual items revealed a significant effect of treatment as a whole in comparison with the control group (see Table 28). However, there was no significant effect of either model-guided observation of sinking and floating phenomena (as opposed to real-world observation only) or of prior introduction to density (as opposed to being introduced to density after the observation of sinking and floating phenomena) on any of the individual items (see Tables 29 and 30). Nonetheless, we may observe a tendency for the independent variables to have encouraged a greater number of responses based on the density of the material for some of the counter-examples which consisted of "heavy floaters."

A still more detailed analysis that could be explored with the present data is whether individual students who made wrong predictions on the basis of weight during the sessions (note: some children managed to make a correct prediction but justified it on the basis of weight) were more willing than students who made correct predictions to revise the basis for their predictions during the experimental sessions and whether the changes for these subjects were maintained for similar cases on the posttests when they had used the sink the raft simulation and/or been introduced to the concept of density first. Such case studies might help us gain more insight into the individual dynamics of change in students' interpretations of sinking and floating phenomena that was taking place in the course of treatment. However, in this study, it was also observed that some students were willing to revise their interpretations even when their predictions were confirmed. Hence, one interesting advantage of giving students access to conceptually relevant information is that it can prompt some of them to consider better alternatives without having first experienced cognitive conflict.

The cognitive experience subjects underwent was contingent upon their starting points. For "weight theorists," the sessions provided some disconfirming evidence plus a tool to visually identify the competing variables of weight and density. For "material kind theorists," the sessions provided some confirming evidence plus a tool to highlight which feature of the material was involved. Thus, an additional consideration for further study would be to examine more closely the intermediate steps involved in moving from a rule based on weight to a rule based on density.

5.4. The representational support offered by the simulation

Since the rationale of the computer-based modelling approach consists in providing students with visual representations to make new conceptions more intelligible, one issue is to what extent students found the computer representation meaningful and had chosen to internalize it as a conceptual aid. All students had been exposed to the grid and dots computer model in the teaching session on density; however, only half of the students had also used in the teaching session on sinking and floating.

To explore to what degree students were relying on this representation while they were solving sinking and floating problems on the test, subjects were asked to interpret the case of a heavy floater coupled with a light sinker and to draw a model illustrating their interpretation. Subjects observed a diagram of the two objects in a container of liquid and did not have to make predictions. The situation was directly reminiscent of the real- world sinking and floating phenomena students had observed in the course of the experimental sessions.

Students responses were analyzed both in terms of the kind of explanation they used in their interpretation (i.e., weight, material kind, density) and the kind of model they drew (to see whether or not they used the grid and dots model). As described in Chapter 2, the drawings were classified into six types of models: computer (i.e.,grid and dots), shading, particulate, hollow-full, figurative and miscellaneous. Examples of each type of model may be found in Figure 13 of Appendix A.

In keeping with the results on the items for which subjects had to provide predictions, there was no main effect of the independent variables on the kind of explanation they provided in this task. On the pretest, when faced with such a situation which cannot be interpreted on the basis of the weight of the object, subjects resorted to material kind as a possible factor or invoked a host of other reasons. On the posttest. there was a major shift to answers based on density although about one quarter of the subjects retained answers based on the material the objects were made of and an equal proportion appealed to other reasons. Participation in any of the treatment groups was significantly related to a higher frequency of density answers ($X^2(1) = 14.70$, $^{***}p < .001$) but this tendency was independent from whether or not they had worked with the Sink the Raft program ($X^2(1) < 0.01$, $p = 1.00$) or from whether or not they had learned about density prior to the exploration of sinking and floating phenomena ($X^2(1) < 0.01$, $p = .97$).

However, there were differences in the kinds of models used on the immediate posttest for children with different treatments (see Table 31). On the pretest, most students (i.e., 60%) did not understand the task and drew figurative illustrations. On the immediate posttest, 30% of the subjects drew the "grid and dots" computer model of weight and density whereas on the delayed posttest, the computer model accounted for only 15% of the drawings. There was still a good number of figurative models on the two posttests, that is, 40% and 30% respectively. Other types of models (i.e., hollow-full, shading, particulate,...) were rather infrequent although there was an increase on the number of particulate models from the first to the second posttest. It may be that, several weeks after treatment, some students had retained the general idea of a model comprised of smaller elements but had forgotten the importance of organizing these elements within standard units. There was also some lack of involvement on the delayed posttest as indicated by the increased number of missing pictures.

There was a significant effect of the *Sink the Raft* program on the type of model subjects chose to draw. On the immediate posttest, students who had worked with the sinking and floating simulation drew the computer model significantly more often as compared with other kinds of models $X^2(2) = 4.16$, $^*p < .05$, whereas the reverse was the case for students who had not worked with the program (see Table 32). This observation is not totally trivial in view of the fact that even students who did not use the *Sink the Raft* program still received some exposure to the grid and dots model through the *Weight and Density* program when they were being introduced to density. The fact that subjects who only worked with this program (unrelated to sinking and floating) did not apply the model to sinking and floating phenomena as often as their peers who worked with both programs on the immediate posttest argues for the importance of having a second program which depicts the model of weight an density as it applies to sinking and floating phenomena. On the other hand, the total number of computer models drawn on the delayed posttest decreased such that there was no significant difference between the groups whether they had used the sinking and floating simulation or not ($X^2(2) = .44$, $p = 1.00$).

The sequence in which students were introduced to density did not influence their tendency to draw the computer model on either posttest ($X^2(2) < .01$, $p = 1.00$ and $X^2(2) < .01$, $p = 1.00$, respectively).

An interesting relationship also emerged between the type of drawing and the interpretation of the phenomenon. Students who drew the computer model to illustrate the phenomenon also provided verbal explanations based on density significantly more often than any other kind of response. Indeed, there was a clear relationship between drawing the computer model and explaining the phenomenon in terms of density both on the immediate posttest ($X^2(2) = 17.49$, $^{**}p < .01$) and on the delayed posttest ($X^2(2) = 10.36$, $^*p < .05$) (see Table 33). However, it is important to note that the converse is not the case: providing an explanation in terms of density was not contingent upon having drawn the computer model. Thus, some students clearly could understand the situation in terms of density without the aid of the computer model. It remains an open question, therefore, whether the importance of the computer model would be more clearly revealed with a set of more challenging problems.

5.5. Issues relating to the paper and pencil test

As a general rule, it may be said that face-to-face situations naturally encourage subjects to be more thorough in their explanations while the written test calls for more effort, and is thus more contingent on the subject's degree of motivation. However, the data collected during the experimental sessions cannot, strictly speaking, be likened to data collected during a clinical interview. Instead of exploring subjects' thought processes, both experimenters adhered to the same procedure which allowed only basic clarification of responses to ensure that all subjects would experience comparable treatments. Hence, the fact that subjects' spoken responses were *not probed* during the experimental sessions minimizes the difference in the quality of the data that would normally be expected between an interview and a written test.

A more important factor in explaining the lower number of density answers on the posttests as compared to the number of density answers expressed during the teaching sessions may have to do with the *cognitive demands* of the sinking and floating tasks on the test. Upon closer examination, the problems on the test did not require students to appeal to the density of the material in order to correctly predict the sinking and floating phenomena. When they were shown an object of like material in water, subjects could make accurate predictions simply by matching the kind of material the objects were made of. Hence, the verbal reference to density was dependent upon the level of articulateness of the subject rather than being called for by the task itself. The sensitivity of the test to different levels of integration of density would undoubtedly be improved by the addition of problems where students need to figure out the density of the material, even if only in a relative way, in order to be able to make their predictions.

5.6. General summary and conclusions

Overall, the results showed that whether or not subjects had prior awareness of density and whether or not subjects explored sinking/floating phenomena using a conceptual simulation in addition to real world materials did affect student's thinking in the teaching sessions. The fact there were significant main effects of these variables in the teaching session data provide some support for the psychological importance of these variables.

At the same time, it should be noted that the effects of the variables were not as extensive as had been predicted and could not be clearly linked to long term differences in student thinking. In particular, during the teaching session, use of the *Sink the Raft* simulation only led to enhanced use : density in revisions of predictions, it did not lead to better initial predictions. Further, students who had prior exposure to the concept of density in a teaching session were only superior in their use of density instead of material kind explanations, not superior in their lesser use of weight based explanations. Finally, none of the differences in the groups remained by the delayed posttest.

Several hypotheses were considered to explain why the variables may not have had more enduring effects. On the one hand, the basic conditions for conceptual change may not have been fully met. It was noted that the teaching problems may not have been challenging enough since many students managed to make the correct prediction, even for the wrong reasons. Then too the brief nature of the teaching session may not have allowed students to consolidate insights that were beginning to emerge. A longer teaching situation which included more varied and challenging problems may be required to translate the initial advantages observed into consolidated effects and insights. On the other hand, the test itself may not have been fully sensitive to important differences in levels of student understanding. Because the range of problems was limited and could be solved somewhat successfully only with a conception of material kind, it is possible that it wasn't sensitive to important differences in the different treatment groups.

We believe then that although the present study did not demonstrate long term effects of the two variables under study it did highlight their short term effects. Further study of the role of these variables in bringing about long term change is warranted using more extensive teaching interventions and more sensitive measures of levels of understanding of density.

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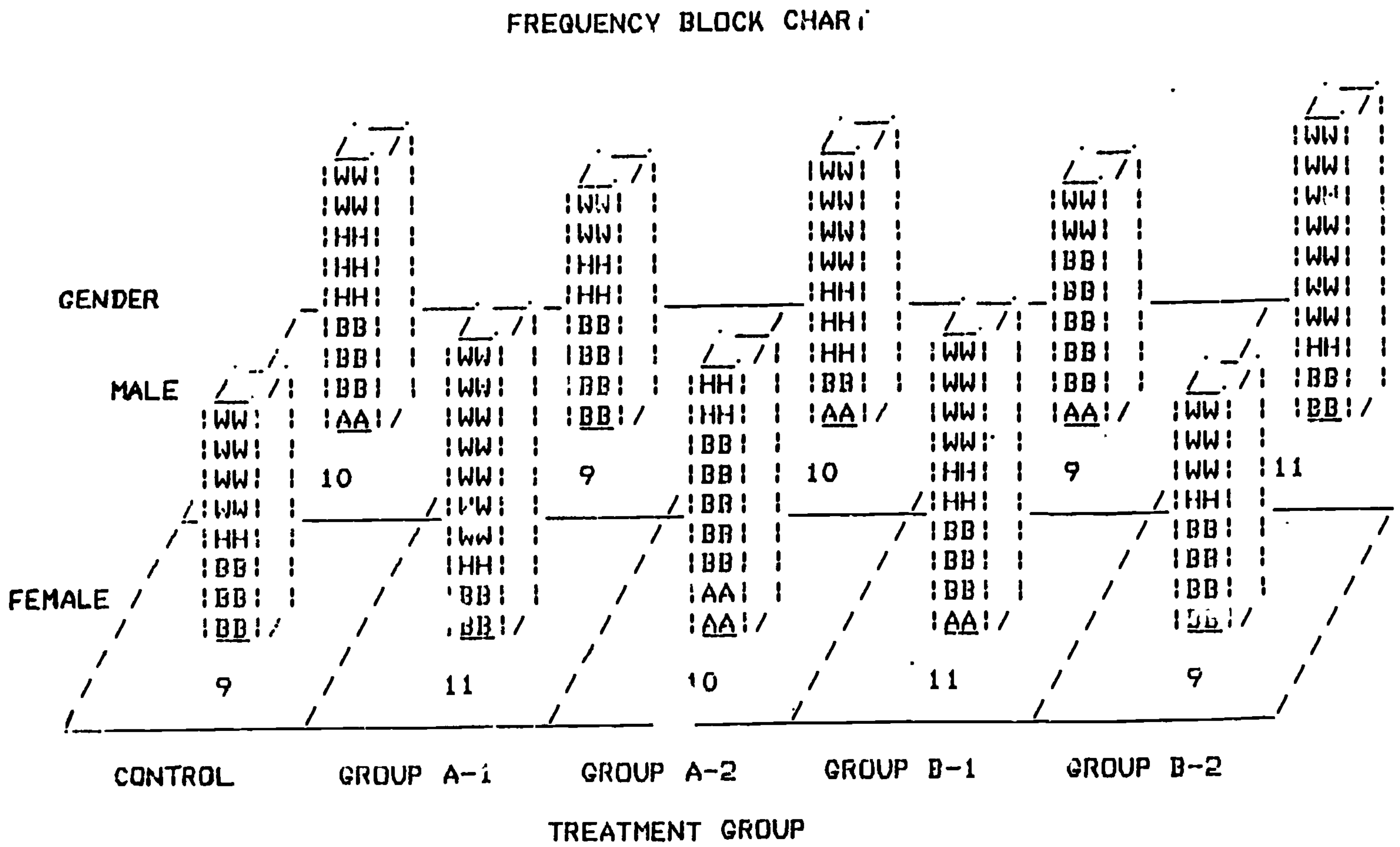
APPENDIX A

Figures 1 through 13

Figure 1. Distribution of subjects in experimental groups by gender and ethnicity.



SYMBOL	ETHNIC	SYMBOL	ETHNIC	SYMBOL	ETHNIC	SYMBOL	ETHNIC
A	ASIAN	B	BLACK	H	HISPANIC	W	WHITE

Figure 2. Screen dump from the Weight and Density program.

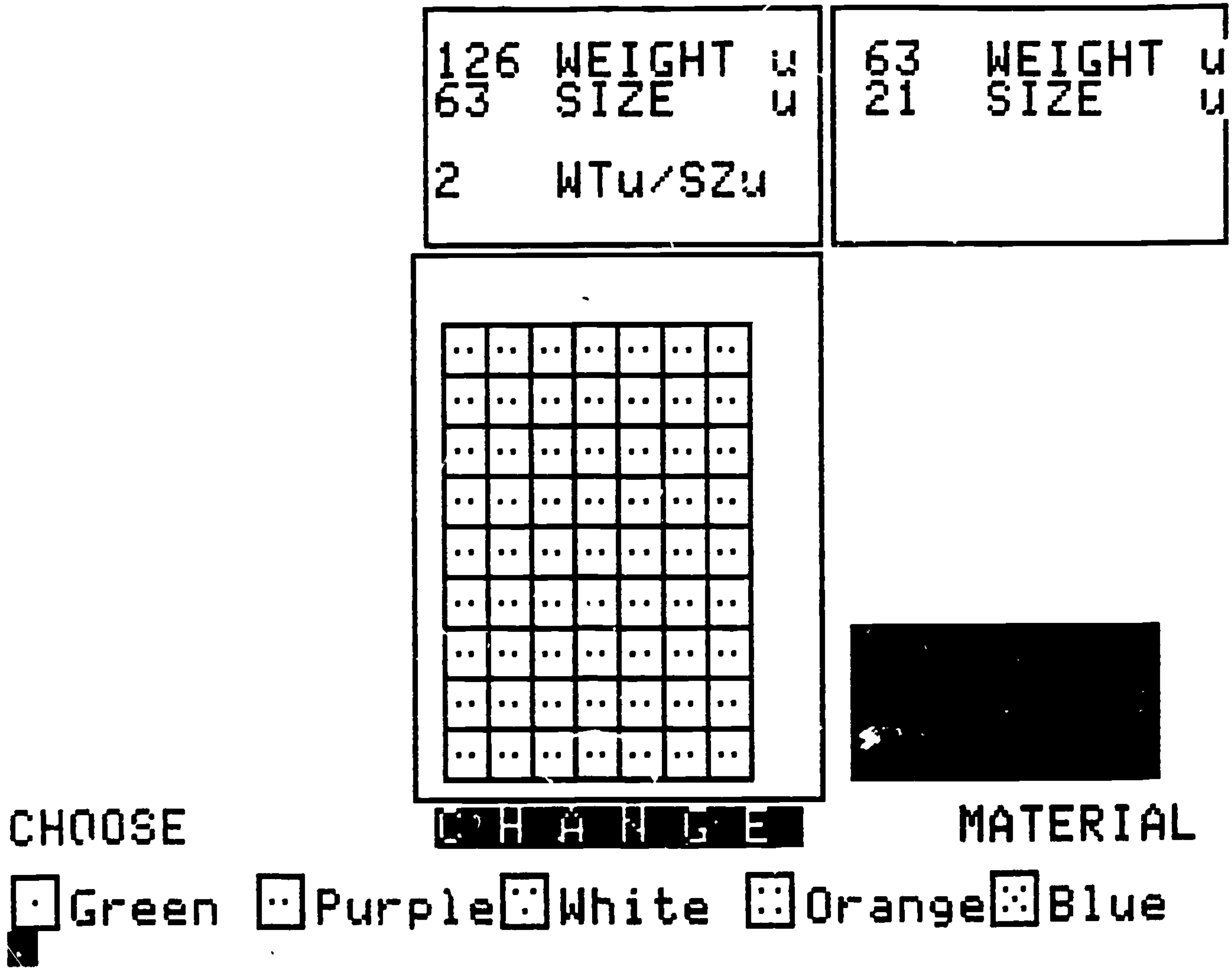


Figure 3. Screen dump from the Sink the Raft program.

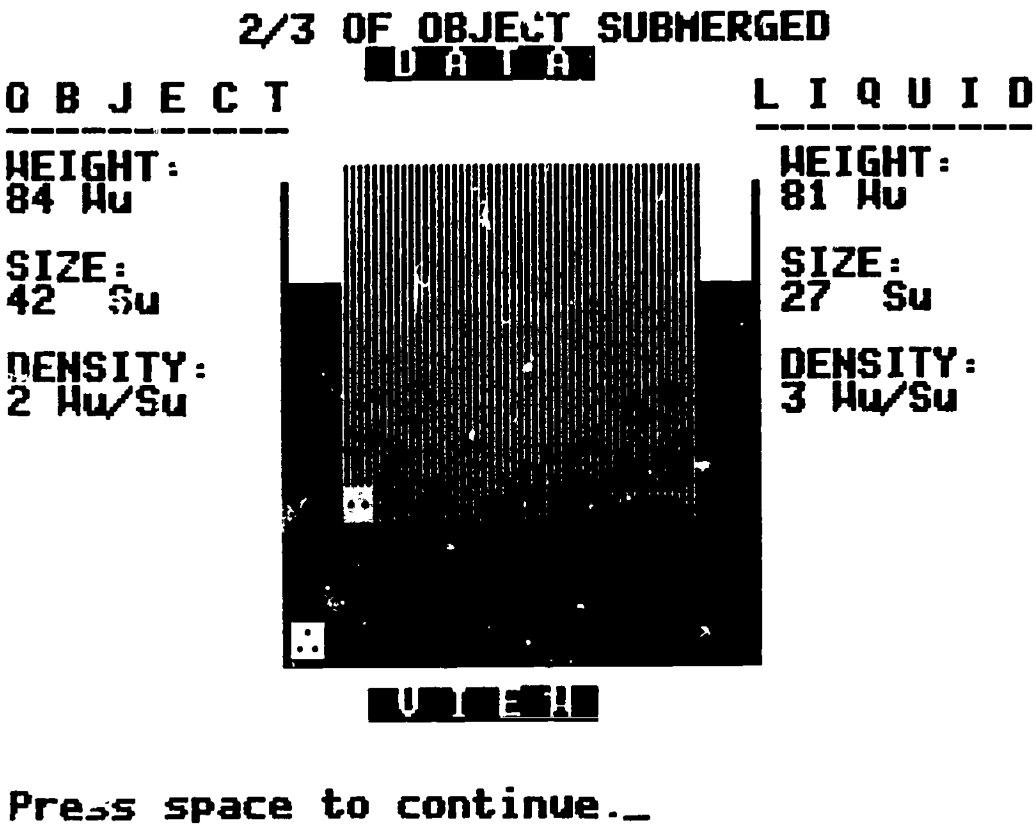


Figure 4. Real-world materials used with the Weight and Density program.

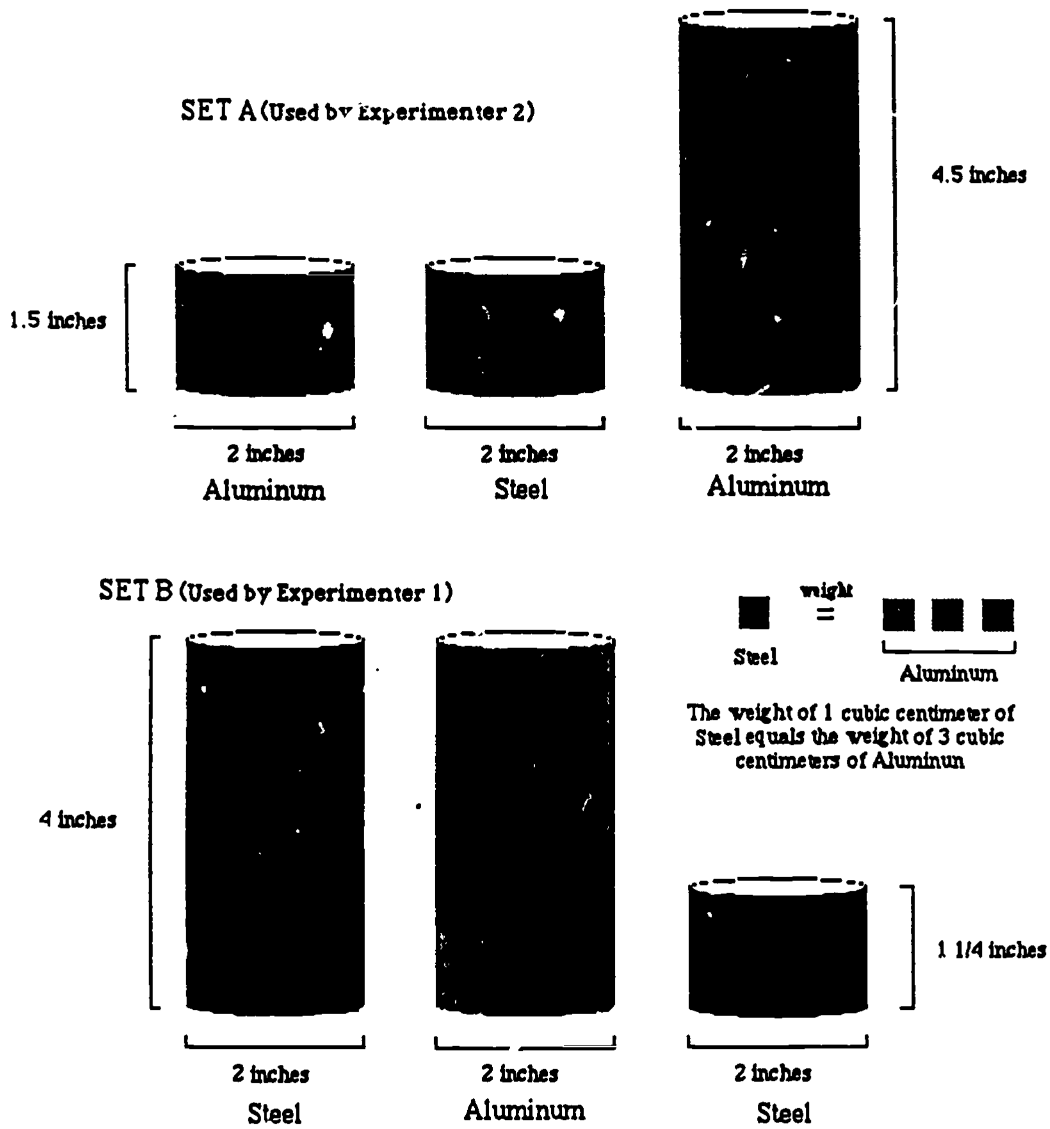
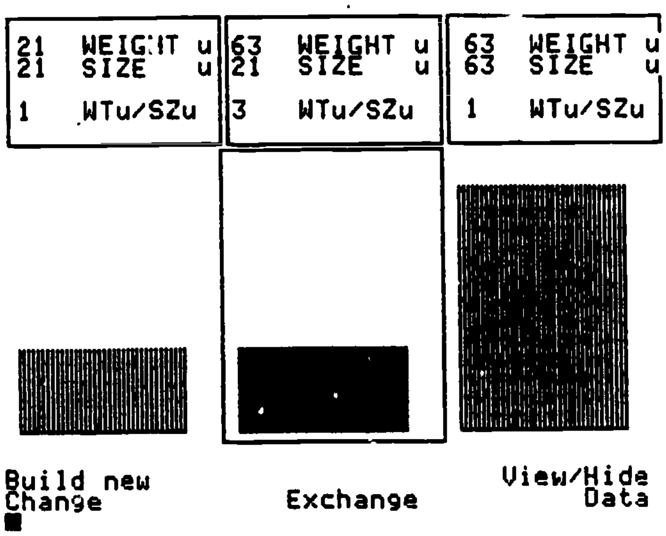


Figure 5. Computer models of steel and aluminum cylinders with data display.

a) Models of set A.



b) Models of set B.

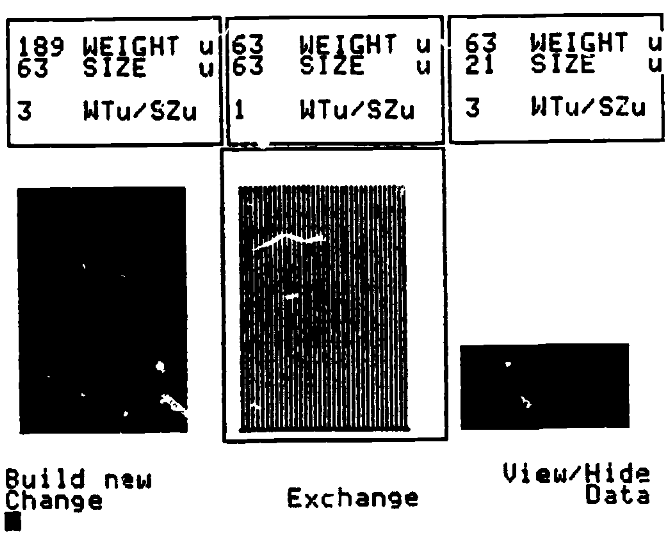
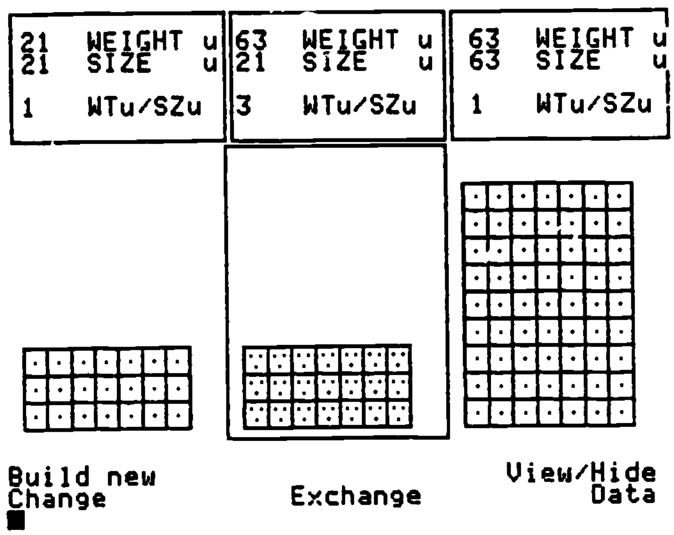


Figure 6. Computer models of steel and aluminum cylinders with data display and viewing option.

a) Models of set A.



b) Models of set B.

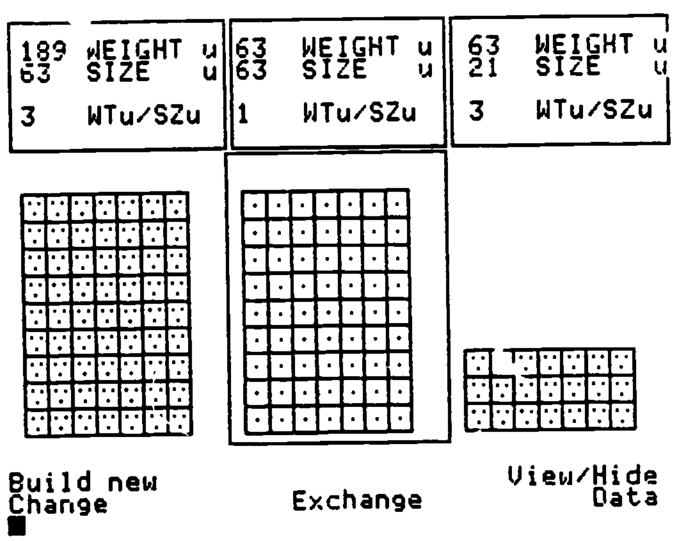


Figure 7. Real-world materials used in sinking and floating experiments (Part I): sets of objects made of the same material varying in weight.

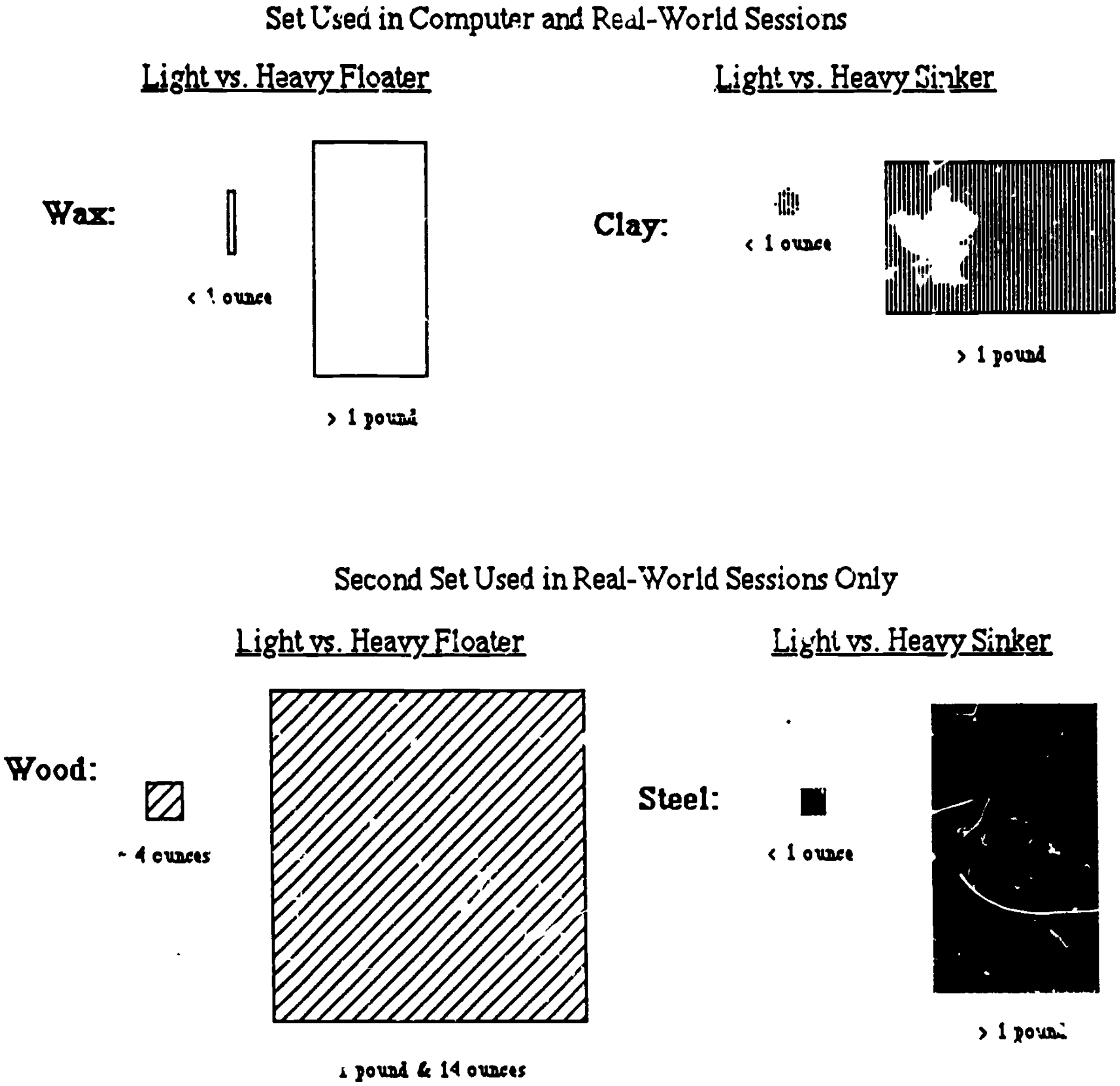
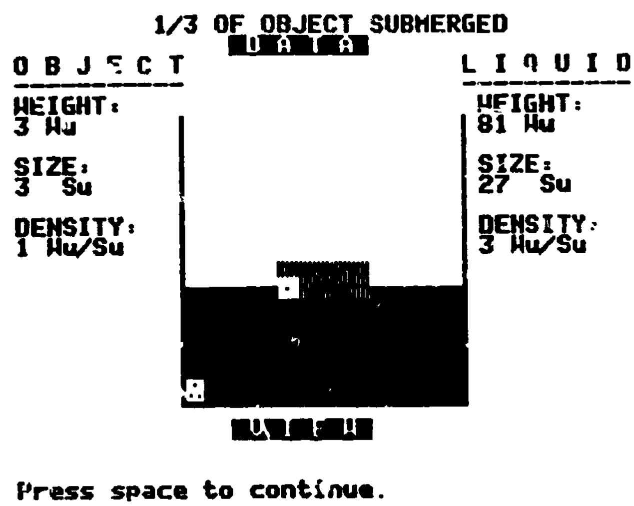


Figure 8. Computer models of a light floater and a heavy floater

a) Model of a light floater.



b) Model of a heavy floater.

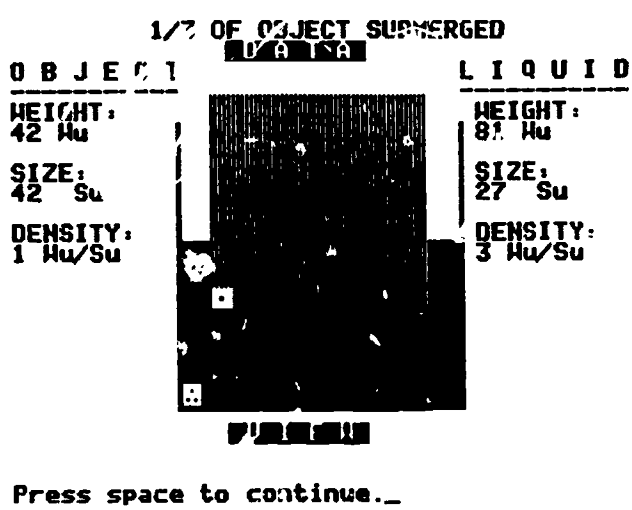
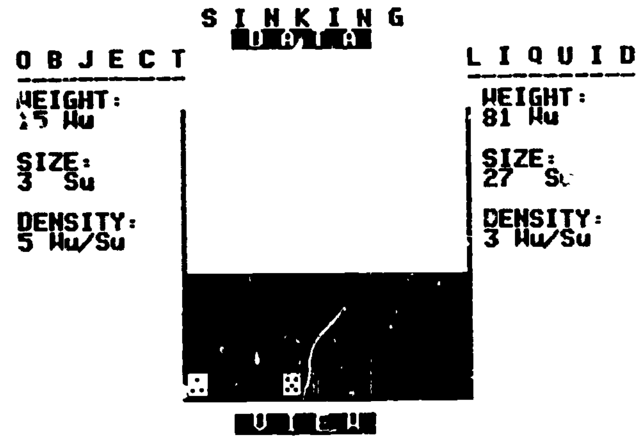


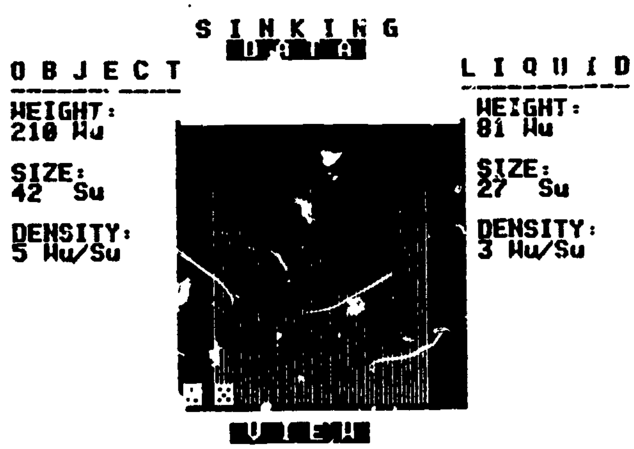
Figure 9. Computer models of light sinker and heavy sinker.

a) Model of light sinker.



Press space to continue.

b) Model of heavy sinker.



Press space to continue.

Figure 10. Real-world materials used in sinking and floating experiments, (Part 2): sets of objects of identical weight varying in kind of material.

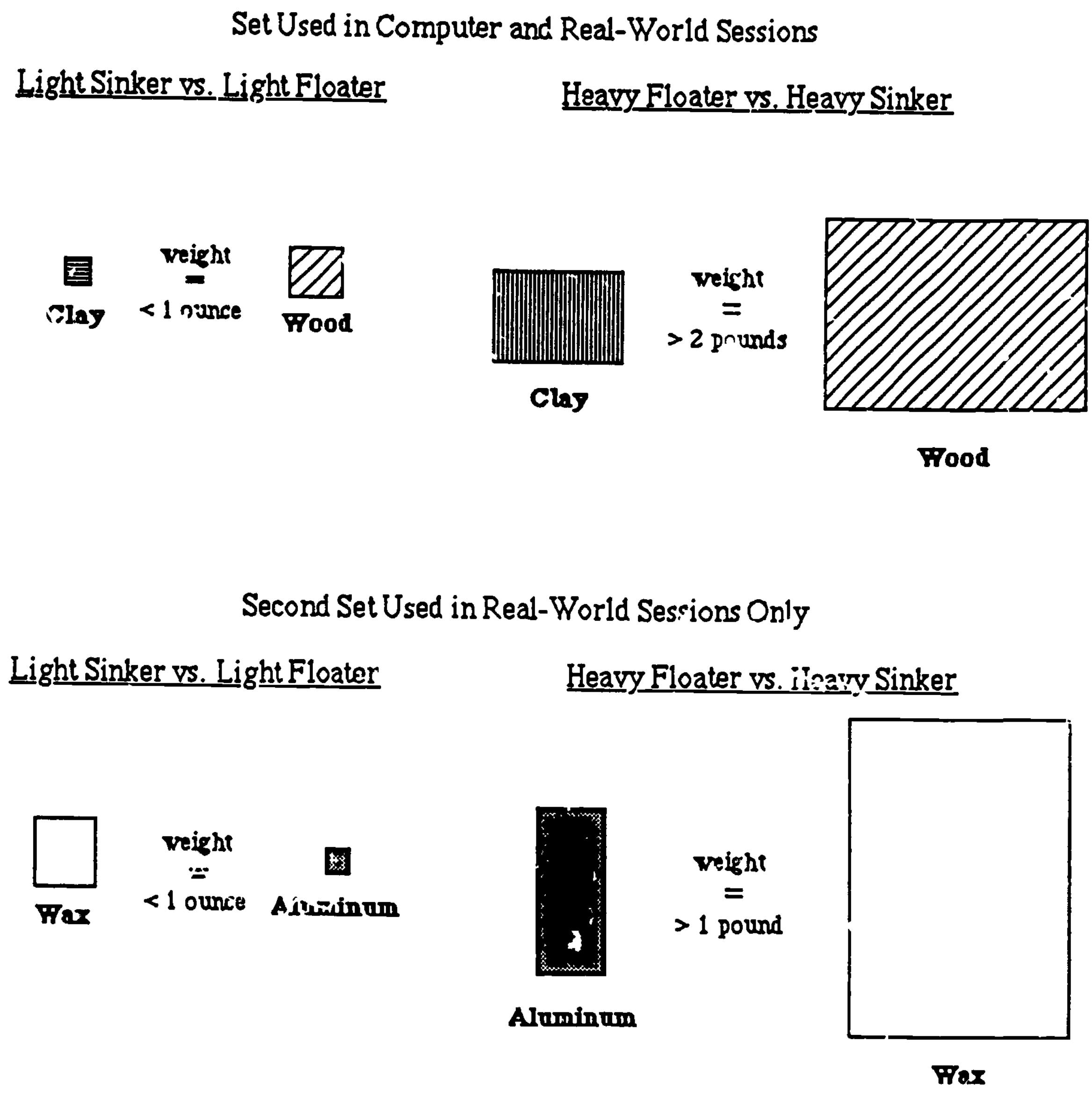
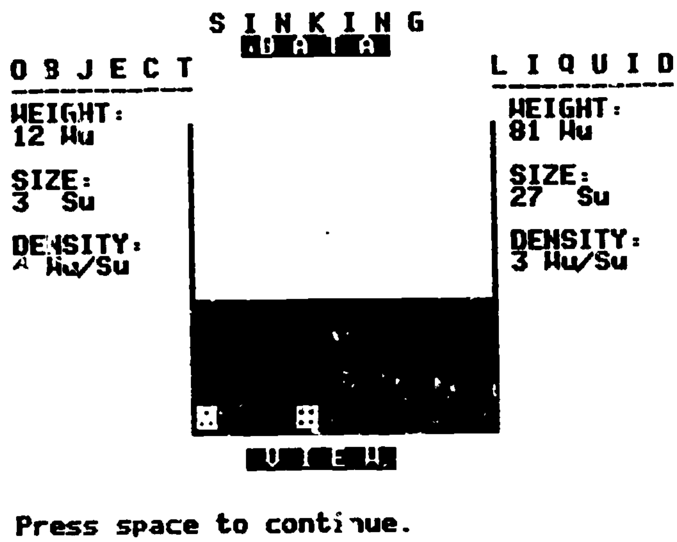


Figure 11. Computer models of a light sinker and a light floater.

a) Model of a light sinker.



b) Model of a light floater.

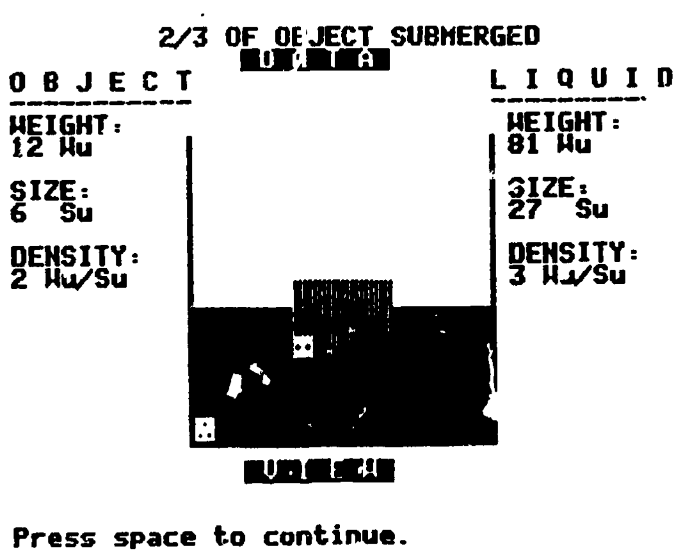
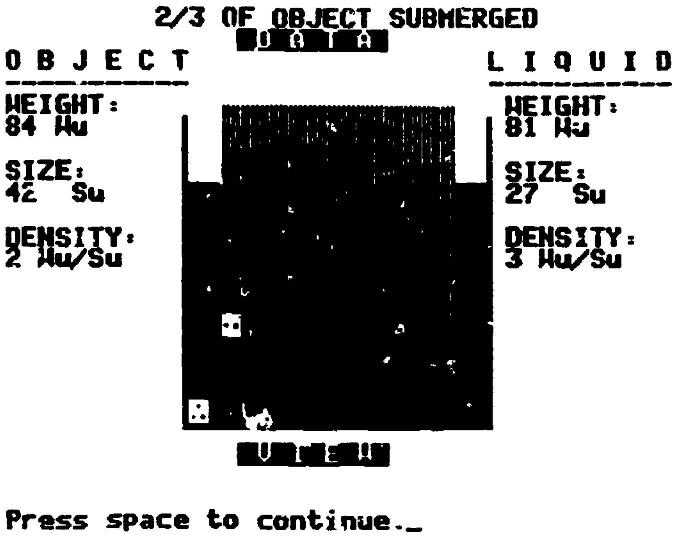


Figure 12. Computer models of a heavy floater anda heavy sinker.

a) Model of a heavy floater.



b) Model of a heavy sinker.

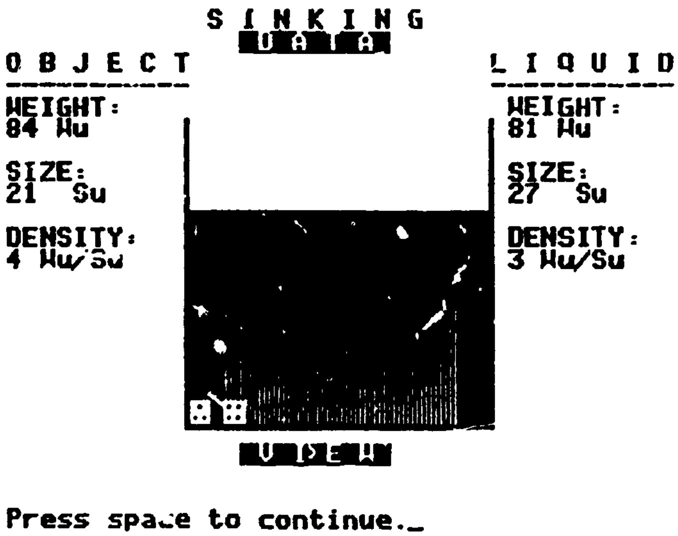
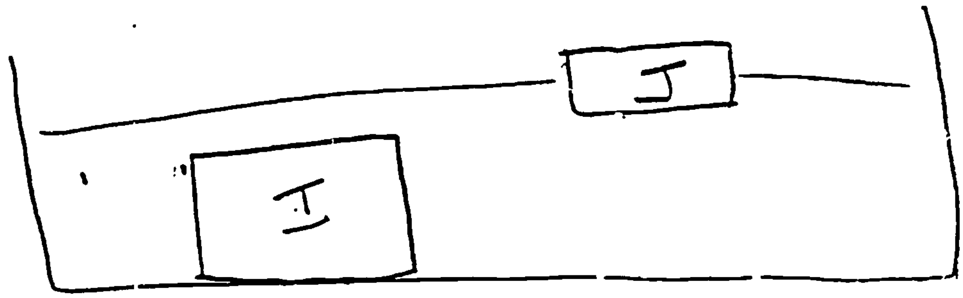
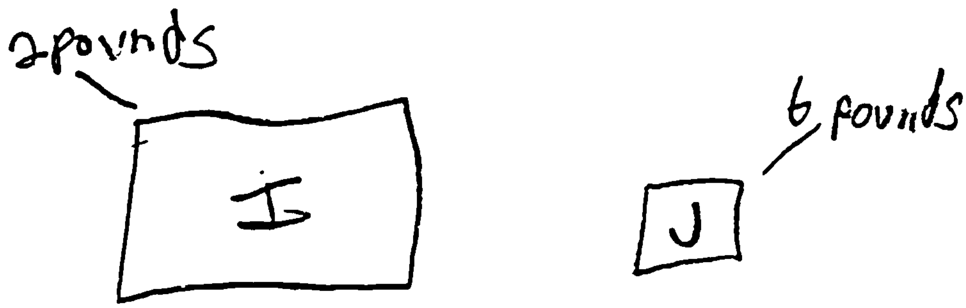


Figure 13. Examples of the types of models drawn by subjects to illustrate their interpretation of a large floating object and a small sunken object equal in weight.

a) Figurative model. (No explanation).



b) Figurative model. (Alternate explanation (weight).



c) Hollow-full model. (Alternate explanation).

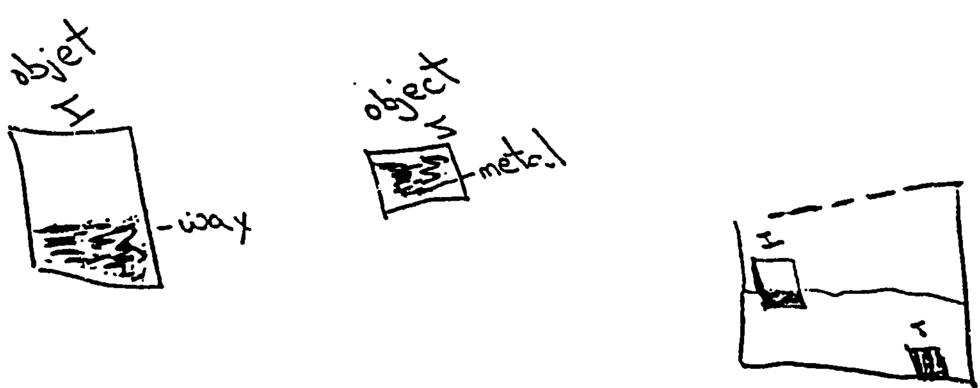
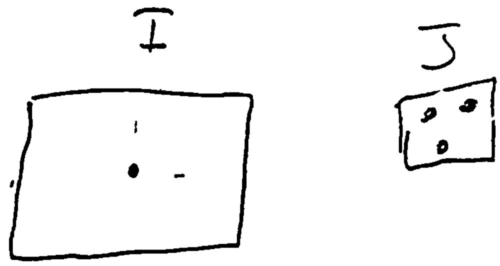
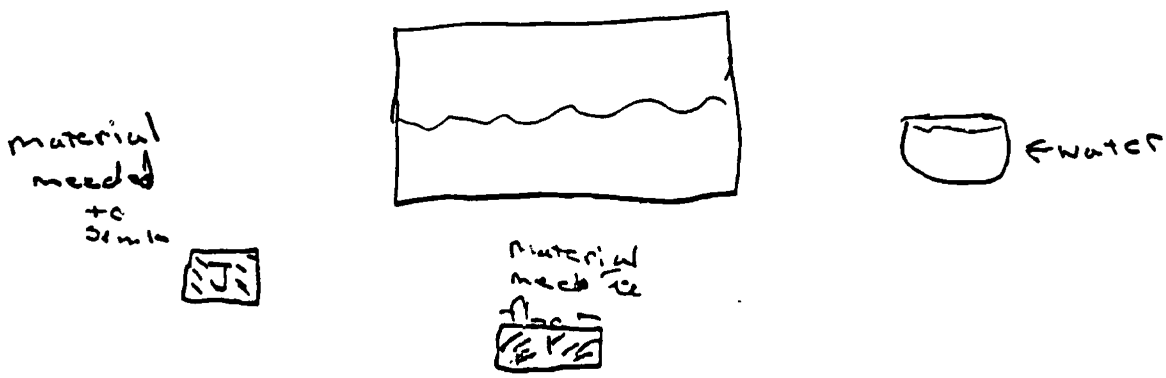


Figure 13. (continued)

d) Computer model. (Transitional explanation).



e) Figurative model. (Explanation based on material kind).



f) Figurative model. (Explanation based on heaviness of kind of material).

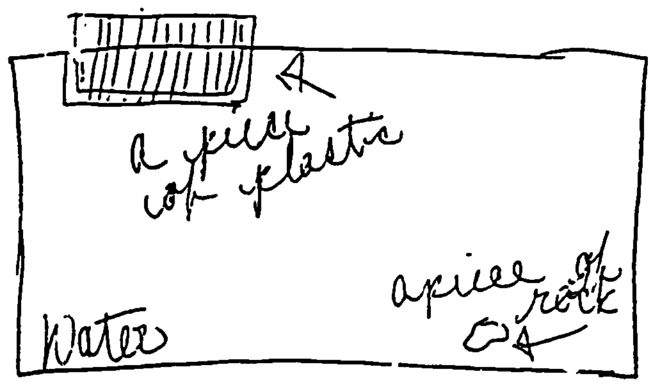
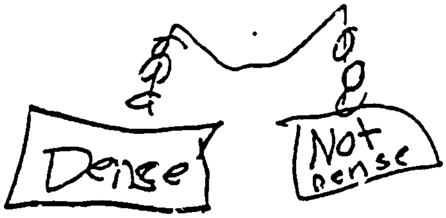
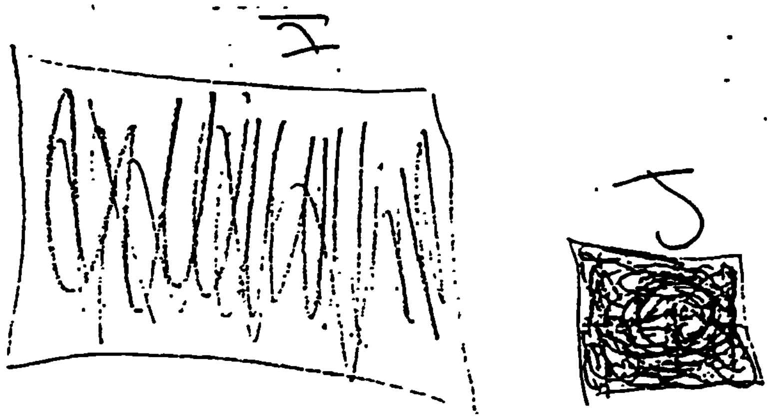


Figure 13. (continued)

g) Figurative model. (Explanation based on general density).



h) Shading model. (Explanation based on density relative to the object).



i) Particulate model. (Explanation based on density relative to the object).

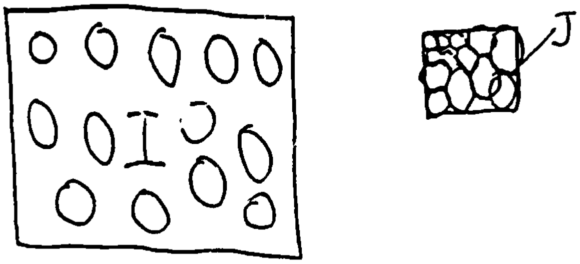
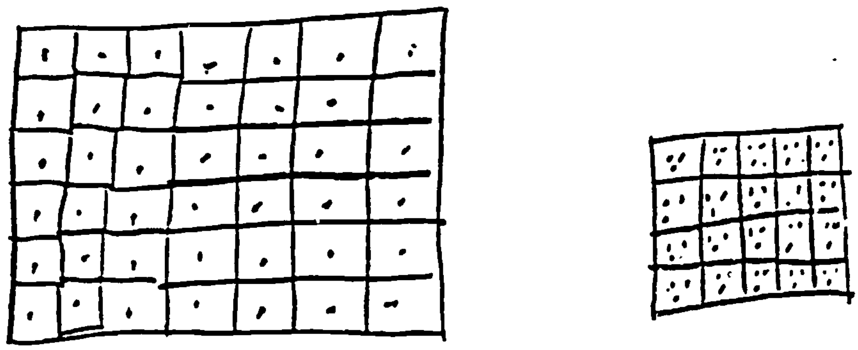
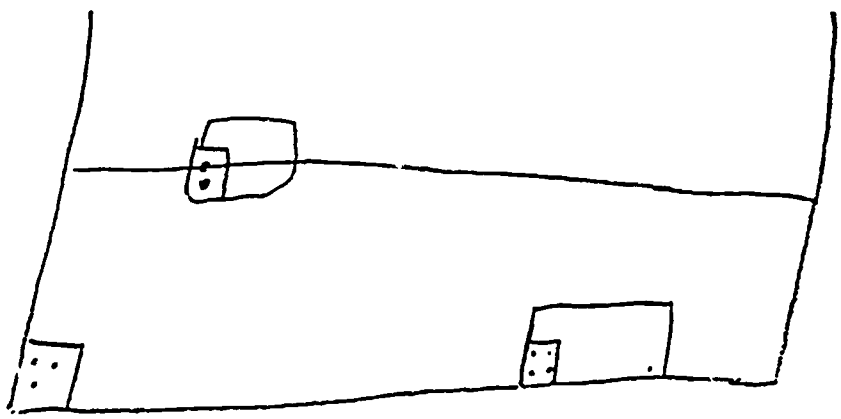


Figure 13. (continued)

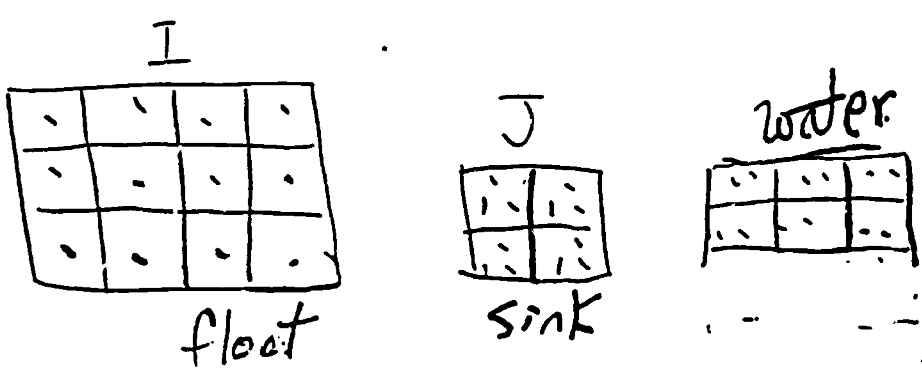
j) Computer model. (Explanation based on density relative to the object).



k) Computer model. (Explanation based on density relative to liquid).



l) Computer model. (Explanation based on density relative to liquid).



APPENDIX B

Script for the introduction to density

INTRODUCTION TO DENSITY
(using Weight & Density program)

Introduction to the session

We have here a computer program that lets us make models of objects which show their size, their weight and the kind of material they are made of. We will use this computer program to help us understand the difference between the weight & the density of these steel and aluminum objects.

1. Making models of equal size Al & STeel cylinders

Pose problem. {HAND EQUAL SIZE ST & AL CYLINDERS}.

Here is a steel rod and an aluminum rod. How can these two objects weigh such different amounts when they are the same size?

We will use the computer to give us a way of thinking about the difference between steel & AL. We will make a model of this AL rod and this steel rod that shows they are the same size but weigh different amounts. Let's first see how the building program works.

Explain symbol of building block.

{BUILD}. In the program, we have different materials to choose from. We use different colors to stand for different kinds of materials. The building blocks are all the same size but they have a different number of dots. This is a way of showing that some materials are denser than others, that is, they have more weight crowded into the same amount of space. {SHOW CUBES MADE OF DIFFERENT MATERIALS}.

In this model, we use dots to show how much something weighs; so one unit of blue material with 5 dots has 5 times more weight in it than one unit of this green material which has only 1 dot in it. In other words, the blue material is very dense when compared to the green material. Now let's think about the steel & AL pieces that we want to model.

Steel as the denser material

Which is the denser material, steel or AL? ________ To find out, we need to compare a unit of steel with a unit of AL.

Let's look at this AL cube and this ST cube. {BALANCE SCALF}. Which one weighs more? ________ Both cubes are the same size but the steel cube has more weight packed into it so we know that steel is a denser material than aluminum. In other words. steel has more wt packed into a same-size unit than AL does.

We need to show this in our model by choosing a denser kind of material for the steel rod. Which materials could represent steel & AL? ______________ {REPEAT if S does not choose denser material for the steel}.

Establish 1:3 ratio between steel and Al

Good. Now, we need to find out just how much denser steel is than Al. How much more weight does the steel cube have packed inside than the AL cube? _________

One way of finding out is to see how many AL cubes it takes to balance with one steel cube.________ {BALANCE SCALE: 3 AL cubes vs 1 ST cube}.

So it takes 3 AL cubes to balance with one steel cube. In other words, one steel cube has 3 more times weight packed into it than one AL cube does. Another way of describing this difference between steel and aluminum is to say that the steel is 3 times denser than AL.

Build model for steel & AL rods

Which materials could we use to show that the steel cube has 3 times more weight in it than the AL cube? _________ {REPEAT explanation if S does not choose matching building blocks in 1:3 ratio}

PUT UP WHITE cube in right window and GREEN cube in left window.

Good, now we have a model of this AL cube and this ST cube. The model is showing that the cubes are the same size but one is made of a denser material since it has more weight packed into the same amount of space.

Now let's make them bigger to have a model of the ST and AL rods. You can change the SIZE by using the ARROW keys. We won't measure the size exactly but simply show how these bigger pieces are made up of a lot of smaller parts of the same material. {GUIDE S in making object equal in size to model of AL}.Good.

Explain data function and symbols for Size, Weight & Density

This computer program can also describe the objects if we ask for DATA which means information. {PUT UP DATA for SIZE, WEIGHT and DENSITY.}

SIZE is how much space an object takes up {show small & big cylinder}; this object is bigger in size than this one. In the computer model, we measure SIZE by the number of squares. How many SIZE units are there in the object you built? _______ Good.

WEIGHT is how much the whole object weighs. With real objects, we can feel them or use scales like these to find out how much an object weighs. In the computer model, we measure WEIGHT by the total number of dots in the object. How many WEIGHT units are there in this object? _____ Good.

DENSITY means how crowded the WEIGHT is in a given SIZE unit. With real objects, we can compare two same-size pieces; if one is heavier, then it is made of a denser material. In the computer model, we measure DENSITY by the number of WEIGHT units packed into one SIZE unit, as shown by the number of dots in a square. What is the density of this material? _________ So this object has a density of 1 WEIGHT unit per SIZE unit.

<u>Compare the data for the two models</u>

Good. Now let's get DATA for this model of the ST rod and compare the two.

What is the model showing about their SIZE? _________ They're both the <u>same size</u> because they have the same number of SIZE units.

And what is the model showing about their WEIGHT? The model of the steel rod has more WEIGHT units than the model of the AL rod, in the same way that the steel rod weighs more than the AL rod when we pick it up.

What is the model showing about the DENSITY of the material? ___________ In the model of the steel rod, there are more WEIGHT units in each SIZE unit than in the model of AL.

What is this model showing? Same-size objects can weigh different amounts when they are made of different kinds of materials, materials which have different densities. Steel is a denser material, therefore each unit of steel weighs more than each unit of AL. If each unit of steel weighs more than each unit of AL, the steel one will always come out weighing more when the rods are the same size. That's why the steel rod comes out weighing more than the AL rod even though they are the same size.

<u>Comment on the function of the computer model</u>

We thought this model of dots and squares could help us remember the difference between weight & density. When we look at real objects, we don't see any squares or dots. In fact, real objects look more like this. {HIDE}. Even though there are no squares or dots in real objects, we can imagine that this AL rod is made of a number of these AL cubes and this ST rod is made up of a number of these ST cubes. Thus we can try to remember that weight means how much the whole thing weighs but that density means how crowded the weight is in each part. {VIEW}.

2. **Puzzle of Steel & AL rods of equal weight**

So far, we have seen that when the steel and AL pieces are the <u>same size</u>, the steel piece weighs more because it is made of a denser material. {SHOW EQUAL WT STEEL & AL CYLINDERS}. Now here is an AL rod that weighs the same as this ST rod. How can that be?____________

Adjust models to show equal weights

Let's use our computer model to help us understand this. How would you change the model to show that the AL rod weighs the same as the STeel rod. {GUIDE S IN MAKING AL BIGGER OR ST SMALLER}.

Good. What is the model showing? That you can have two objects that weigh the same even though they are different sizes when they are made of materials with different densities. When we look at these two models, we can see that AL is a less dense material since it only has one WEIGHT unit in each SIZE unit. So it takes more AL to come out weighing the same as a steel rod. {REPEAT EXPLANATION IF NECESSARY}.

3. **Review meaning of density**

Let's review what we have learned about the difference between weight & density. What do we mean by the density of a material? _______ That there is more weight crowded into the same-size space. For example, steel is a denser material than AL because each unit of steel weighs more than a unit of AL whereas weight means how much weight there is in the whole object.

Pick an Al piece from this set that weighs more than a steel piece? _____ Good. Now, which one is made of a denser material? ____ Right, the steel, because it has more weight in each unit. {SHOW WITH MODEL}. Let's see what happens when we bring our model of steel down to one unit. The weight changes but the density of the material is still the same, just like this steel cube is still 3 times denser than the big AL rod.

Review procedures to infer density of real objects

Before we end this session, let's remember how to tell if an object is made of a denser material. How did we find out that steel was a denser material than AL? We compared two pieces that were the same size, like these two cubes or these two rods. The steel rod weighs more than the AL rod even though it's the same size so it has to have more weight packed inside the same amount of space.

Would it be fair to compare two pieces that are different sizes to find out which one is denser? _______ No, because we could not figure out how much weight is packed into one unit.

Another way that we know steel is made of a denser material than AL is by comparing two pieces that weigh the same; (equal weight ST & AL on POSTAGE) the steel & al rods weigh the same but the steel one is smaller; then we know that the steel one is denser bec it has less space for all that weight. In other words, the weight is more crowded in the steel units.

Questions ....

Comments on program ....

APPENDIX C

Script for the model-guided observation of sinking and floating phenomena

SINKING AND FLOATING EXPERIMENTS
WITH THE COMPUTER MODEL

General introduction

For students having worked with the Weight & Density program: The last time, we made some models of steel and aluminum cylinders with a computer program to help us understand the difference between weight & density. Today, we'll so some sinking and floating activities using the computer and some real objects and we'll think about the best way to predict if something will sink or float. Let me start by showing you how this computer program works.

For students for whom this is the first session: Thank you for pa-ticipating in this project. Meeting with the students in your class will help us plan some interesting science activities for Grades 6 & 7. We are working on two topics. One is to find ways of understanding the difference between weight & density; the second is to make up some sinking and floating experiments. I'll be meeting with you two times; I'll show you some software and some materials that we have developed and ask you some questions. I'm interested in what you have to say about these topics and it doesn't matter if you haven't learned this in school yet. However, I would like you to look carefully at what I'll be showing you and let me know what you think. Today we'll do some sinking and floating activities using the computer and these materials.

Introduction to the Sink the Raft program

We have here a computer program that lets us do sinking and floating experiments while giving us some information about the size, the weight and the density of objects and liquids. Let's first build an object. OBJECT. We have different materials to choose from. These dots stand for how much weight is in one unit of a material. Hence the blue material is the densest because it has more weight units in a building block and the green material is the least dense because it only has one weight unit in a building block.

WOOD & STEEL CUBES. To understand what these building blocks stand for, take this wood cube and this steel cube that are the same size; the steel cube weighs more because it has more weight packed into each part than the wood does; therefore, we know that steel is a denser material than wood. {OBJECT} Let's build an object made of this green material for now.

We also need a liquid. Again we have different materials to choose from according to how dense the liquid might be. Let's imagine you had a cup of water and a cup of honey. The cup of honey would weigh more because it is a denser kind of liquid, meaning it has more weight crowded into each part than the water does. These building blocks are a way of showing how much weight is packed into one unit of a liquid. Let's say the white liquid stands for water and use that for now.

{BUILD}. We see that this object floats in this liquid.

When we ask for DATA, we can have the program describe the object. DATA FOR OBJECT. We can get information on the size, the weight & the density of the object we built. Let's review what this data means.

This object has SIZE units. What do we mean by size? It's the amount of space an object takes up, in other words, whether it is big or small. We can compare the size of real objects by measuring them or by seeing which one is bigger. In this computer model we can tell the size by the number of SIZE units in the object. VIEW, SCAN. Underneath, the object is made up of these same-size squares that stand for SIZE units. So when we ask for the size, the computer will count how many SIZE units or squares are in the object.

This object has WEIGHT units. What do we mean by weight? It's how much something weighs, in other words, whether it is light or heavy. We can compare the weight of real objects by feeling which one is heavier or by weighing them on a scale like this postage scale or this balance scale (DEMO). In this computer model, we can tell the WEIGHT of an object by the total number of WEIGHT units in the object. So when we ask for the weight, the computer will count up how many WEIGHT units or dots there are in the whole object.

You notice that this object also has a certain number of WEIGHT units in each SIZE unit and that is what we call DENSITY. What do we mean by DENSITY? It's the amount of weight crowded into one unit of that material. We can compare the DENSITY of real materials by taking two pieces that are the same size; the one that has more weight packed into the same space is made of a denser material. In the computer model, we can tell the DENSITY of a material by the number of WEIGHT units in one SIZE unit. When we ask for the density, the computer will tell us how many WEIGHT units or dots there are in one SIZE unit or building block of that material. Each material has a different number of dots in a square but the number of dots in a square is always the same for a given material.

DATA FOR LIQUID. We can also ask the computer to give us information about the SIZE, WEIGHT or DENSITY of the liquid in the same way that it does for objects. VIEW, SCAN. This liquid is made up of x Su (that's how many squares there are), it weighs x Wu (that's how many dots there are altogether) and has a density of x Wu/Su (that's how many dots are in each building block).

VIEW BOTH. We can also view inside the object and the liquid at the same time to remind us of the kind of building blocks that each is made of.

OBJECT OUT. We'll always be using water so this white liquid will stay the same but we will build objects of different sizes and made of different materials. These arrow keys allow us to change the size of objects. CHANGE SIZE TO SMALLEST. Now we are ready to begin the activities.

Sinking and floating phenomena

1. Variations in weight of the same material

a) MAKING MODELS OF LIGHT & HEAVY WAX (F)

(HAND S SMALL & LARGE WAX). Here is a small piece of wax and a big piece of wax. Would you say the small wax is light and the big wax is heavy in comparison? (USE SCALE IF NECESSARY)

Do you think the small piece of wax will S or F? _____ PUT IN WATER

Do you think the big piece of wax will S or F? _______ PUT IN WATER

Is there anything about these two pieces of wax that suggests how come they are both floating even though one is light and the other one is heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

Good. Now let's use the computer program to make models of a light object and of a heavy object made of the same material that both float to see if that will give us any other idea about what is happening.

MENU. What kind of material will we use for the wax? We are using a liquid with 3 weight units in one size unit for water so let's find out if a unit of wax has more or less weight in it.

WAX SAMPLER AND SAME-SIZE CONTAINER FOR WATER

The way to find that out is to compare an equal amount of wax and an equal amount of water. (BALANCE SCALE). The same amount of wax weighs less, therefore it is a less dense material than water; in other words, it has less weight packed into each part. So we need a material that has a density of less than three weight units in a size unit. This green material has only one weight unit in each part so it could stand for wax.

This piece of green material is small and light like the small piece of wax. EXPERIMENT - Also, it floats in the white liquid like the wax floats in water so it seems to be a pretty good model. VIEW BOTH. We can also remember what the density of the object and the liquid are by looking at how much weight is in a building block.

OBJECT OUT. This small object doesn't weigh much. Let's see what happens when we make it as big as possible to model this other piece of wax. (CHANGE SIZE.)

When we made it bigger, did the weight change? Yes, it increased. Did the density change? No, there is still the same amount of weight in each unit. EXP, VIEW. So this model of the heavier piece of wax is also floating and we can see that it is still made of the same building blocks.

Now that we have made models of these two pieces of wax on the computer, is there anything else about these two objects that suggests how come they are both floating even though one is light and the other one is heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

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b) <u>MAKING MODELS OF LIGHT & HEAVY CLAY</u> (S)

(HAND SMALL & LARGE CLAY). Here is a small piece of clay and a big piece of clay. Would you say the small piece is light and the big piece is heavy in comparison to each other? (USE SCALE IF NECESSARY)

Do you think the big piece of clay will S or F? ______ PUT IN WATER

Do you think the small piece of clay will S or F? _____ PUT IN WATER

Is there anything about these two pieces of clay that suggests how come they are both sinking even though one is light and the other one is heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

Good. Now let's use the computer program to make a model of these two pieces of clay that will show their size, their weight & their density to see if that will give us any other idea about what is happening.

(MENU). What kind of material will we use for the clay? We are using a liquid with 3 weight units in one size unit for water so let's find out if a unit of clay has more or less weight in it than this liquid does.

CLAY SAMPLER AND SAME-SIZE CONTAINER FOR WATER

The way to find that out is to compare an equal amount of clay with an equal amount of water. (BALANCE SCALE). The same amount of clay weighs more, therefore it is a denser material than water; in other words, it has more weight packed into each part. So we need a material that has more than three weight units in a size unit. This orange material has four weight units in each part so it could stand for clay. CHANGE MATERIAL

This piece of orange material is big and heavy like the big piece of clay. EXPERIMENT - Also, it sinks in the white liquid like the clay sinks in water so it seems to be a pretty good model. VIEW BOTH. Again we can remember what the density of the object and the liquid are by looking at how much weight is in a building block.

OBJECT OUT. This big object weighs a lot. Let's see what happens when we make it as small as possible to model this other piece of clay. (CHANGE SIZE.)

When we made it smaller, did the weight change? Yes, it decreased. Did the density change? No, there is still the same amount of weight in each unit. EXPERIMENT, ' EW. So this model of the smaller piece of clay is sinking also, and we can see that it is still made of the same building blocks.

Now that we have made models of these two pieces of clay on the computer, is there anything else about these two objects that suggests how come they are both sinking even though one is light and the other one is heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

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2. <u>Same weight leads to two different outcomes</u>

a) <u>MAKING MODELS OF EQUALLY LIGHT WOOD</u> (F) <u>AND CLAY</u> (S)

HAND SMALL WOOD ROD & SMALL CLAY. Here is a small piece of wood and a small piece of clay that are both equally light (BALANCE).

Do you think the piece of <u>wood</u> will S or F? __________

What about the piece of <u>clay</u>? Will it S or F? __________

PUT BOTH IN WATER

Is there anything about these two objects that suggests how come the wood floats and the clay sinks even though they are both very light?

NO IDEA - WEIGHT - MATERIAL - DENSITY

Let's use the computer program to make a model of two things that are equally light but where one is floating and the other one is sinking, like the SMALL WOOD and the SMALL CLAY.

We already have on the screen a model of a small piece of clay; it is light and it has sunk in water. To choose a material for the wood, we need to find out if wood is denser or less dense than clay.

When we compare two equal size pieces of wood & clay (small rods), we see that the wood weighs less. So wood is a less dense material than clay; in other words, it has less weight packed in each part. Therefore, we need a material that has a density of less than 4 weight units in each part for the wood.

MENU. In our model, the water has a density of 3 Wu/Su and the wax had a density of 1 Wu/Su. Let's use the purple material with a density of 2 Wu/Su and see if that will work. CHANGE MATERIAL.

To make it come out equal in weight to the piece of clay, we need to make it a little bigger. {CHANGE SIZE}. So this object is a good model of the small wood; it is as light as the clay and it is floating.

Now that we have made models of the piece of wood and of the piece of clay on the computer, is there anything else about these two objects that suggests how come the piece of clay is sinking and the piece of wood is floating even though they both weigh very little?

NO IDEA - WEIGHT - MATERIAL - DENSITY

____
____

b) <u>MAKING MODELS OF EQUALLY HEAVY WOOD</u> (F) <u>AND CLAY</u> (S)

HAND BIG WOOD AND BIG CLAY. Here is a big piece of wood and a big piece of clay that are both rather heavy. {POSTAGE SCALE}.

Do you think the piece of <u>wood</u> will S or F? ________

What about the piece of <u>clay</u>? Will it S or F? ________

PUT BOTH IN WATER

Is there anything about these two objects that suggests how come the wood floats and the clay sinks even though they are both rather heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

____

Let's make a model of two things that are equally heavy where one is floating and the other one is sinking, like the BIG WOOD and the BIG CLAY.

How could we change our model to represent this bigger piece of wood? OBJECT OUT. CHANGE SIZE. EXPERIMENT. So this seems to be a good model of the big piece of wood that is floating in water. VIEW. And we can see the number of weight units in each building block.

Now to make a model of the big piece of clay ,we need to change to the material with a density of 4 WEIGHT units in each SIZE unit. CHANGE MATERIAL. We also want it to weigh the same as the big wood, so we can make the weight go down by making it smaller. CHANGE SIZE. EXPERIMENT.

So this seems to be a good model of the big piece of clay; it now weighs as much as the wood and it is sinking. VIEW. And we can see what is the density of the material by looking at the number of weight units in each building block.

Now that we have made models of the piece of wood and the piece of clay on the computer, is there anything else about these two objects that suggests how come the wood floats and the clay sinks even though they are both rather heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

CONCLUSION

To wrap things up, could you tell me what is a good way to predict if something will sink or float based on the activities we did?

NO IDEA - WEIGHT - MATERIAL - DENSITY

APPENDIX D

Script for the observation of sinking and floating phenomena without the computer model

SINKING AND FLOATING EXPERIMENTS
WITHOUT THE COMPUTER MODEL

General introduction

For subjects who have already worked with the Weight & Density program: The last time we met, we made models of some steel and aluminum cylinders with the computer program to help us understand the difference between weight & density. Today we'll do some sinking and floating activites.

For subjects for whom this is the first session: Thank you for participating in this project. Meeting with the students in your class will help us plan some interesting science activities for Grades 6 & 7. We are working on two topics. One is to find ways of understanding the difference between weight & density; the second is to make up some sinking and floating experiments. I'll be meeting with you two times; I'll show you some software and some materials that we have developed and ask you some questions. Remember that we're interested in what you have to say and it doesn't matter if you haven't learned this in school yet. However, I would like you to look carefully at what I'll be showing you and to let me know what you think. Today we'll do some sinking and floating activities with these materials and we'll use the computer the next time.

Introduction to variables

We'll be doing some sinking and floating experiments and thinking about ways to predict whether something will sink or float. We'll be using objects of different sizes and made of different materials and we'll see what information we have about the size, the weight and the density of these objects.

What do we mean by SIZE? It's the amount of space an object takes up, in other words whether it is big or small. How can we compare the SIZE of real objects? By measuring them or by seeing which one is bigger.

What do we mean by WEIGHT? It's how much something weighs, in other words whether it is light or heavy. How can we compare the WEIGHT of real objects? By weighing them on a postage scale or a balance scale (DEMO) or by feeling which one is heavier.

What do we mean by DENSITY? Well, another difference between objects is the material they are made of. Some materials are denser than others, meaning that they have more weight packed into the same amount of space. How can we compare the DENSITY of real materials? We compare two pieces that are the same size. If one is heavier, we can know that it is made of a denser material because it has more weight packed into the same amount of space. (WOOD & STEEL CUBE) Take this wood cube and this steel cube for instance; the steel cube weighs more because it has more weight packed into the same space than the wood does; one way of describing this difference is to say that steel is a denser material.

Liquids too come in different amounts or sizes, different weights and different densities. To help us understand that, let's imagine you had a cup of water and a cup of honey. The cup of honey would weigh more because it is a denser kind of liquid, meaning it has more weight crowded into the same amount of space than water does.

Sinking and floating experiments

1. Variations in weight do not affect S/F outcome

a) EXPERIMENT WITH LIGHT & HEAVY WAX (F)

(HAND SMALL & LARGE WAX). Here is a small piece of wax and a big piece of wax. Would you say the small wax is light and the big wax is heavy in comparison to each other? (USE SCALE IF NECESSARY)

Do you think the small piece of wax will S or F? _____ PUT IN WATER

Do you think the big piece of wax will S or F? _______ PUT IN WATER

Is there anything about these two pieces of wax that suggests how come they are both floating even though one is light and the other one is heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

Good. Now let's get see what information we have available about these two pieces of wax.

We know something about their size (SMALL, LARGE).

We also know something about how much they weigh (SCALE, STATE WEIGHTS); the larger piece of wax weighs more.

We already know these two objects are made of the same material. Another thing we can find out is the density of wax or how much weight is in one unit of wax when compared to water.

WAX SAMPLER AND SAME-SIZE CONTAINER FOR WATER

The way to find that out is to compare an equal amount of wax and an equal amount of water like this. (BALANCE SCALE). The same amount of wax weighs less so wax is a less dense material than water because it has less weight in each unit than water does.

Now that we have some information about these two pieces of wax, is there anything else about these objects that suggests how come they are both floating even though one is light and the other one is heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

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b. PREDICTION WITH LIGHT & HEAVY WOOD (F)

(HAND SMALL & LARGE WOOD). Here is a small piece of wood and a big piece of wood. Would you say the small wood is light and the big wood is heavy in comparison to each other? (USE SCALE IF NECESSARY)

Do you think the small piece of wood will S or F? ____ PUT IN WATER

What about the big piece of wood? Will it S or F? ____ PUT IN WATER

Is there anything about these two pieces of wood that suggests how come they are both floating even though one is light and the other one is heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

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c) EXPERIMENT WITH LIGHT & HEAVY CLAY (S)

(HAND SMALL LARGE CLAY) Here is a small piece of clay and a big piece of clay. Would you say the small wax is light and the big wax is heavy in comparison to each other? (USE SCALE IF NECESSARY)

Do you think the big piece of clay will S or F? ______ PUT IN WATER

Do you think the small piece of clay will S or F? ______ PUT IN WATER

Is there anything about these two pieces of clay that suggests how come they are both sinking even though one is light and the other is heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

Good. Now let's see what information we have available about these two pieces of clay.

We know something about their <u>size</u> (SMALL, LARGE).

We also know something about how much they <u>weigh</u> (SCALE, STATE WEIGHTS); the larger piece of clay weighs more.

We already know that these two objects are made of the same <u>material</u>. Another thing we can find out is the <u>density</u> of clay or how much weight is in one unit of wax when compared to water.

CLAY SAMPLER AND SAME-SIZE CONTAINER FOR WATER

The way to find that out is to compare an equal amount of clay with an equal amount of water like this. (BALANCE SCALE). The same amount of clay weighs more, so clay is a material that has more weight in each unit than water does.

Now that we have some information about these two pieces of clay, is there anything else about these objects that suggests how come they are both sinking even though one is light and the other one is heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

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d) PREDICTION WITH LIGHT & HEAVY STEEL (S)

HAND SMALL & LARGE STEEL. Here is a small piece of steel and a big piece of steel. Would you say the small steel is light and the big steel is heavy in comparison to each other? (USE SCALE IF NECESSARY)

Do you think the big piece of steel will S or F? ______ PUT IN WATER

What about the small piece of steel? Will it S or F? ___ PUT IN WATER

Is there anything about these two pieces of steel that suggests how come they are both sinking even though one is light and the other one is heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

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2. The same weight leads to two different outcomes

a) EXPERIMENT WITH EQUALLY LIGHT WOOD (F) & CLAY (S)

HAND SMALL WOOD & SMALL CLAY. Here is a small piece of wood and a small piece of clay that are both equally light. (BALANCE)

Do you think the piece of wood will S or F? _________

What about the piece of clay? Will it S or F? _________

PUT BOTH IN WATER

Is there anything about these two objects that suggests how come the wood floats and the clay sinks even though they are both very light?

NO IDEA - WEIGHT - MATERIAL - DENSITY

Let's see what kind of information we have available on this piece of wood and this piece of clay.

We know something about their <u>size</u>. They are both small but we notice that the piece of clay is smaller than the piece of wood.

We also know something about their <u>weight</u>. They are both very light and they weigh the same. {SCALE}.

We already know they are made of two different <u>materials</u>. We can also find out something about the <u>density</u> of these materials. When we compare two equal-size pieces of wood and clay [SMALL RODS] we find that the same amount of clay weighs more. Hence we can say that clay is a denser material than wood because it has more weight units in one size unit than the wood does. That's how come the piece of clay weighs the same as the piece of wood even though it is smaller.

Now that we have some information about the piece of wood and the piece of clay, is there anything else about these objects that suggests how come the piece of wood floats and the piece of clay sinks even though they both weigh very little?

NO IDEA - WEIGHT - MATERIAL - DENSITY

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b) <u>EXPERIMENT WITH EQUALLY HEAVY WOOD</u> (F) <u>& CLAY</u> (S)

{HAND BIG WOOD AND BIG CLAY}. Here is a big piece of wood and a big piece of clay that are both equally heavy {SCALE}.

Do you think the piece of <u>wood</u> will S or F? _________

What about the piece of <u>clay</u>? Will it S or F? _________

PUT BOTH IN WATER

Is there anything about these two objects that suggests how come the wood floats and the clay sinks even though they are both rather heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

Let's review the information we have available on these two objects.

We know something about their size. They are both rather big but we notice that the piece of wood is bigger than the piece of clay.

We also know something about their weight. The piece of wood and the piece of clay are both rather heavy and they weigh the same. {SCALE}.

We already know they are made of two different materials. We can also find out something about the density of these materials. When we compared two equal-size piecesof wood and clay [SMALL RODS] , we found out that the same amount of clay weighs more. Hence we can say that clay is a denser material than wood because it has more weight units in one size unit than the wood does. That's how come the piece of clay weighs the same as the piece of wooa even though the clay is smaller.

Now that we have some information about the piece of wood and the piece of clay, is there anything else about these objects that suggests how come the wood floats and the clay sinks even though they are both rather heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

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c) <u>PREDICTION WITH EQUALLY LIGHT WAX</u> (F) <u>& ALUMINUM</u> (S)

HAND SMALL WAX & SMALL AL. Here is a small piece of wax and a small piece of AL that are both equally light? (BALANCE)

Do you think the piece of <u>wax</u> will S or F? _________

What about the piece of <u>AL</u>? Will it S or F? _________

PUT BOTH IN WATER

Is there anything about these two objects that suggests how come the wax floats and the AL sinks even though they are both very light?

NO IDEA - WEIGHT - MATERIAL - DENSITY

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d) <u>PREDICTION WITH EQUALLY HEAVY WAX</u> (F) <u>& ALUMINUM</u> (S)

{HAND BIG WAX AND BIG AL}. Here is a big piece of wax and a big piece of Al that are both equally heavy (SCALE).

Do you think the piece of <u>wax</u> will S or F? _________

What about the piece of <u>AL</u>? Will it S or F? _________

PUT BOTH IN WATER

Is there anything about these two objects that suggests how come the wax floats and the AL sinks even though they are both rather heavy?

NO IDEA - WEIGHT - MATERIAL - DENSITY

CONCLUSION

To wrap things up, could you tell me what is a good way to predict if something will sink or float based on the experiments that we just did?

NO IDEA - WEIGHT - MATERIAL - DENSITY

APPENDIX E

Outline of experimental treatments

Treatment Group1

BOTH CONCEPT and MODELLING TOOL AVAILABLE

Session 1- Introduction to the concept of density

GOAL: Articulate the distincti n between weight and density.

METHOD: Make models of objects with the Weight and Density program.

1. Represent steel and aluminum cylinders of equal size.
2. Represent steel and aluminum cylinders of equal weight.
3. Review definition and procedures for inferring density.

Session 2 - Model-guided observation of sinking and floating phenomena

GOAL: Compare weight and density as predictive variables for sinking and floating phenomena with the benefit of an interactive visual model.

METHOD: Observe real-world sinking and floating phenomena and represent the variables with the Sink the Raft program.

1. Variations in weight do not affect the outcome

   i) Light Floater vs Heavy Floater:
   -small wax, large wax: PREDICT, EXPLAIN, MODEL, EXPLAIN

   ii) Heavy Sinker vs Light Sinker :
   -big clay, small clay: PREDICT, EXPLAIN, MODEL, EXPLAIN

2. The same weight leads to different outcomes

   i) Light Floater vs Light Sinker:
   -small wood vs small clay: PREDICT, EXPLAIN, MODEL, EXPLAIN

   ii) Heavy Floater vs Heavy Sinker:
   -big wood vs big clay: PREDICT, EXPLAIN, MODEL, EXPLAIN

Conclusion: Provide a rule to predict sinking and floating phenomena.

Treatment Group 2

MODELLING TOOL AVAILABLE WITHOUT CONCEPT

Session 1 - Model-guided observation of sinking and floating phenomena

GOAL: Compare weight and density as predictive variables in sinking and floating phenomena with the benefit of an interactive visual model.

METHOD: Observe real-world sinking and floating phenomena and represent the variables with the Sink the Raft program.

1. Variations in weight do not affect the outcome

   i) Light Floater vs Heavy Floater:
   -small wax, large wax: PREDICT, EXPLAIN, MODEL, EXPLAIN

   ii) Heavy Sinker vs Light Sinker :
   -big clay, small clay: PREDICT, EXPLAIN, MODEL, EXPLAIN

2. The same weight leads to different outcomes

   i) Light Floater vs Light Sinker:
   -small wood vs small clay: PREDICT, EXPLAIN, MODEL, EXPLAIN

   ii) Heavy Floater vs Heavy Sinker:
   -big wood vs big clay: PREDICT, EXPLAIN, MODEL, EXPLAIN

Conclusion: Provide a rule to predict sinking and floating phenomena.

Session 2- Introduction to the concept of density

GOAL: Articulate the distinction between weight and density.

METHOD: Make models of objects with the Weight and Density program.

1. Represent steel and aluminum cylinders of equal size.
2. Represent steel and aluminum cylinders of equal weight.
3. Review definition and procedures for inferring density.

Treatment Group 3

CONCEPT AVAILABLE WITHOUT MODELLING TOOL

Session 1- Introduction to the concept of density

GOAL: Articulate the distinction between weight and density

METHOD: Make models of objects with the Weight and Density program.

1. Represent steel and aluminum cylinders of equal size.
2. Represent steel and aluminum cylinders of equal weight.
3. Review definition and procedures for inferring density.

Session 2 - Observation of sinking and floating phenomena

GOAL: Compare weight and density as predictive variables for sinking and floating phenomena without the benefit of a model.

METHOD: Observe real-world phenomena, obtain simple measurements of the variables and observe a second instance.

1. Variations in weight do not affect the outcome.

i) Light Floater vs Heavy Floater:
- small wax, large wax: PREDICT, EXPLAIN, MEASURE, EXPLAIN.
- small wood, large wood: PREDICT, EXPLAIN.

ii) Heavy Sinker vs Light Sinker :
- big clay, small clay: PREDICT, EXPLAIN, MEASURE, EXPLAIN.
- big steel, small steel: PREDICT, EXPLAIN.

2. The same weight leads to two different outcomes

i) Light Floater vs Light Sinker:
- small wood, small clay:PREDICT, EXPLAIN, MEASURE, EXPLAIN.
- small wax, small aluminum: PREDICT, EXPLAIN.

ii) Heavy Floater vs Heavy Sinker:
- big wood, big clay : PREDICT, EXPLAIN, MEASURE, EXPLAIN.
- big wax, big aluminum: PREDICT, EXPLAIN.

Conclusion: Provide a rule to predict sinking and floating phenomena.

Treatment Group 4

NEITHER CONCEPT NOR MODELLING TOOL AVAILABLE

Session 1 - Observation of sinking and floating phenomena

GOAL: Compare weight and density as predictive variables for sinking and floating phenomena without the benefit of a model.

METHOD: Observe real-world phenomena, obtain simple measurements of the variables and observe a second instance.

1. Variations in weight do not affect the outcome.

   i) Light Floater vs Heavy Floater:
   - small wax, large wax: PREDICT, EXPLAIN, MEASURE, EXPLAIN.
   - small wood, large wood: PREDICT, EXPLAIN.

   ii) Heavy Sinker vs Light Sinker :
   - big clay, small clay: PREDICT, EXPLAIN, MEASURE, EXPLAIN.
   - big steel, small steel: PREDICT, EXPLAIN.

2. The same weight leads to two different outcomes

   i) Light Floater vs Light Sinker:
   - small wood, small clay: PREDICT, EXPLAIN, MEASURE, EXPLAIN.
   - small wax, small aluminum: PREDICT, EXPLAIN.

   ii) Heavy Floater vs Heavy Sinker:
   - big wood, big clay : PREDICT, EXPLAIN, MEASURE, EXPLAIN.
   - big wax, big aluminum: PREDICT, EXPLAIN.

Conclusion: Provide a rule to predict sinking and floating phenomena.

Session 2- Introduction to the concept of density

GOAL: Articulate the distinction between weight and density.

METHOD: Make models of objects with the Weight and Density program.
1. Represent steel and aluminum cylinders of equal size.
2. Represent steel and aluminum cylinders of equal weight.
3. Review definition and procedures for inferring density.

APPENDIX F

Paper and pencil test on density and sinking and floating phenomena

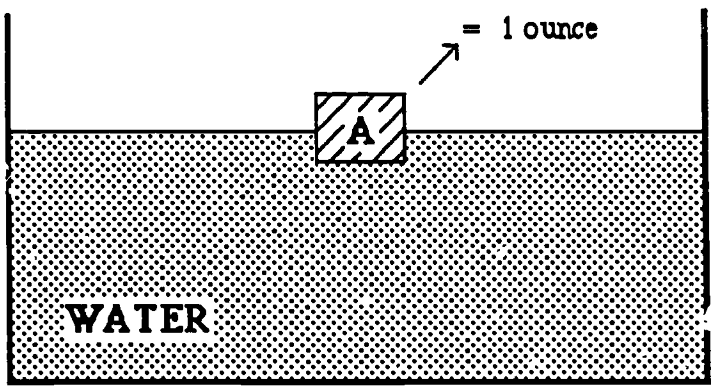
Name: ______________________ ______________________

Grade: ________________ Date: ______________________

IDEAS ABOUT SINKING AND FLOATING

ANNOTATED VERSION:
For the reader's convenience, this version of the test shows the correct answers in bold face and indicates the theory tapped by the multiple-choice statements (W=Weight, M=Material, D=Density). Obviously, this information did not appear on the test that students filled out.

1. Here is an object that is floating in water. This object is made of material A and weighs 1 ounce.



WHAT WILL HAPPEN IF WE PUT HEAVIER OBJECTS MADE OF THE SAME MATERIAL IN THE WATER?

Circle your prediction and give your reason:

a) An object weighing 1 pound will: SINK or FLOAT

Why? ______________________________

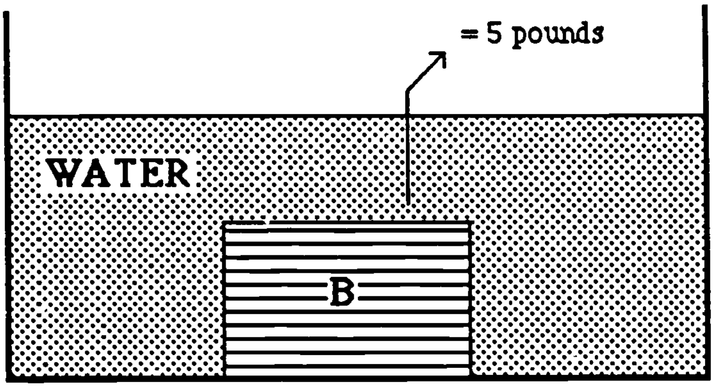
____

b) An object weighing 5 pounds will: SINK or FLOAT

Why? ______________________________

____

2. Here is an object that has sunk to the bottom of the water. It is made of material B and weighs 5 pounds.



WHAT WILL HAPPEN IF WE PUT LIGHTER OBJECTS MADE OF THE SAME MATERIAL IN THE WATER?

Circle your prediction and give your reason:

a) An object weighing 1 pound will: SINK or FLOAT

Why? ____

____

____

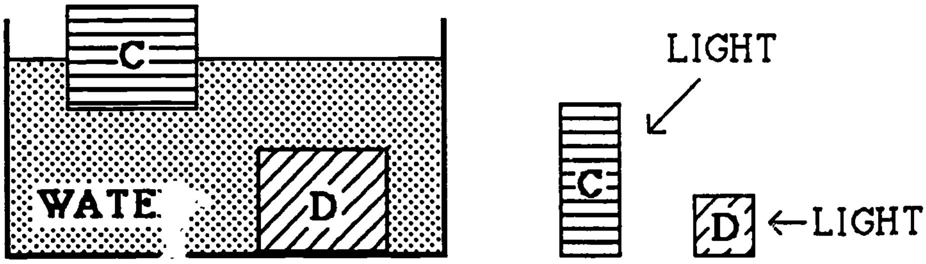
b) An object weighing 1 ounce will: SINK or FLOAT

Why? ____

____

____

3. An object made of material C floats in water and an object made of material D sinks in water. Beside the tank are two other objects made of materials C and D. They are both very light.



WHAT WILL HAPPEN IF WE PUT THEM BOTH IN THE WATER?:

Circle your prediction

* They will both float.
* **C will FLOAT but D will SINK.**
* C will SINK but D will FLOAT.

Explain your prediction:

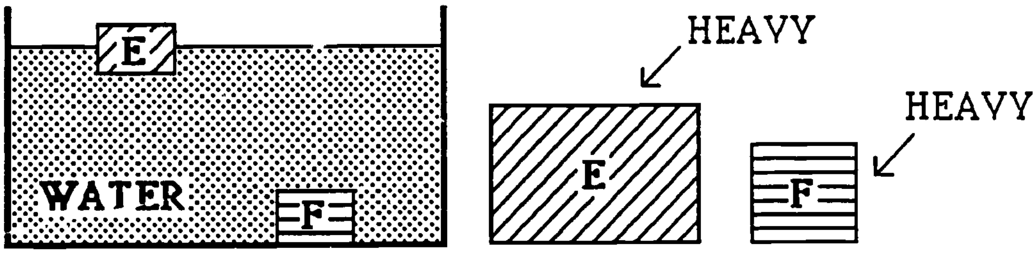
____

____

____

____

4. An object made of material E floats in water and an object made of material F sinks in water. Beside the tank are two other objects made of materials E and F. They are both rather heavy.



WHAT WILL HAPPEN IF WE PUT THEM BOTH IN THE WATER?:

Circle your prediction

* **E will FLOAT but F will SINK.**
* They will both sink.
* F will FLOAT but E will SINK.

Explain your prediction:

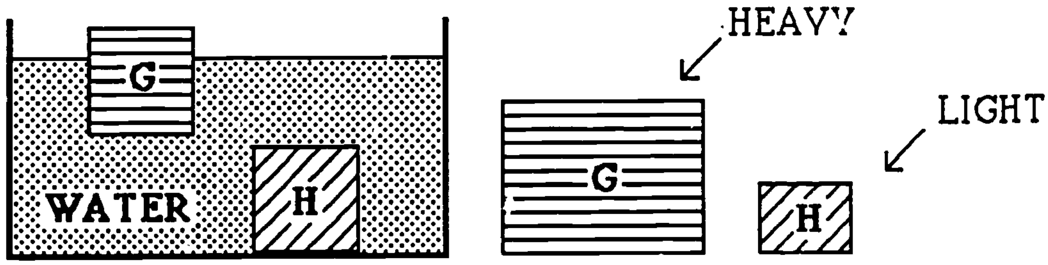
____

____

____

____

5. An object made of material G floats in water and an object made of material H sinks in water. Beside the tank are two other objects made of materials G and H. The object made of G weighs more than the one made of H.



WHAT WILL HAPPEN IF WE PUT THEM BOTH IN THE WATER?:

Circle your prediction

* G will SINK but H will FLOAT.
* They will both float.
* **G will FLOAT and H will SINK.**

Explain your prediction: .

____

____

____

6. HOW CAN WE PREDICT IF SOMETHING IS GOING TO FLOAT OR SINK IN A GIVEN LIQUID?

____

____

____

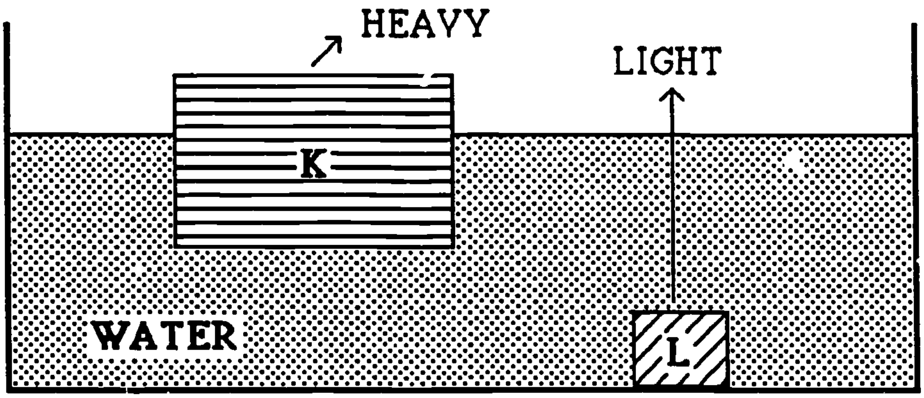
____

7. HERE ARE SOME STATEMENTS ABOUT SINKING AND FLOATING. WHAT DO YOU THINK?

For each sentence, circle YES if you agree or NO if you disagree

				Theory
a)	An object that weighs a lot will always sink in water.	Yes	No	W
b)	An object that floats in water will also float in any other liquid.	Yes	No	M
c)	An object will sink in water if it weighs more than an equal amount of water.	Yes	No	D
d)	An object that weighs very little will always float in water.	Yes	No	W
e)	An object that sinks in water will also sink in any other liquid.	Yes	No	M
f)	Objects that float in water are less dense than water.	Yes	No	D

8. Here are two objects, K and L, made of different materials. Object K is <u>much bigger and also heavier</u> than object L. When we put them in the water, object K floats and object L sinks.



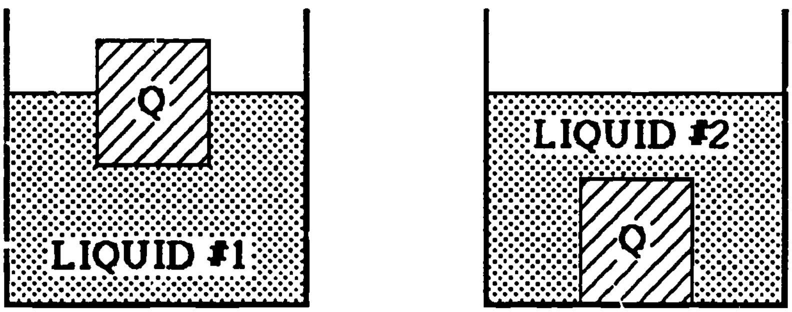
WHAT COULD HELP US UNDERSTAND THIS SITUATION?

____

____

____

9. Object Q floats in liquid #1 but sinks in liquid #2.



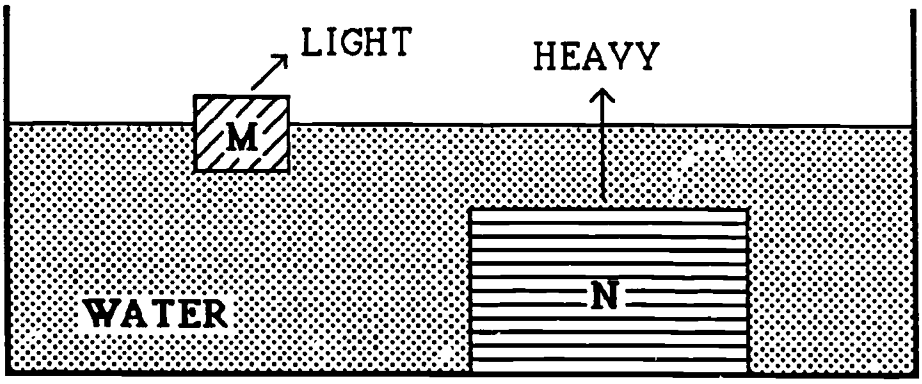
WHAT COULD HELP US UNDERSTAND THIS SITUATION?

____

____

____

10. Here are two objects, M and N made of different materials. Object N is bigger and heavier than object M. When we put them in water, object N sinks and object M floats.

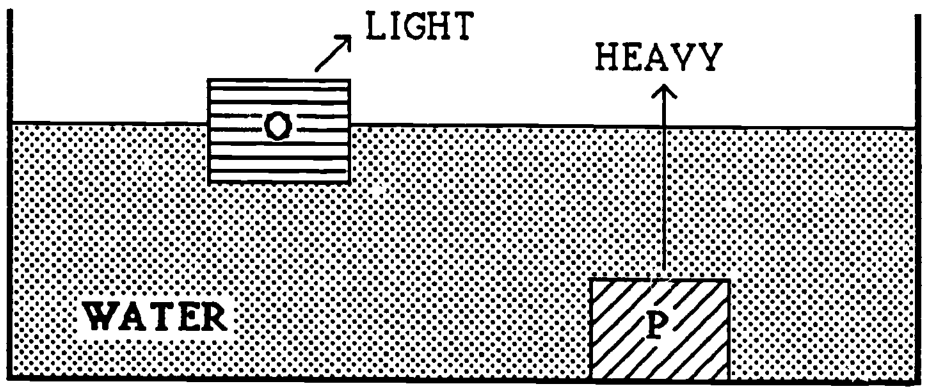


Here are some possible reasons why object M floats and object N sinks.

Circle YES if you agree with the reason given or NO if you disagree

				Theory
a)	Object N is sinking because it is heavier than object M.	Yes	No	W
b)	Object M is floating because it weighs less than all the water.	Yes	No	W
c)	Object N is sinking because it has more weight packed in each part than the water does.	Yes	No	D
d)	Object M is floating because it is denser than Object N.	Yes	No	D

11. Here are two objects, O and P made of different materials. Object O is the same size as object P but it weighs less. When we put them in the water, object O floats and object P sinks.

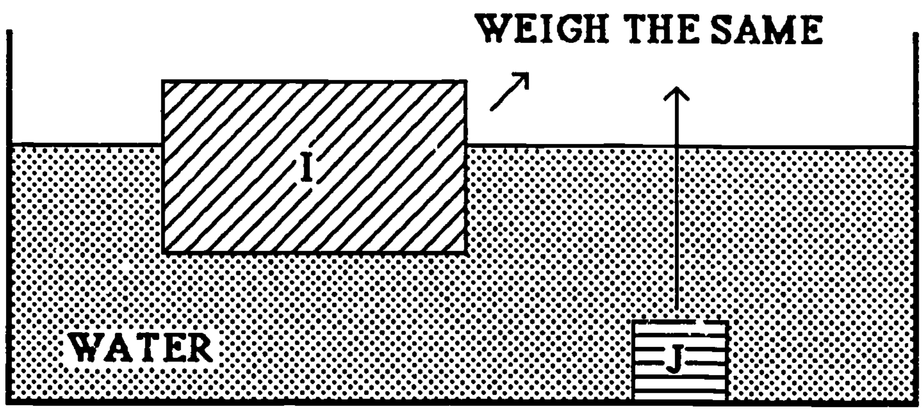


Here are some possible reasons why object O floats and object P sinks.

Circle YES if you agree with the reason given or NO if you disagree

				Theory
a)	Object O floats because it weighs less than an equal amount of water.	Yes	No	D
b)	Object P sinks in water because it is denser than object O.	Yes	No	D
c)	Object P sinks because it weighs a lot.	Yes	No	W
d)	Object O floats because it is lighter than object P.	Yes	No	W

12. Here are two objects, I and J made of different materials. Object I is bigger than object J but weighs the same. When we put them in water, object I floats and object J sinks.

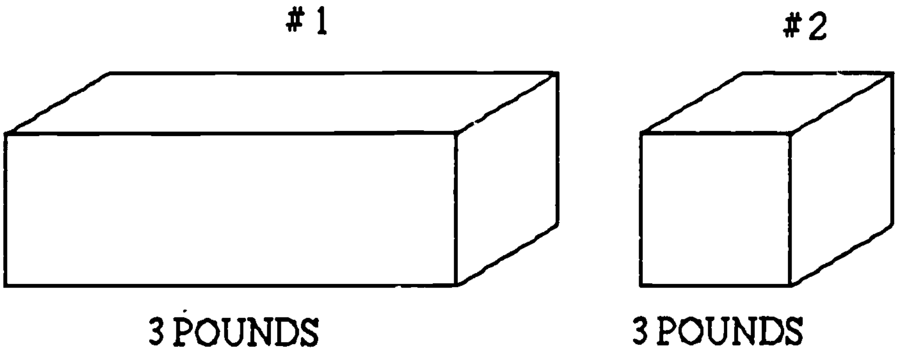


WHAT COULD HELP US UNDERSTAND WHY I FLOATS AND J SINKS?

MAKE A MODEL TO SHOW WHAT YOU MEAN.

EXPLAIN HOW YOUR MODEL WORKS.

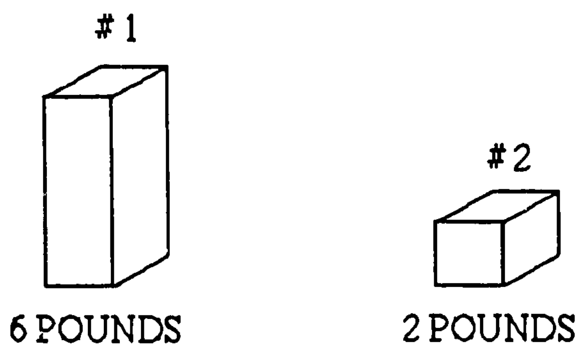
13. HERE ARE TWO PIECES OF WOOD THAT WEIGH THE SAME. PIECE #1 IS 3 TIMES BIGGER.



Circle your answer

	LESS THAN	
The density of piece #2 is:	THE SAME AS	the density of piece #1.
	MORE THAN	

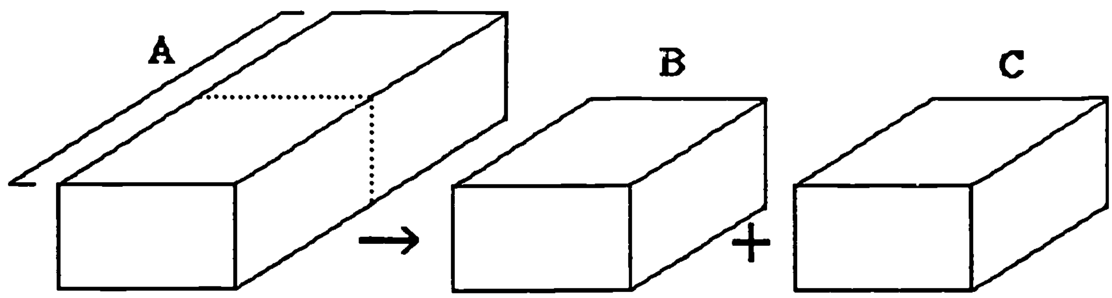
14. HERE ARE TWO PIECES OF METAL THAT WEIGH DIFFERENT AMOUNTS. PIECE #1 IS 3 TIMES BIGGER.



Circle your answer

	LESS THAN	
The density of piece #2 is:	THE SAME AS	the density of piece #1.
	MORE THAN	

15. HERE IS A BLOCK OF PINE THAT IS CUT INTO 2 PIECES.

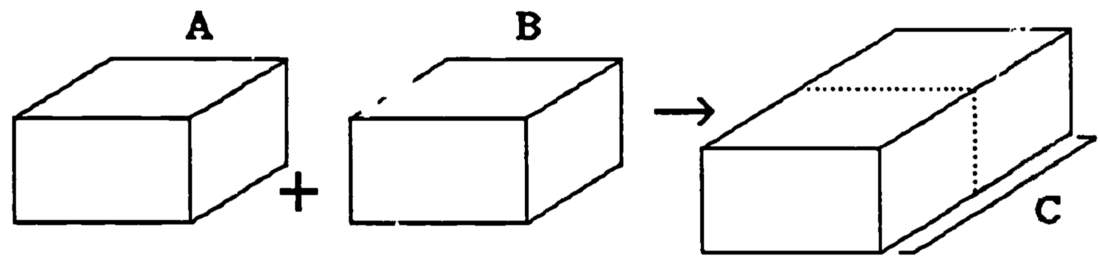


HAVE WE CHANGED THE WEIGHT OR THE DENSITY OF THE WOOD BY CUTTING IT?

Circle your answer:

		LESS THAN	
a)	The weight of block B is:	THE SAME AS	the weight of block A.
		MORE THAN	
		LESS THAN	
b)	The density of block B is:	THE SAME AS	the density of block A.
		MORE THAN	

16. HERE ARE 2 BLOCKS OF SILVER THAT WERE MELTED INTO 1 PIECE.



HAVE WE CHANGED THE WEIGHT OR THE DENSITY OF THE METAL BY COMBINING THE PIECES?

Circle your answer.

a) The weight of block C is:

LESS THAN
THE SAME AS
MORE THAN

the weight of block B.

b) The density of block C is:

LESS THAN
THE SAME AS
MORE THAN

the density of block B.

17. HERE ARE SOME STATEMENTS ABOUT WEIGHT AND DENSITY. WHAT DO YOU THINK?

For each sentence, circle YES or NO

a)	If 2 objects are different sizes but weigh the same, the smaller one is less dense.	Yes	No
b)	An object made of a dense material can be very light.	Yes	No
c)	The density of a tiny piece of material is less than the density of a big piece of that material.	Yes	No
d)	If 2 objects are the same size but weigh different amounts, the heavier one has to be made of a a denser material.	Yes	No
e)	Heavier objects are always denser.	Yes	No
f)	Objects made of a less dense material can sometimes weigh more than objects made of a dense material.	Yes	No

18. WHAT DO WE MEAN BY DENSITY?
IS DENSITY THE SAME AS WEIGHT?
Explain your answer.

APPENDIX G

Scoring criteria and examples for the definition of density and the open-ended questions on sinking and floating phenomena

DEFINITION OF DENSITY

Criteria and examples

0 - ABSENT OR INADEQUATE CONCEPTION

(k) Don't know (distinguished from blank record).

(n) Not the same as weight (unexplained).

(w) Equates density with weight.

(o) Equates density with other parameters:
-"Density is the same as size".

(a) Ambiguous attempts to dissociate density from weight:
-"Weight is how heavy something is and density is how much something contains".
-"Density is how much matter is inside".
-"Density means if it's hollow inside or not".
-"Thickness of material" / "Weight of material".
-"Density is an object that is all filled in and weight is the ounces".
-"Density is the measurement if it sinks or floats".
-"The little parts in the big part".

1 - QUALITATIVE CONCEPT OF DENSITY

-The intensive nature of density is acknowledged in intuitive way as crowdedness of weight/material where space is undefined (keywords: "packed", "compact", crowded", "bunched", "squished"); procedure is based on comparison of same-weight or same-size objects..

- "Density means how compact".
- "Density means how closely something is packed together" .
- "how much is packed in something".
- "How much of something that you can fit into the mass of an object".
- "It's the amount of weight packed into the space" .
- "Density is when the heavier one is the same size".

2 - FORMAL CONCEPT OF DENSITY

-Density defined more explicitly as the amount of weight/material allocated to a given space (keywords: "unit", "part", "block", "cube" "part"); procedure based on sampling of material.

- "It means more weight packed into a part of it" .
- "Density means more packed into the block".
- "Density means like 5 oz per square inch".
- "Density is how much something weighs per some form of measurement; weight is how much something weighs total" .
- "More stuff compacted into a small area".

2. TYPES OF JUSTIFICATIONS

FOR SINKING AND FLOATING PHENOMENA

a) Criteria

0 - NO EXPLANATION

(k) Don't know (distinguished from blank record).

(d) Descriptive: repeats givens of the problem or describes outcome without attempting an explanation.

(a) Ambiguous: an explanation is attempted but it is not possible to interpret what is actually meant.

1 - ALTERNATE

The explanation is different from the accepted scientific view (appeals to factors which do not lead to reliable predictions).

(w) Weight: appeals exclusively to absolute weight of object, either singly or in relation to other object or liquid.

(w+) Weight plus: appeals to weight and factors other than material or density (i.e., size, absorption, shape, etc...).

(w-) Weight less: weight used counter-intuitively (i.e., heavy objects float).

(h) Hollow-full: objects not acknowledged as being made of material throughout.

(o) Other: "size, shape, absorption, gravity, pressure" used singly or in combination.

2 - TRANSITIONAL

-Material kind or density is confused with weight: response merges two incompatible reasons or does not correspond to givens of problem.

Note: Scores 3 to 7 contingent upon correct prediction

3 - MATERIAL KIND

-material kind is the predictive variable on a nominal level (simple identification of floaters and sinkers).

(v) Verbal statement.

(v+) Mentions factors other than weight in addition to material.

(i) Inference: makes an inference about which material it could be without clearly alluding to heaviness of that material.

(i+) Mentions factors other than weight in addition to material.

4 - HEAVINESS OF THE KIND OF MATERIAL

A feature of material kind relevant to the phenomenon is specified.

(v) Verbal statement

(v+) Mentions factors other than weight in addition to heaviness of material.

(i) Inference: infers heaviness of material through contrasting examples.

(i+) Mentions factors other than weight in addition to heaviness of material.

5 - DENSITY OF THE MATERIAL (general)

More specific characterization of material in terms of weight relative to volume but the densities are not related or related incorrectly.

(v) Verbal statement.

(q) Qualitative precursor concept of density as "heaviness for size" or "compactness of weight" (see criteria for Question #8).

(f) Formal concept of density as "weight per unit volume" (see criteria for Question #18).

6 - DENSITY OF THE MATERIAL (relative to the second object)

Correct relationship between density of two objects.

(v) Verbal statement

(q) Qualitative (see #5)

(f) Formal (see #5)

7 - <u>DENSITY OF THE MATERIAL (relative to the liquid)</u>

Correct relationship between density of object(s) and liquid

(v) Verbal statement

(q) Qualitative (see # 5)

(f) Formal (see # 5)

Note 1 - If S refers to only one instance in the problem, assume same level for second instance (ex. "F is made of a material that floats", assume S also thought "G is made of a material that sinks" and score #1).

Note 2 - If S gives different correct answers for 2 objects, give the highest score for that problem (ex."F floats because it is made of a light material; G sinks because it is denser").

2. TYPES OF JUSTIFICATIONS

FOR SINKING AND FLOATING PHENOMENA

b) Examples for questions 1 through 5

0 - NO EXPLANATION

(k) -"I have no idea".
-"It's hard to tell".

(d) -"Because it will float".
-"They'll both sink but one of them will probably lift up a little".

(a) -"G gets smaller than the H and they get heavier".
-"Because they should do the same thing".

1 - ALTERNATE EXPLANATION

(w) -"5 pounds is way too heavy to float".

(w+) - "It is very light but it is also flat and smooth".

(w-) - "It's heavy enough to float".

(h) - "One is hollow so it floats".
- "Maybe they put something in it to make it sink".

(o) - "It would sink because the pressure of the object would push through the water".

2 - TRANSITIONAL EXPLANATION

-"E will float because it's made of a lighter material but F will sink because it's much too heavy" (theory is inconsistent).

-"It might float because it is lighter but it might sink because it is denser" (theory does not lead to prediction).

- "It depends on the material but mostly materials will float no matter what the size" (overgeneralization).

3 - MATERIAL KIND

(v) -"They will both float because they are made of the same material".
-"It depends on the material they are made of".

(v+) -"They're made of the same material and they're the same shape".

(i) -"One might be steel so it would sink".

(i+) -"It's probably a metal that doesn't absorb water".

4 - HEAVINESS OF THE KIND OF MATERIAL

(v) -"Heavy kinds of material will most usually sink".
-"The C material is lighter than the D material".

(v+) -"One is a light kind of material and it's flat".

(i) - "The smallest rock sinks and the biggest stryrofoam floats".
- "Maybe because I is foam and J is a penny".

(i +) - "One is wood so it floats and the other is metal so it sinks but they're also the same shape".

5- DENSITY OF THE MATERIAL (general)

(v) - "It's the same density".
- "It is still the same material and weight won't matter because of its density".

(q) - "It floats because it is not too heavy for its size" .
- "It sinks because the weight is compacted in it".

(f) - "I sinks because there is a lot of weight in each part of it".

6 - DENSITY OF THE MATERIAL (relative to the second object)

(v) - "C is made of a less dense material than D".

(q) - "The material/weight is more crowded in one object" .

(f) -"Because the size of C is larger so each part of D is lighter than each part of D which is smaller" .

7 - DENSITY OF THE MATERIAL (relative to the liquid)

(v) -"Object A floats because it is less dense than the liquid and any object made of A will float".

(q) -"The weight of A is more spread out than the weight of the The liquid is more compact than A".

(f) -"Because the material A weighs less than an equal amount of water".

2. TYPES OF JUSTIFICATIONS

FOR SINKING AND FLOATING PHENOMENA

d) Examples for Q6 (formulation of a predictive rule)

0 - NO RULE

(d) Descriptive:

-"Put them in water to see".

-"Because I think so".

(a) Ambiguous:

-"You have to compare everything of the objects".

-"Well you can test the othor object and if it's good to do it".

-"It's weight and the given liquid in the same container's weight".

1 - ALTERNATE

(w) -"If it is light enough to float".

-"Maybe it will sink when it weighs more than the water".

(w+) -"I think you could predict in two ways, see how big/small they are, another way is to see how heavy/light they are".

(w-) -"If it's heavy, it could hold itself up in the water".

(o) -"Sometimes you can feel the object and it feels like it could float".

-"If you look at how thick it is, you will know".

2 - TRANSITIONAL

-"It will sink if it's denser and heavier".

-"It depends on the size and the material".

-"Sometimes you can tell by the material, sometimes by the weight".

3 - MATERIAL KIND

(v) -"It depends on the kind of material; some float and some don't".

(v+) -"It floats if it is made of a certain material and is flat".

(i) -"I know wood floats and most metals sink".
(i+) -"Wood floats when it is flat".

4 - HEAVINESS OF THE KIND OF MATERIAL

(v) -"If it's made of a heavier kind of material, it will sink".
(v+) -"Light kinds of materials can float when they have a smooth surface".

(i) -"It depends if the liquid is thick or watery".

(i+) -"Wood floats when it is flat".

5 - DENSITY OF THE MATERIAL (general)

(v) - "You need to know the density of the object and the density of the liquid".

(q) - "If it's heavy for its size it might sink".

(f) -"It depends how much weight is in each size unit".

6 - DENSITY OF THE MATERIAL (general)

(v) -"If it's a denser material or not".

(q) - "If the material in one object is less crowded/packed than in the other".
-"If they are both the same size and one is heavier than the other, then the one that is heavy s going to sink".

(f) - "If there's more weight packed into one part than the other object, then that one will sink".

7 - DENSITY OF THE MATERIAL (relative to second object)

(v) - "An object will float if it is less dense than the liquid".

(q) - "If the weight is more spread out in the object than in the water, then it will float but if it is more compact, then it will sink".

(f) - "It floats if the object weighs less than an equal amount of water".

2. SINKING AND FLOATING SCALE

c) Examples for questions 8 - 9 - 12

INTERPRETATIONS OF SINKING/FLOATING PHENOMENA

0 - NO EXPLANATION

(d) Descriptive:

- "All objects that float in one liquid don't float in another necessarily".
- "It would help to know what the liquids are".
- "K is heavier than L".
"Heavier objects don't always sink".

(a) Ambiguous:

-"We could try different liquids".
- "That it doesn't matter by the size, it matters by the weight".
- "Which one is solid and which one is light".

1 - ALTERNATE

(w) Weight:

-"The liquid in # 1 is heavier than in #2".
-"J is heavier than #I".
- "K weighs less than the liquid".

(w+) -"The heavier one is floating because it's long and the lighter one might be able to absorb water to make it heavier than K".

(w-) -"Because light things sink".

(h) Hollow-full

-"K is bigger and maybe is hollow and yet still heavy".
- "K has air inside but L doesn't".
-"I floats because it has nothing in it and J has something in it".

(o) Other

-"Whatever liquid #2 is made of, it must have some gravity pull".
- "Because I is wider and J is skinnier".
- "J could have holes in it".

- "K could be an object that absorbs water so it could sink".

2 - TRANSITIONAL

- "K (floating) is made of a heavier material and is less dense than the water".
- "Liquid #2 is thicker".
- "liquid #1 has less density than liquid # 2, that is why Object O floats in 1 and sinks in 2".
- "The objects have the same amount of size units packed in but are not the same size".
- "Object I floats because it is a denser material and J has more amount of material built into it".

3 - MATERIAL KIND

(v) Verbal:

- "They're made of different kinds of materials". "Different liquids do different things".
- "The chemicals are different".

(I) Inference:

- "Maybe one is water but the other is something else".
- "I know wood floats so I could be wood".
- "K could be styrofoam or sponge".

4 - HEAVINESS OF THE KIND OF MATERIAL

(v) Verbal:

-"Liquid #1 is thicker", "stronger"
- "Liquid #1 has heavier chemicals".
- "F is made of a buoyant material".
- "K is made of a lighter kind of material than L".

(i) Inference:

-"K could be plastic and L a piece of metal".
- "The water if it's salty or fresh".
-"Maybe one is oil and the other is water".
-I may be a sponge and J a penny".

5 - DENSITY OF THE MATERIAL (general)

(v) Verbal:

- "They have different densities".

(q) Qualitative:

-"Maybe liquid #1 has a lot of weight compacted in it".
-"the weight in K is spread out so it can float".

(f) Formal:

- "K Does not have a lot of weight per size unit".

6 - DENSITY OF THE MATERIAL (relative to second object)

(v) Verbal:

-"Liquid #2 is less dense than liquid #1".
- "K is less dense than L".

(q) Qualitative:

-"Liquid #1 has less weight compacted in it than liquid #2".
-"They both weigh the same but J has more packed in it".
-"Because in K the weight is spread out and in L the weight is combined into a small square".

(f) Formal:

-"Liquid #1 has less weight per size unit than liquid #2".
-"One cube of I would weigh less than one cube of J".
-"One part of K weighs less than a part of L".

7 - DENSITY OF THE MATERIAL (relative to second object)

(v) Verbal:

-" Q is less dense than # 1 but denser than # 2".

- "K has to be less dense than the liquid".

(q) Qualitative:

-"The weight in Q is more spread out than in liquid #1 but it is more compact than for liquid #2".

- "The weight of K is not as compact as in the water".

(f) Formal:

-"Each part of Q weighs less than an equal part of liquid #1 but it's the opposite for liquid 2".

-"There is more weight in one unit of J than in one unit of water".

- "If you take a piece of K, it weighs less than the same piece of water even though the whole thing is heavy.

APPENDIX H

Tables 1 through 35

Table 1

Experimental design of the study

Group	n	Experimental condition	Pre-test	Treatment: First session	Treatment: Second session	Post-test 2	Post-test 1
1	20	Observation of sinking and floating phenomena with computer model and with prior introduction to density	X	ID	SF/CM	X	X
2	20	Observation of sinking and floating phenomena with computer model and without prior introduction to density	X	SF/CM	ID	X	X

(...continued on next page)

Table 1 (continued)

Group	n	Experimental condition	Pre-test	First session	Second session	Post-test 2	Post-test 1
3	20	Observation of sinking and floating phenomena without computer model and with prior introduction to density	X	ID	SF/NoCM	X	X
4	20	Observation of sinking and floating phenomena without computer model and without prior introduction to density	X	SF/NoCM	iD	X	X
5	20	Control group	X	-	-	X	X

Note. ID: Introduction to density; SF/CM: Observation of sinking and floating phenomena while interacting with the computer model; SF/NoCM: Observation of sinking and floating phenomena without interacting with the computer model.

Table 2

Time intervals in number of days between the events of the study for each treatment group

Time period	M	SD	Range
Treatment group 1			
Pre-test to session 1	37.4	15.1	14-59
Session 1 to session 2	7.2	4.7	0-14
Session 2 to post-test 1	5.2	4.3	0-15
Post-test 1 to post-test 2	52.9	4.9	41-60
Treatment group 2			
Pre-test to session 1	38.2	14.9	14-58
Session 1 to session 2	6.5	4.4	1-14
Session 2 to post-test 1	5.4	4.3	0-17
Post-test 1 to post-test 2	51.4	12.9	2-65
Treatment group 3			
Pre-test to session 1	39.3	16.0	10-63
Session 1 to session 2	5.9	5.6	0-21
Session 2 to post-test 1	5.5	4.8	0-20
Post-test 1 to post-test 2	53.0	4.6	41-60
Treatment group 4			
Pre-test to session 1	39.8	13.2	15-59
Session 1 to session 2	5.8	4.9	0-15
Session 2 to post-test 1	5.9	3.1	1-10
Post-test 1 to post-test 2	54.4	4.5	47-65

Table 3

Ratings of consistency of treatment between the two experimenters given by two independent judges for eight experimental sessions chosen at random.

Experimental sessions	Judge # 1	Judge #2
Experimenter #1		
1. Introduction to density	1.5	1
2. Introduction to density	1.5	1
3. Flotation experiments with computer	1.5	1
4. Flotation experiments without computer	1	·5
	M 1.3	M 1.1
Experimenter #2		
5. Introduction to density	3	2.5
6. Introduction to density	1.5	1.5
7. Flotation experiments with computer	3	3
8. Flotation experiments without computer	2	1.5
	M 2.3	M 2.1

Note. Scale: 1 = Excellent; 2 = Adequate; 3 = Unsatisfactory.

Table 4

Content analysis of the paper and pencil test by topic area, problem type and forma

Question	Content area	Type of problem		Format	
1 to 5	SF (Predictions and justifications)	V	I	O-E	M-C
6 & 7	SF (Rule)	V		O-E	M-C
8 to 12	SF (Interpretations)	V		O-E	M-C
12b & 12c	Model of SF (Drawing)	V	I	O-E	
13 to 16	Density (Judging objects)		I		M-C
17 & 18	Density (Definition)	V		O-E	M-C

Note. SF = Sinking and floating; V= Verbal; I = Illustrated; O-E = Open-ended; M-C = Multiple-choice.

Table 5

Pattern scoring procedure for multiple-choice items

Answers to paired statements			Score in theory group			
Weight	Material	Density	Weight	Mixed	Material	Density
Yes	- -	No	1	- -	- -	- -
Yes	- -	Yes	- -	1	- -	- -
No	Yes	No	- -	- -	1	- -
No	- -	Yes	- -	- -	- -	1

Table 6

General effect of treatment as opposed to control group on students' ability to define density on the paper and pencil test.

Experimental condition	n	Definition of density: Inadequate	Satisfactory
		Pre-Test	
Treatment groups	69	84	16
Control group	19	89	11
		X^2 (1) = 0.05, p = .83	
		Immediate post-test	
Treatment groups	72	33	67
Control group	18	78	22
		X^2 (1) =9.91, **p <.01	
		Delayed post-test	
Treatment groups	70	30	70
Control group	16	75	25
		X^2 (1) = 9.33, *p <.05	

Note. There were 80 subjects in the treatment groups and 20 subjects in the control group. The smaller n's indicate that some subjects did not answer this question. Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 7

Experimenter effect on students' ability to define density on the test

Experimenters	n	Definition of density: Inadequate	Satisfactory
		Pre-Test	
Experimenter 1	43	81	19
Experimenter 2	26	88	12
		X^2 (1) = 0.19, p = .66	
		Immediate post-test	
Experimenter 1	45	27	73
Experimenter 2	27	44	56
		X^2 (1) =1.67, p =.20	
		Delayed post-test	
Experimenter 1	43	30	70
Experimenter 2	27	30	70
		X^2 (1) < 0.01, p = 1.00	

Note. Experimenter 1 worked with 48 subjects and experimenter 2 worked with 32 subjects. The smaller n's indicate that some subjects did not answer this question.
Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 8

Effect of model-guided observation of sinking and floating phenomena on students' ability to define density on the paper and pencil test.

Treatment group	n	Definition of density: Inadequate	Satisfactory
		Pre-Test	
Observation with model	36	83	17
Observation without model	33	85	15
		X^2 (1) < 0.01, p = 1.00	
		Immediate post-test	
Observation with model	37	35	65
Observation without model	35	31	69
		X^2 (1) = 0.01, p = .93	
		Delayed post-test	
Observation with model	36	33	67
Observation without model	34	26	74
		X^2 (1) = 0.13, p = .71	

Note. There were 40 subjects in each treatment group. The smaller n's indicate that some subjects did not answer this question. Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 9

Effect of introduction to density prior to observation of sinking and floating phenomena on students' ability to define density on the test.

Treatment group	n	Definition of density: Inadequate	Satisfactory
Pre-Test			
Prior introduction to density	33	82	18
No prior introduction to density	36	86	14
		X^2 (1) = 0.02 , p = .87	
Immediate post-test			
Prior introduction to density	35	29	71
No prior introduction to density	37	38	62
		X^2 (1) = 0.34, p = .56	
Delayed post-test			
Prior introduction to density	35	29	71
No prior introduction to density	35	31	69
		X^2 (1) < 0.01 , p = 1.00	

Note. There were 40 subjects in each treatment group. The smaller n's indicate that some subjects did not answer this question. Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 10

Effect of model-guided observation of sinking and floating phenomena on the percentage of weight, material and density justifications for real-word cases during the experimental sessions before and after testing predictions.

Treatment group	n	Weight	Material	Density
		Categories of justifications		
Before testing predictions				
Observation with model	40	13	41	46
Observation without model	40	17	42	41
		F.39, p.54	F<.01, p =1	F.35, p.56
After testing predictions				
Observation with model	40	10	23	67
Observation without model	40	24	27	49
		F5.94, *p<.05	F.36, p.55	F4.12, *p<.05

Note. The values represent the percentages of answers in the different categories for each group.
Note. Separate analyses were conducted on each dependent variable. The respective F values and p values are reported in abbreviated fashion below each variable. The degrees of freedom for the F values = 1.76.

Table 11

Effect of prior introduction to density concept on the percentage of weight, material and density justifications for real-world sinking and floating phenomena during the experimental sessions before and after testing predictions.

		Categories of justifications		
Treatment group	n	Weight	Material	Density
		Before testing predictions		
Prior introduction to density	40	15	28	57
No prior introduction to density	40	14	57	29
		F = .02, p = .90	F = 11.83, ***p ≤ .001	F = 12.64, ***p < .001
		After testing predictions		
Prior introduction to density	40	16	15	69
No prior introduction to density	40	17	36	47
		F = .01, p = .92	F = 8.03, ** p < .01	F = 6.82, **p < .01

Note. The values represent the percentages of answers in the different categories for each group.
Note. Separate analyses were conducted on each dependent variable. The respective F values and p values are reported below each variable. The degrees of freedom for the F values = 1,76.

Table 12

Percentage of weight, material and density justifications for real-word sinking and floating phenomena during the experimental sessions before and after testing predictions

Treatment group	n	Categories of justifications: Weight	Material	Density
		Before testing predictions		
1. SF model and density first	20	14	26	60
2. SF model and density second	20	12	56	32
3. No SF model and density first	20	15	30	55
4. No SF model and density second	20	18	55	27
		After testing predictions		
1. SF model and density first	20	11	13	76
2. SF model and density second	20	8	34	58
3. No SF model and density first	20	22	16	62
4. No SF model and density second	20	26	38	36

Note. The values represent the percentages of answers in the different categories for each group.
Note. SF model refers to the computer model of sinking and floating phenomena.

Table 13

Effect of model-guided observation of sinking and floating phenomena on the number of subjects showing low, moderate and high levels of integration of density in response to real-world cases during the experimental sessions before and after testing predictions.

		Levels of integration of density		
Treatment group	n	Low	Moderate	High
		Before testing predictions		
Observation with model	39	36	38	26
Observation without model	40	38	48	15
		X^2 (2) =1.49, p = .47		
		After testing predictions		
Observation with model	39	23	23	54
Observation without model	40	48	23	29
		X^2 (2) = 6.02, *p< .05		

Note. One subject answered fewer than 60% of the items and therefore was not attributed a pattern.
Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 14

Effect of prior introduction to density on the number of subjects showing low, moderate and high levels of integration of density in response to real-world sinking and floating phenomena during the experimental sessions before and after testing predictions.

Treatment group	n	Levels of integration of density: Low	Moderate	High
Before testing predictions				
Prior introduction to density	39	36	36	28
No prior introduction to density	40	38	50	12
		X^2 (2) =2.33, p = .19		
After testing predictions				
Prior introduction to density	39	33	13	54
No prior introduction to density	40	38	33	29
		X^2 (2) = 6.14, *p< .05		

Note. One subject answered fewer than 60% of the items and therefore was not attributed a pattern.
Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 15

Comparison of the number of subjects showing low, moderate and high levels of integration of density in response to real-world sinking and floating phenomena during the experimental sessions before and after testing their predictions among the four single treatment groups.

Treatment group	n	Levels of integration of density: Low	Moderate	High
		Before testing predictions		
1. SF model and density first	20	7	6	7
2. SF model and density second	19	7	9	3
3. No SF model and density first	19	7	8	4
4. No SF model and density second	20	8	10	2
		$X^2(6) = 4.86$, $p = .56$		
		After testing predictions		
1. SF model and density first	20	5	2	13
2. SF model and density second	19	4	7	8
3. No SF model and density first	19	8	3	8
4. No SF model and density second	20	10	6	4
		$X^2(6) = 12.64$, $^*p < .05$		

Note. Two subjects answered fewer than 60% of the items and therefore were not attributed a pattern Note. SF model refers to the computer model of sinking and floating phenomena.

Table 16

One-way analysis of variance assessing the difference between the five exp imental groups on the percentage of weight, material and density justifications for sinking and floating predictions on the pre-test and post-tests.

Experimental group	n	Categories of justifications: Weight	Material	Density
		Pre-test		
1. SF model and density first	20	88	12	0
2. SF model and density second	20	73	27	0
3. No SF model and density first	20	73	18	9
4. No SF model and density second	20	77	19	4
5. Control group	20	72	28	0
		$F = 1.94$, $p = .11$	$F = .74$, $p = .56$	$F = 1.68$, $p = .15$

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Table 16 (continued)

Experimental group	n	Weight	Material	Density
		Immediate Post-Test		
1. SF model and density first	20	21	29	50
2. SF model and density second	20	14	59	27
3. No SF model and density first	20	19	29	52
4. No SF model and density second	20	32	34	34
5. Control group	20	52	47	1
		$F = 4.97$, *** $p < .001$	$F = 2.31$, $p = .06$	$F = 4.20$, ** $p < .01$
		Delayed Post Test		
1. SF model and density first	20	23	39	38
2. SF model and density second	20	14	53	33
3. No SF model and density first	20	24	30	46
4. No SF model and density second	20	32	34	34
5. Control group	20	55	45	0
		$F = 3.57$ ** $p < .05$	$F = 0.58$, $p < .68$	$F = 3.19$ * $p < .05$

Note. The values represent the percentages of answers in the different categories for each group.
Note. Degrees of freedom for the F values = 4, 95.
Note. SF model refers to the computer model of sinking and floating phenomena.

Table 17
Proportion of weight material and density justifications for the sinking and floating predictions on the pre-test and the post-tests given by the treatment groups combined by independent variable.

Independent variable	n	Categories of justifications: Weight	Material	Density
		Pre-test		
Model-guided observation				
Yes (Groups 1 & 2)	40	81	19	0
No (Groups 3 & 4)	40	75	19	6
Prior introduction to density				
Yes (Groups 1 & 3)	40	81	15	4
No (Groups 2 & 4)	40	75	23	2
		Immediate post-test		
Model-guided observation				
Yes (Groups 1 & 2)	40	17	45	38
No (Groups 3 & 4)	40	25	32	43
Prior introduction to density				
Yes (Groups 1 & 3)	40	20	29	51
No (Groups 2 & 4)	40	23	46	31

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Table 17 (continued)

Independent variable	n	Weight	Material	Density
		Delayed post-test		
Model-guided observation				
Yes (Groups 1 & 2)	40	19	46	35
No (Groups 3 & 4)	40	28	32	40
Prior introduction to density				
Yes (Groups 1 & 3)	40	24	34	42
No (Groups 2 & 4)	40	24	43	33

Note. The values represent the percentages of answers in the different categories for the pairs of groups.

Table 18

Main effects and interaction effects of the independent variables on the proportion of weight, material and density justifications for the sinking and floating predictions on the pre-test and post-tests.

Independent variable	n	Weight F	Weight p	Material F	Material p	Density F	Density p
Pre-test							
Model-guided observation		2.21	.14	0.12	.74	3.80	.06
Prior introduction to density		0.19	67	1.04	.31	0.42	.59
Interaction effect	80	5.53	<.05*	0.21	.65	0.42	52

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Table 18 (continued)

Independent variable	n	Weight		Material		Density	
		F	p	F	p	F	p
			Immediate post-test				
Model-guided observation		1.19	.28	2.52	.12	0.05	.83
Prior introduction to density		0.43	.52	4.29	<.05*	2.76	.10
Interaction effect	80	2.33	.13	2.23	.14	0.09	.77
			Delayed post-test				
Model guided observation		1.70	.20	1.08	.30	0.40	.53
Prior introduction to density		0.00	1.00	0.73	.39	0.53	.47
Interaction effect	80	1.41	.24	0.05	.82	0.03	.86

Note. The degrees of freedom for the F values = 1,76.

Table 19

General effect of treatment on the level of integration of density in response to the sinking and floating tasks on the pre-test and post-tests.

Experimental condition	n	Levels of integration of density: Low	Moderate	High
Pre-Test				
Treatment groups	79	92	6	2
Control group	20	90	10	0
		X^2 (2) = 0.57, p = .75		
Immediate post-test				
Treatment groups	80	69	9	22
Control group	20	85	15	0
		X^2 (2) = 5.71, p = .06		
Delayed post-test				
Treatment groups	75	67	12	21
Control group	20	85	15	0
		X^2 (2) = 5.13, p = .08		

Note . There were 80 subjects in the treatment groups and 20 subjects in the control group. Smaller n's indicate that some subjects answered too few items to be attributed a pattern.

Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 20

Effect of model-guided observation of phenomena on the level of integration of density in response to the sinking and floating tasks on the pre-test and the post-tests.

Treatment group	n	Levels of integration of density: Low	Moderate	High
Pre-test				
Observation with model	40	93	7	0
Observation without model	39	92	6	2
		X^2 (2) = 1.20, p = .55		
Immediate post-test				
Observation with model	40	60	10	30
Observation without model	40	78	8	14
		X^2 (2) = 3.03, p = .22		
Delayed post-test				
Observation with model	36	69	8	23
Observation without model	39	69	15	16
		X^2 (2) = .88, p = .64		

Note. There were 40 subjects in each treatment group. Smaller n's indicate that some subjects answered too few items to be attributed a pattern.
Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 21

Effect of prior introduction to density on the number or subjects showing low, moderate and high levels of integration of density in response to the sinking and floating tasks on the pre-test and the post-tests.

Treatment group	n	Levels of integration of density: Low	Moderate	High
		Pre-Test		
Prior introduction to density	39	94	6	0
No prior introduction to density	40	90	8	2
		X^2 (2) = 1.20, p = .55		
		Immediate post-test		
Prior introduction to density	40	73	2	25
No prior introduction to density	40	65	15	20
		X^2 (2) = 3.96, p = .14		
		Delayed post-test		
Prior introduction to density	38	71	8	21
No prior introduction to density	37	62	16	22
		X^2 (2) = 1.31, p = .52		

Note. There were 80 subjects in the treatment groups and 20 subjects in the control group. Smaller n's indicate that some subjects answered too few items to be attributed a pattern.
Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 22

Effect of the independent variables on the kind of predictive rules for sinking and floating phenomena formulated orally during the experimental sessions.

Treatment group	n	Predictive rules: Weight	Material	Density
First independent variable				
Observation with model	37	16	16	68
Observation without model	40	25	33	42
		χ^2 (2) = .4.99, p = .08		
Second independent variable				
Prior introduction to density	37	22	16	62
No prior introduction to density	40	20	33	47
		χ^2 (2) = 3.42, p = .18		

Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 23

Frequencies of different types of predictive rules for sinking and floating phenomena provided by the whole sample on the pre-test and post-tests.

Time of testing	N	Predictive rules: Other	Weight	Material	Density
Pre-test	100	32	50	17	1
First post-test	100	31	17	27	25
Second post-test	100	22	13	39	26

Table 24

General effect of treatment on the kind of predictive rule for sinking and floating phenomena expressed on the pre-test and post-tests.

Experimental condition	n	Predictive rules: Weight	Material	Density
Pre-test				
Treatment groups	54	78	20	2
Control group	14	57	43	0
		X^2 (2) = 3.15, p = .21		
Immediate post-test				
Treatment groups	55	29	27	44
Control group	14	7	86	7
		X^2 (2) = 16.02, ***p < .001		
Delayed post-test				
Treatment groups	64	16	47	37
Control group	14	21	64	15
		X^2 (2) = 2.79, p = .25		

Note. There were 80 subjects in the treatment groups and 20 subjects in the control group. The smaller n's indicate that some subjects did not answer this question.
Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 25

<u>Effect of model-guided observation of sinking and floating phenomena on the kind of the predictive rule expressed on the pre-test and post-tests.</u>

Treatment group	n	Predictive rules: Weight	Material	Density
Pre-test				
Model-guided observation	29	83	17	0
Observation without model	25	72	24	4
		X^2 (2) = 1.66 p = .44		
Immediate post-test				
Model-guided observation	29	28	24	48
Observation without model	26	31	31	38
		X^2 (2) = 0.57, p = .75		
Delayed post-test				
Model-guided observation	31	23	45	32
Observation without model	33	9	48	43
		X^2 (2) = 2.34, p = .31		

Note. There were 40 subjects in each treatment group. The smaller n's indicate that some subjects did not answer this question.
Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 26

Effect of being introduced to density prior to observing sinking and floating phenomena on the kind of predictive rule expressed on the pre-test and post-tests.

Treatment group	n	Predictive rules: Weight	Material	Density
Pre-test				
Prior introduction to density	27	81	19	0
No prior introduction to density	27	74	22	4
		X^2 (2) = 1.19, p = .55		
Immediate post-test				
Prior introduction to density	32	31	28	41
No prior introduction to density	23	26	26	48
		X^2 (2) = 0.30, p = .86		
Delayed post-test				
Prior introduction to density	31	16	45	39
No prior introduction to density	33	15	48	36
		X^2 (2) = 0.07, p = .97		

Note. There were 40 subjects in each treatment group. The smaller n's indicate that some subjects did not answer this question.
Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 27

Overview of significant effects of treatment on the mean number of weight, material and density justifications and on the individual patterns of integration of density in response to sinking and floating phenomena for real-world cases during the experimental sessions and for the illustrated cases on the post-tests.

	Real-world phenomena					
Independent variable	Before testing predictions			After testing predictions		
	Group means					
	Weight	Material	Density	Weight	Material	Density
Model-guided observation	*n.s.*	*n.s.*	*n.s.*	Lower*	*n.s.*	Higher*
Prior introduction to density	*n.s.*	Lower***	Higher***	*n.s.*	Lower**	Higher**
	Individual patterns					
	Low	Moderate	High	Low	Moderate	High
Model-guided observation	*n.s.*	*n.s.*	*n.s.*	Fewer*	*n.s.*	More*
Prior introduction to density	*n.s.*	*n.s.*	*n.s.*	*n.s.*	Fewer*	More*

(...continued on next page)

Table 27 (continued)

	Illustrated phenomena					
	Immediate post-test			Delayed post-test		
	Group means					
	Weight	Material	Density	Weight	Material	Density
Treatment in general	Lower***	*n.s.*	Higher**	Lower**	*n.s.*	Higher*
Model-guided observation	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Prior introduction to density	*n.s.*	Lower*	>Higher	*n.s.*	*n.s.*	*n.s.*
	Individual patterns					
	Low	Moderate	High	Low	Moderate	High
Treatment in general	>Fewer	*n.s.*	>More	>Fewer	*n.s.*	>More
Model-guided observation	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Prior introduction to density	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*

Note . (n.s.) = non-significant; (>) = tendency, $p < .10$; (*) = $p < .05$; (**) = $p < .01$; (***) = $p < .001$

Table 28

Summary of the analyses comparing the number of weight, material and density responses provided by the five experimental groups for each item on the pre-test and post-tests.

Item	Phenomenon	Pre-test		Post-test 1		Post-test 2	
		X^2	p	X^2	p	X^2	p
1.a)	Heavy floater	.60	.74	14.29	<.001***	10.62	<.01*
1.b)	Heavy floater	1.56	.46	9.10	<.01**	8.34	<.05*
2.a)	Light sinker	.67	.72	10.57	<.01**	8.11	<.05*
2.b)	Light sinker	1.49	.48	9.82	<.01**	9.90	<.05*
3.	Light floater/ Light sinker	2.31	.32	14.63	<.001***	12.46	<.01**
4.	Heavy floater/ Heavy sinker	1.07	.59	17.73	<.001***	13.57	<.001***
5.	Heavy floater/	.50	.78	9.94	<.01**	10.45	<.01**

Note. The degrees of freedom for the X^2 values = 2.
Note. There were 80 subjects in the treatment groups and 20 subjects in the control group.

Table 29

Summary of the analyses comparing the number of weight, material and density responses provided by subjects who observed sinking and floating phenomena guided by the computer model and those who observed real-world phenomena only for each item on the pre-test and post-tests.

Item	Phenomenon	Pre-test		Post-test 1		Post-test 2	
		X^2	p	X^2	p	X^2	p
1.a)	Heavy floater	1.27	.53	0.13	.94	5.99	.05
1.b)	Heavy floater	1.15	.56	0.86	.65	2.54	.28
2.a)	Light sinker	2.68	.26	2.44	.30	.53	.77
2.b)	Light sinker	2.11	.35	1.21	.55	1.47	.48
3.	Light floater/ Light sinker	4.11	.13	2.46	.29	1.68	.43
4.	Heavy floater/ Heavy sinker	2.74	.25	3.57	.17	1.43	.49
5.	Heavy floater/ Light sinker	1.87	.39	4.60	.10	2.94	.23

Note. The degrees of freedom for the X^2 values = 2.
Note. There were 40 subjects in each comparison group.

Table 30

Summary of the analyses comparing the number of weight, material and density responses provided by subjects who were introduced to density prior to the observation of sinking and floating phenomena and those who were introduced afterward for each item on the pre-test and post-tests.

Item	Phenomenon	Pre-test		Post-test 1		Post-test 2	
		X^2	p	X^2	p	X^2	p
1.a)	Heavy floater	1.11	.57	4.21	.12	.34	.84
1.b)	Heavy floater	1.10	.58	3.29	.19	.63	.73
2.a)	Light sinker	1.87	.39	4.03	.13	.71	.70
2.b)	Light sinker	3.11	.21	3.09	.21	.75	.69
3.	Light floater/ Light sinker	2.94	.23	1.17	.56	3.02	.22
4.	Heavy floater/ Heavy sinker	2.05	.36	4.41	.11	2.04	.36
5.	Heavy floater/ Light sinker	1.15	.56	5.74	.06	2.10	.35

Note. The degrees of freedom for the X^2 values = 2.
Note. There were 40 subjects in each comparison group.

Table 31

Types of models drawn by the subjects to illustrate their interpretation of a heavy floating object and a light sunken object.

Type of model	Pre-test	Post-test 1	Post-test 2
Computer	0	30	14
Other types			
Shading	2	4	5
Particulate	6	2	11
Hollow-full	11	8	8
Figurative	63	42	32
Miscellaneous	0	0	6
Missing	18	14	24

Note. The values represent the number of drawings out of 100 at each time of testing.

Table 32

Effect of model-guided observation of sinking and floating phenomena and of prior introduction to density on the type of model drawn on the post-tests to illustrate the interpretation of a heavy floater as opposed to a light sinker.

Independent variable	n	Type of model: Computer model	All other models
Immediate post-test			
Model-guided observation	39	54	46
Observation without model	33	27	73
		X^2 (2) = 4.16, p < .05*	
Prior introduction to density	35	43	57
No prior introduction to density	37	41	59
		X^2 (2) < .01, p = 1.00	
Delayed post-test			
Model-guided observation	34	26	74
Observation without model	32	16	84
		X^2 (2) = .60, p = .44	
Prior introduction to density	32	22	78
No prior introduction to density	34	21	79
		X^2 (2) < .01, p = 1.00	

Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.

Table 33

Relationship between the verbal interpretation of a heavy floate, and a light sinker and the type of model drawn to illustrate that interpretation.

Type of model	n	Weight	Material	Density
		Categories of interpretation		
Immediate post-test				
Computer model	30	13	3	84
Other models	56	29	34	37
		X^2 (2) = 17.49, $^{**}p < .01$		
Delayed post-test				
Computer model	13	8	0	92
Other models	63	33	52	15
		X^2 (2) = 10.36, $^{*}p < .05$		

Note. The values show the percentages of subjects. Frequencies were used in the actual analysis.