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AN INVESTIGATION OF MEANINGFUL UNDERSTANDING AND EFFECTIVENESS OF THE IMPLEMENTATION OF PIAGETIAN AND AUSUBELIAN THEORIES IN PHYSICS INSTRUCTION

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BY

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ABSTRACT

One section of college students (N= 25) enrolled in an algebra-based physics course was selected for a Piagetian-based learning cycle (LC) treatment while a second section (N=25) studied in an Ausubelian-based meaningful verbal reception learning treatment (MVRL). This study examined the students' overall (concept + problem solving + mental model) meaningful understanding of force, density/Archimedes Principle, and heat. Also examined were students' meaningful understanding as measured by conceptual questions, problems, and mental models. In addition, students' learning orientations were examined. There were no significant posttest differences between the LC and MVRL groups for students' meaningful understanding or learning orientation. Piagetian and Ausubelian theories explain meaningful understanding for each treatment.

Students from each treatment increased their meaningful understanding. However, neither group altered their learning orientation. The results of meaningful understanding as measured by conceptual questions, problem solving, and mental models were mixed. Differences were attributed to the weaknesses and strengths of each treatment.

This research also examined four variables (treatment, reasoning ability, learning orientation, and prior knowledge) to find which best predicted students' overall meaningful understanding of physics concepts. None of these variables were significant predictors at the .05 level. However, when the same variables were used to predict students' specific understanding (i.e. concept, problem solving, or mental model understanding), the results were mixed. For forces and density/Archimedes Principle, prior knowledge and

reasoning ability significantly predicted students' conceptual understanding. For heat, however, reasoning ability was the only significant predictor of concept understanding. Reasoning ability and treatment were significant predictors of students' problem solving for heat and forces. For density/Archimedes Principle, treatment was the only significant predictor of students' problem solving. None of the variables were significant predictors of mental model understanding.

This research suggested that Piaget and Ausubel used different terminology to describe learning yet these theories are similar. Further research is needed to validate this premise and validate the blending of the two theories.

CHAPTER 1

Introduction

Background of the Study

Physics is a course dreaded by nearly all who are required to take it. Teachers also know that students gain little meaningful understanding from conventional physics instruction (McCloskey, Carmazza & Green, 1980; Moreira, 1977; Williams & Cavallo, 1995). Physics students often confess to memorizing material to get through courses (Williams & Cavallo, 1994). One possible reason for students' tendency to memorize facts, equations, and laws and, consequently, to have a lack of understanding of physics is that the subject consists of many abstract concepts (Inhelder & Piaget, 1958; Prosser, 1983; Linn, Clement, & Pulos, 1983). Students who do not possess the reasoning ability needed to deal with such concepts may resort to memorizing facts, formulas, and problem types to get through physics courses (Hammer, 1989; Hewett, 1995; Renner & Marek, 1988). Also, many physics teachers focus on formulas without emphasizing the need for conceptual understanding of the subject. Hewett (1995) states that "students can learn to solve problems... without the faintest gut feeling for the concepts that underlie them" (p. 85).

Meaningful learning is defined as "the formation of viable relationships among ideas, concepts, and information" (Williams & Cavallo, 1995). In other words, students with a meaningful learning orientation attempt to make connections between concepts. Whereas, students not possessing a meaningful learning orientation memorize facts or verbatim statements of ideas found in a text or said by the teacher (Novak, 1984). The latter are called "rote learners". Learning orientation is not dichotomous, either rote or meaningful, but rather, may exist along a continuum between the rote and meaningful extremes. Meaningful understanding is the product that may result when a person with a meaningful learning orientation and sufficient prior knowledge interacts with content that has the potential of being learned in a meaningful way (Novak, 1984).

The U.S. Department of Education (McKinney, 1993) stresses the need to teach mathematics and science for understanding rather than for absorbing facts. More recently, the National Science Teachers Association (NSTA, 1993) recommended that the most appropriate approach to teaching is a constructivist approach. The NSTA addressed the problem of the lack of meaningful learning in this statement: "the typical U.S. science program discourages real learning not only in its overemphasis on facts, but in its very structure which inhibits students from making important connections between facts" (NSTA, 1993, p. 2). They further state that this roteness of learning deters many students from continuing to study the sciences. Others who make recommendations about teaching physics also emphasize teaching so that understanding results from instruction (Michels, Sears, Verbrugge, & Palmer, 1957; Dickie, 1994; Aldridge & Strassenburg, 1995). Aldridge and Strassenburg (1995) describe content standards for high school physics in terms of understanding the relationship of a concept to various other related concepts. Although not explicitly mentioned, meaningful learning was described in terms of understanding the relationships of various physics concepts to one another. Thus, meaningful learning and its product, meaningful understanding, are important outcomes of physics instruction.

Instruction that promotes meaningful learning according to Ausubelian theory would promote meaningful understanding (Ausubel, 1963; Novak, 1984; Wandersee, 1988). For meaningful understanding to occur, physics concepts must be potentially meaningful to the students. In addition, students must possess sufficient prior knowledge about a concept and a meaningful learning orientation for meaningful learning to occur (Pines & Novak, 1985). Furthermore, students must make connections between concepts, ideas, and knowledge. These are the requirements that instruction aimed at promoting meaningful learning must satisfy.

The learning cycle is a teaching procedure which has been found to increase reasoning ability, concept understanding, and achievement (Lawson, Abraham, & Renner, 1989; Lawson, 1995), but what effect would a learning cycle have on students' meaningful learning orientations and meaningful understandings? Since the learning cycle increases reasoning ability, concept understanding, and achievement, what relationships are there between these variables, meaningful learning orientation, and meaningful understanding? It seems reasonable that a teaching procedure which produces increased conceptual understanding might also produce meaningful understanding of concepts. Williams and Cavallo (1995) found students' reasoning ability to be significantly related to meaningful learning orientation. Hence, it is possible that the learning cycle, which has been found to increase reasoning ability, could also increase students' meaningful learning orientation. Students' meaningful understanding of physics concepts could be increased if the learning cycle shifted the students' learning orientation more toward the meaningful end of the continuum.

Thus, the learning cycle is an instructional procedure that might promote meaningful learning as defined by Novak (1984) and Ausubel (1963). Does a learning cycle treatment have an effect on students' meaningful learning orientations and meaningful understanding? In other words, does allowing students to: (1) experiment with materials to gather data, (2) construct a concept from those data, and (3) expand this idea or concept cause a change in a students' meaningful learning orientation in physics or meaningful understanding of physics concepts? If so, are these shifts significant?

In this study, students' meaningful understanding of physics will be determined from the students' scores on three measurement items: (1) questions about physics concepts that are categorized as being at higher levels of Bloom's taxonomy (comprehension, synthesis, and analysis); (2) solving physics problems, typically the only method of assessment of student understanding in many physics courses; and (3) mental models in which students respond in writing to demonstrate their meaningful understanding of a topic by their ability to successfully relate it to other items in correct ways. If the learning cycle treatment improves meaningful learning, then at least one of the three measures must indicate higher average scores for the students in the learning cycle as a result of the treatment used in this study.

In meaningful verbal reception learning (MVRL), students are presented potentially meaningful material. In other words, the content is not to be discovered or invented by the learner; it must be non-arbitrarily incorporated by the students into their cognitive structure. Thus, by being related to items in cognitive structure, the content is made available for future use (Ausubel, 1963; Novak, 1984). Hence by design, MVRL is not rote in nature, and students engaged in meaningful verbal reception learning are not necessarily passive learners. MVRL was designed to be more efficient at promoting meaningful understanding than discovery (Ausubel, 1963; Novak & Gowin, 1984; Novak, 1988a), but how does MVRL affect meaningful understanding of physics concepts? How does learning to incorporate content via MVRL affect students' meaningful learning orientation and meaningful understanding of physics concepts? If MVRL does cause shifts in meaningful orientation or understanding, what is the magnitude of the shifts? If such shifts are significant, MVRL should also promote improvements in meaningful understanding according to Ausubel (1963).

The learning cycle and MVRL treatments have been presented as possibly having an effect on students' meaningful learning orientation and meaningful understanding. The two treatments will be compared to determine if one treatment has a greater influence upon students' meaningful learning orientation and meaningful understanding of physics concepts.

It has been hypothesized that the learning cycle and MVRL treatments positively affect meaningful learning orientation, and thus, meaningful understanding. Could there be variables other than meaningful learning orientation that contribute to a student's meaningful understanding of physics? Reasoning ability has been mentioned as a predictor of students' meaningful understanding of physics concepts. Williams and Cavallo (1995) found that reasoning ability, and not meaningful learning orientation, was a statistically significant predictor of physics understanding as measured by the FCI. Cavallo and Schafer (1994) found that meaningful learning orientation was the best predictor of meaningful understanding of genetics topics on all but one measure for which prior knowledge was a better predictor. Ausubel claimed that prior knowledge was necessary for meaningful understanding; thus, prior knowledge should be examined as a predictor for meaningful understanding of physics concepts. This research will also examine the effect that instructional treatment has upon meaningful understanding. These questions will also be investigated in this study. Of the variables hypothesized to be useful predictors of students' meaningful learning, which variable is more important for students' meaningful understanding of physics concepts? Does students' reasoning ability, their meaningful learning orientation, their prior physics knowledge, or their instructional treatment better predict students' meaningful understanding of physics concepts?

Purpose of the Study

The purpose of this study is to determine if a learning cycle style physics class and a MVRL style physics class have any effects on students' meaningful learning orientation and meaningful understanding of physics concepts. If so, in what direction are the effects, and are the effects significant? The two treatments will then be compared to determine if one style causes significantly more students to increase their tendency to learn meaningfully and to have increased meaningful understanding of physics concepts. In addition, any effects due to instruction that exist on each sub-measure of meaningful understanding of physics as well as for overall meaningful understanding of physics will be examined.

What other variables may predict students' meaningful understanding of physics concepts? Reasoning ability, meaningful learning orientation, prior knowledge, and instructional treatment will be examined to determine their power to predict students' meaningful understanding of physics concepts.

Significance of the Study

No reported research has examined the use of the learning cycle to alter students' meaningful learning orientation or students' meaningful understanding of physics concepts. Students may need to be instructed in a way that promotes the abandonment of rote learning in favor of more meaningful learning approaches. When this occurs according to Ausubel, more meaningful understanding of physics concepts should occur. As has been stated earlier, students' tendency to learn more and more meaningfully and with more meaningful understanding are desired outcomes of physics education. Thus, this study is significant to physics educators interested in improving students' meaningful understanding.

Why was the learning cycle treatment chosen since it has not been examined with respect to meaningful learning? Williams and Cavallo (1995) found that students' reasoning ability was significantly positively correlated to their meaningful learning orientation, and according to Lawson (1995) learning cycle instruction has been found to increase students' reasoning ability. Based upon these findings, it seems possible that the learning cycle may promote an increased meaningful learning orientation, and consequently, more meaningful understanding of physics concepts by students. If learning cycle instruction increases reasoning ability, then perhaps, meaningful learning orientation is increased in a similar manner. Thus, this research will provide information about the effects of the learning cycle on meaningful learning.

Why was meaningful verbal reception learning chosen as a treatment? MVRL, as espoused by Ausubel (1963) and further modernized through the use of aids (concept maps and Vee diagrams) by Novak and Gowin (1984), was designed to be an efficient way for students to learn meaningfully. MVRL is often confused with traditional lecture instruction. However, the order of the presentation of material in MVRL differs from that of traditional lectures. In traditional lectures, material is presented as homogeneous topics. Topics are typically taught in the order that the chapters are presented because the topics are related, not because they are more general or inclusive than another topic. In MVRL, material is presented so that the most general topics are presented first, then the more detailed and specific concepts are related to the more general ones. According to Ausubelian theory, meaningful learning must begin with the more general topics that provide the scaffolding for the more specific ones presented later.

If MVRL produces increased meaningful understanding with students in college physics, it could be a more economical teaching procedure than the learning cycle since MVRL can withstand higher student-to-teacher ratios with fewer negative effects than learning cycle instruction. In addition, MVRL style physics classes at the college level could be taught over the Internet as MVRL does not require laboratory materials and instructors to lead students to the concept. Before universities invest much time and money in the design of such a course, the efficiency of MVRL to produce meaningful understanding must be examined. Ausubel said that having a meaningful learning orientation was necessary for meaningful understanding, but he did not elaborate on how students should attain such an orientation. For example, MVRL might not increase students' meaningful learning orientation. Therefore, if MVRL does not produce an increase in students' meaningful learning orientation, it may not be a procedure that universities should select. Having an increasingly meaningful learning orientation should result in meaningful understanding over time, while having an increasingly more rote orientation should result in less meaningful understanding over time. Using MVRL to increase students' meaningful learning orientation has not been examined. This research will provide information about any effects of meaningful verbal reception learning on aspects of meaningful learning.

Problem Statement

The magnitude and the direction of measurable differences in students' meaningful learning orientation and their meaningful understanding of physics concepts as determined by three separate measures will be examined after treatments. These differences will be examined for a class of students with learning cycle instruction and for a class of students with meaningful verbal reception learning instruction. The study will determine which variable (students' reasoning ability, their meaningful learning orientation, their prior knowledge of physics concepts, or the instructional treatment) is the better predictor of students' meaningful understanding of physics concepts.

Research Questions

The study is designed to allow the investigation of the following research questions:

1. What are the magnitude and direction of measurable significant differences in meaningful learning orientation and meaningful understanding of physics concepts between students with learning cycle instruction and those with meaningful verbal reception learning instruction?
2. What are the magnitude and direction of measurable significant differences in meaningful understanding of physics concepts measured by (1) conceptual questions, (2) problem-solving, and (3) mental models between students with the learning cycle and meaningful verbal reception learning instruction?
3. Which variable (reasoning ability, meaningful learning orientation, prior knowledge, or instructional treatment) is the best predictor of overall meaningful understanding of physics concepts?
4. Which variable (reasoning ability, meaningful learning orientation, prior knowledge, or instructional treatment) is the best predictor for each sub-measure of meaningful physics understanding?

CHAPTER 2

Literature Review

Ausubelian Theory and Meaningful Learning

Learning, inquiry or reception, can be rote or meaningful. So what is it that distinguishes rote from meaningful learning? Rote learning is the "arbitrary, verbatim, non-substantive incorporation of new knowledge into cognitive structure" (Novak & Gowin, 1984, p. 167). Rote learners do not try to integrate new information with existing information, nor is their learning related to experience. Meaningful learning occurs if the learning task can be related in a "non-arbitrary, substantive fashion to what the learner already knows, and if the learner adopts a corresponding learning set to do so" (Ausubel, 1963, p. 18). The first requirement above stipulates that the task must be potentially meaningful or, in other words, that the task content is such that it can be related to previous knowledge, concepts, or ideas. For example, the memorization of nonsense letters, words, syllables, or numbers would not be considered a meaningful learning task because any relationship to previous concepts would be arbitrary. The second requirement for meaningful learning demands that the learner adopt a learning set. A person has a meaningful learning set if he or she can "relate substantive aspects of new concepts, information, or situations to relevant components of existing cognitive structure in ways that make possible the incorporation of derivative, elaborative, correlative, supportive, qualifying or representational relationships" (Ausubel, 1963, p. 22). A rote learning set, on the other hand, is one in which the learner intends only to memorize. Hence, what is internalized remains discrete and isolated from other information because it is not related to other parts of existing cognitive structure. Researchers (Cavallo & Schafer, 1994) have defined meaningful learning orientation as the tendency to form relationships between ideas, information, and facts of science. A person may tend to learn meaningfully and thus have a more meaningful learning set or orientation. Another person may tend to learn by rote, and thus, have a more rote learning orientation. Orientation or learning set is not dichotomous, either rote or meaningful, but rather exists along a continuum between the rote and the meaningful extremes. Possessing a meaningful learning set enables one to have a meaningful learning process, but does not ensure that meaningful learning will occur. As one moves toward the meaningful end of the continuum in a discipline, the conceptual structures become more like those of an expert in the discipline (Novak, 1988b).

Ausubel uses the adverb "potentially" to emphasize that a task cannot be meaningful, only potentially so. Being potentially meaningful requires that: (1) the material be capable of being non-arbitrarily related as well as (2) the individual doing the learning can relate the concept to his or her own structures. Thus, the second criterion requires that the learner possess relevant prior knowledge before the task may be potentially meaningful. Hence, the term "potentially meaningful" brings with it two criteria that must exist for meaningful learning to occur. In summary, the conditions that Ausubel claimed must exist for meaningful learning are: (1) the learner must have relevant prior knowledge, (2) the tasks must have the potential to be learned meaningfully, and (3) the learner must adopt a meaningful learning set or orientation. A successful outcome, meaningful understanding or meaning, may or may not occur depending on the above conditions surrounding the learner and the task.

The theory behind Ausubel's position espousing verbal reception learning is based on several key concepts or processes: subsumption, progressive differentiation, superordinate learning, and integrative reconciliation. Subsumption is the process in which "new information often is relatable to and subsumable under more general, more inclusive concepts" (Novak & Gowin, 1984, p. 97). Novak (1988b) defined subsumption as the "incorporation of new knowledge into a specifically existing concept or proposition" (p. 11). General concepts are superordinate to less inclusive or more specific concepts or propositions. That material is subsumable in a "non-arbitrary, non-verbatim fashion accounts for its potential meaningfulness" (Ausubel, 1963, p. 25). If material was not subsumable, the material would be considered rote and not potentially meaningful. Subsumption provides the "anchorage for new material". However, subsumption also has an obliterative tendency. As a result of being related to and included with other items, the specific items become more and more melded together or less dissociable. Thus, obliterative subsumption may also result in forgetting if the material becomes indissociable. So to be subsumed means possible meaningfulness for material as well as later forgetting due to the obliterative tendency of subsumption. In meaningful verbal reception learning, repetition or overlearning has been advocated to maximize learning and minimize forgetting.

Progressive differentiation is the principle that "meaningful learning is a continuous process wherein new concepts gain greater meaning as new relationships (propositional links) are acquired" (Novak & Gowin, 1984, p. 99). Concepts are continually being: modified, made more explicit, and made more inclusive as the learner perceives greater and greater differences between the concept and related concepts. As a result of progressive differentiation, preciseness of understanding, or meaning, increases.

Superordinate learning refers to the process in which a more general new concept subsumes previous subsumers (Novak, 1984). "New concepts or propositions acquired that connect the meanings of two or more related, less inclusive ideas" is called superordinate learning (Novak, 1988, p. 12). One's concept of learning must be adjusted. No longer must we think that learning is accompanied by a change in behavior, but rather, learning is observed by a change in the learner's meaning of experience. Therefore, previously learned concepts are subsumed and thus take on new meaning. They can have new or different relationships with one another through progressive differentiation and integrative reconciliation.

Integrative reconciliation is the principle by which the learner "recognizes new relationships (concept linkages) between related sets of concepts or propositions" (Novak & Gowin, 1984, p. 103). Integrative reconciliation tends to break the isolation or compartmentalization of concepts as relationships are formed between various previously isolated concepts or ideas. Furthermore, they propose that often new propositional linkages between concepts displace misconceptions because a misconception is often simply the failure to integrate a particular concept.

Meaningful Verbal Reception Learning (MVRL)

How is MVRL implemented in the classroom? Ausubel proposed the use of "appropriately relevant and inclusive" advance organizers to allow for progressive differentiation and integrative reconciliation (Ausubel, 1963, p. 81). Research by Purdom and Kromrey (1992), Glover, Bullock, and Dietzer (1990), Novak and Musonda (1991), as well as that by Rubin and Tamir (1988) support this claim by Ausubel. Rubin and Tamir (1988) state, "the function of advance organizers is to provide a bridge between the existing cognitive structure of the learner and the new content they have to learn" (p. 477). The organizers are called "advance organizers" in that they are presented before the learning task. Research has shown that a short delay should occur between the reading of the advance organizer and the reading of the assignment (Glover, Bullock, and Dietzer, 1990). Such organizers should be more abstract and more generalized as well as more inclusive in order that they explain, integrate, and interrelate the material that follows. The organizers act as subsumers in that they (1) provide a general overview prior to the material and (2) encompass the content and relevant concepts in an efficient manner. Such ultimate organizers do not exist in the learner. Only less relevant and less inclusive ones exist since the learner cannot have such organization prior to learning. Ausubel claimed that organizers prevent the isolation of similar concepts and terms because organizers "mobilize all available concepts in cognitive structure that are relevant for and can play a subsuming role" (Ausubel, 1963, p. 82). Subsumers may be relatively large or may be poorly developed "depending on the frequency that meaningful learning occurs in conjunction with a given subsumer" (Moreira, 1977, p. 8). According to Ausubel, without advance organizers or subsumers to provide anchorage, one must resort to rote learning. He claimed much rote learning is caused by students being forced to learn details before they have sufficient subsumers available on which to anchor the new material. Pines and West (1986) claim "the majority of students learn to play the 'school game' of rote learning and regurgitation of curricular knowledge" when students' spontaneous knowledge and formal knowledge do not match (p. 597).

The important point to remember in delivering instruction that is consistent with Ausubelian theory is that one must begin with the most general and more inclusive concepts and then anchor more detailed and specific concepts to the more general ones (Ausubel, 1963; Trowbridge & Wandersee, 1994). According to Ausubel (1968, p. 152), "it is less difficult for human beings to grasp the differentiated aspects of a previously-learned, more inclusive whole than to formulate the inclusive whole from its previously-learned differentiated parts". He states that it is rare for textbooks to be organized from the more general concepts to the more specific. Rather, topics that are homogeneous are put into separate chapters or subchapters because they are related (Ausubel, 1963; Moreira, 1977). There is little or no consideration for the concepts' inclusiveness, generality, or level of abstraction when topics are arranged topically.

Moreira (1977) outlined a second semester calculus-based physics course consistent with Ausubelian theory and MVRL. He recommended that the course begin with a general discussion of physics and physicists, the context of physics whether it be classical or modern, the role of concepts in physics, the key concepts of classical physics, and then a general discussion of the concepts of force and field. These concepts become subsumers for other subsumers in the learners' cognitive structures and the new concepts to come. Forces such as electrical or nuclear forces should be learned and related to one another only after the concept of force is already situated in cognitive structure. It is in this hierarchical way that meaningful learning takes place.

Fisher and Lipson (1985) state that those who attempt on a regular basis to integrate knowledge and resolve contradictions are "more proficient learners than those who routinely compartmentalize information" (p. 51). They claim learning meaningfully fits the old adage: "the more we know, the more we realize how much we don't know" (Fisher & Lipson, 1985, p. 52). Pines and West (1986) examined cases in which students compartmentalized knowledge. For example, when a student learned a topic in school that contradicted his or her prior personal knowledge, the student usually abandoned his or her personal knowledge and rotely repeated the school knowledge without reconciling the two. This is not meaningful learning. Meaningful learning only occurs when prior knowledge and formal (i.e., school) knowledge coexist. In physics, students' misconceptions and their lack of understanding often occur, perhaps because of this lack of knowledge intertwinement.

The association between Ausubel's key processes (subsumption, progressive differentiation, superordinate learning, integrative reconciliation, and the use of advance organizers) and learning should be evident. It is in this theoretical framework that Ausubel embraces meaningful verbal reception learning. Any method or tool that increases the use of these processes increases meaningful learning. Using these tools and advance organizers as well as implying a careful adherence to Ausubel's three criteria for meaningful learning provide for meaningful verbal reception learning.

Research in Meaningful Learning

Research on various aspects of meaningful learning will be summarized and categorized into five areas: (1) studies finding rote learning orientations or lack of meaningful learning; (2) studies finding increases in meaningful learning; (3) studies relating meaningful learning orientation or meaningful understanding to other variables; (4) studies on concept maps or Vee diagrams; and (5) studies about other tools or techniques that may bring about an increase in meaningful learning orientation, help students acquire meaningful understanding, or improve meaningful learning.

Studies Illustrating Rote Learning/Little Meaningful Learning

Research in meaningful verbal learning shows that many college-age students learn science content, concepts, and ideas by rote (Dickie,1994; Edmondson & Novak, 1993; Novak, 1988a; Williams & Cavallo, 1994). It is reported that meaningful learning potential is undeveloped in our students (Novak & Musonda, 1991). Novak (1988a) stated that "the small amount of science that is taught in most elementary schools is similarly dominated by rote learning of names, definitions, and miscellaneous facts" (p. 82). Novak reported that many learners admitted learning by rote without recognizing that another way of learning existed. Also, most students were not conscious of the fact that learning is their responsibility.

Wandersee (1988) found that fewer than half of the college students questioned claimed to use organizational tools when studying from a textbook and that only 6% of students questioned claimed to make a conscious effort to make connections between prior knowledge and new textbook concepts. These findings indicated that students are not approaching textbook study in meaningful ways.

Dickie (1994) examined the meaningful learning orientation of college physics students in Canada and found that students "approached physics with the intention of memorizing formulas rather than understanding concepts" (p. 33). In fact, only 5.6% of the students had a deep approach or meaningful approach to learning on the pretest given at the beginning of the course. This percentage illustrates the magnitude of the problem of rote learning in college physics.

Studies That Increased Some Aspect of Meaningful Learning

Moreira (1977) conducted a study in Brazil with students enrolled in a calculus-based second semester physics course and found that there were no differences on traditional achievement measures between the experimental group (Ausubelian organizational method) and the control group (traditional lecture method). This "finding suggests that the Ausubelian approach was at least as effective as the conventional approach, in terms of conventional achievement measures" (Moriera, 1977, p. 62). Additional results revealed that the degree of concept differentiation and the degree of association between related concepts were greater for the experimental group based upon word association tests and numerical association tests, respectively. Also, the concept maps of the experimental group were "qualitatively different from those of the control group students, and indicated better concept differentiation, more meaningful association and a hierarchical disposition coherent with Ausubel's theory" (Moreira, 1977, p. 124). However, it seems that this outcome was ensured since he introduced the experimental group to concept maps (concepts with linking words related to them) in the 'notes' sections and did not introduce them to the control group. He concluded that teaching according to Ausubelian theory produces greater concept learning, but not greater achievement.

Cullen (1983) examined concept learning in a college chemistry course to determine whether or not a concept of minor importance could be raised to the position of a high order or subsuming concept. He found that overt attempts, via written passages explaining the concept of entropy and describing how entropy explained phenomena observed in the laboratory, were effective for some students in improving their ability to show linkages between lower level concepts and a subsuming concept. In other words, some learners began to view the minor concept as a subsuming or higher level concept. Only about one half of the experimental group responded to the treatment and restructured their conceptual structure. He concluded that there must be some "preexisting desire to acquire and use high-order concepts" (p. 109). Cullen (1983) claims his research findings "indicate that careful preparation of meaningful instructional materials will not alone result in all students grasping the significance of high order concepts" (p. 110). He claimed that educators can and must help students understand the need for conceptual learning. Based on this work, advance organizers similar to Cullen's treatment should cause some physics students to learn more meaningfully.

Taylor (1985) examined the thinking, feeling, and acting of 30 college biology students who were taught a laboratory in which concept maps, Vee diagrams, and questioning techniques were implemented. Taylor claimed the use of these tools combined with a learning-how-to-learn focus changed the meaning of the laboratory for her students. Her students rated the laboratory course higher on end-of-semester evaluations than the remaining students in the course who had other laboratory activities. On the evaluation, her students also claimed to have learned more biology and rated highly the use of concept maps and Vee diagrams in the laboratory. Taylor concluded that empowering the students so that their meaning of a laboratory or course is changed requires educators to provide the tools and experiences with which they can learn to learn meaningfully. Meaningful learning is necessary for students' meaning of an educational experience to be changed as well as for them to integrate thinking-feeling-acting. From this, it seems possible that concept maps, Vee diagrams, and questioning in the physics lab could also cause the thinking-feeling-acting that is consistent with meaningful learning.

Bar-Lavie (1987) conducted research with 11th grade students of environmental science in Israel. He taught a version of Novak and Gowin's (1984) Learning How to Learn (LHTL) course before the students took part in an environmental science field program. Student achievement improved 80% after the LHTL course and continued to improve throughout the field program. The LHTL program improved both integrative thinking and hierarchical organization to a greater degree than was achieved in the field program. Meaningful learners continued to improve their ability to integrate concepts in field settings; whereas, rote learners failed to integrate concepts when in a field setting. He found that meaningful learners had higher achievement scores than rote learners and that objective evaluations did not detect as great a difference in the learners' achievement as was detected when evaluated by other methods such as concept mapping or interviews. Bar-Lavie (1987) also found that the environmental science field program increased the rate of "thinking-feeling-acting" (p, 127) behavior. This behavior is consistent with meaningful learning. However, meaningful learners tended to integrate the "thinking-feeling-acting" behavior as much in school as in the field while rote learners tended to integrate the behavior more in the field setting. These findings about concept maps and meaningful learning courses are easily applicable to the meaningful verbal reception learning treatment this study proposed.

Jegede, Alaiyemda, and Okebukola (1989) found that concept mapping instruction was more effective ($p < .01$) than traditional expository instruction in enhancing meaningful learning of a 10th grade biology course. The concept mapping group had greater achievement as well as less anxiety than the expository group. Jegede, Alaiyemda, and Okebukola (1989) concluded that "concept mapping promotes meaningful learning" (p. 7).

Amir and Tamir (1994) found that remedial activity materials significantly ($p < .01$) improved the understanding of photosynthesis and respiration for 11th and 12th grade students. The remedial materials were designed to promote progressive differentiation of photosynthesis and respiration. Once the concepts were differentiated, the number of misconceptions the students had about these topics tended to decrease. This study found that meaningful learning of concepts can be taught by the appropriate use of remedial materials. This supports the use of advance organizers in a meaningful verbal reception learning treatment.

<u>Studies Relating Meaningful Learning Orientation, Prior Knowledge, or Meaningful Understanding to Other Variables</u>

Ausubel claimed prior knowledge affects cognitive structure and subsequent meaningful learning. However, there was little evidence to support his claim. Pines and Novak (1985) indicated a need for empirical tests of Ausubelian theory because of the absence of support for his claims. The authors examined the effects of an Ausubelian-based audio-tutorial science treatment for first and second grade students to gain insight about prior knowledge and to determine whether or not instruction was effective. Children's propositions were examined since the number of propositions a student exhibits is indicative of the degree of differentiation and integration of the concept. Hence, if the number of propositions is greater after instruction, meaningful learning occurred. They found that audio-tutorial instruction was effective in creating valid concepts in children. Pines and Novak (1985) concluded that prior knowledge did affect post instruction concept knowledge. This conclusion provides support for Ausubelian theory in which new learning is related to prior knowledge.

BouJaoude (1992) examined the relationships among high school students' learning approaches, their prior knowledge and attitudes toward chemistry, and their chemistry misunderstanding score. Also, the differences between rote and meaningful learners were examined. The sample consisted of high school students taught by lecture and laboratory. Findings revealed that the pretest misunderstandings and the students' learning approach accounted for a statistically significant ($p < .01$) proportion of the variance on the chemistry misunderstandings test. They found the meaningful learners performed significantly ($p < .0001$) better than the rote learners on the misunderstanding measure (BouJaoude, 1992). The reason given for this finding was that meaningful learners appear better able to relate information acquired in the classroom to their prior knowledge and store the information in bigger, more organized chunks. When more of the information about a subject is organized together, misconceptions are easier to correct. On the other hand, rote learners store their information in smaller chunks. BouJaoude (1992) concluded it is necessary to teach students how to be meaningful learners. This study provides evidence that prior knowledge, as well as meaningful learning orientation should be variables included as predictors of meaningful understanding or physics. Also, it supports the need for students to possess a greater meaningful learning orientation since these students had greater understanding.

Ramsden and Entwistle (1981) examined three factors of approaches or orientations to studying: personal meaning, reproducing, and achieving and found that meaningful learning orientation was positively related to achievement, while the reproducing orientation had a negative relationship. Students indicated that the approach used depended upon the manner in which the test was taught. Conclusions were that good teaching, freedom in learning, and not overloading are good practices that would promote deep learning orientations. These changes should also promote the quality of what is learned. This study is applicable to the proposed study in that it provides evidence that meaningful learning orientation is related to achievement and treatment.

Entwistle and Waterston (1988) examined students' styles of studying with revised versions of two inventories. One was derived from cognitive psychology and the other from research. The Approaches to Studying Inventory suggested four main orientations: achieving (career motivation, hope for success), meaning (deep approach and intrinsic motivation), reproducing (surface approach and fear of failure) and non-academic (social motivation and negative attitudes) (Entwistle & Waterston, 1988). The Inventory of Learning Processes also suggested four main orientations: deep processing (evaluates and compares), elaborative processing (incorporates own terminology), fact retention, methodical study (study guide type activities). The two inventories had very close agreement between each set of scales. The authors reminded us that "approaches to studying are a product of the interaction between characteristics of individual students and their perceptions of the courses, teaching, and assessment procedures"

(Entwistle & Waterston, 1988, p. 264). Hence, attempts to alter a student's study strategies will be more effective if the learning environment is also changed so that the students will perceive the rewards of improved methods of studying. They emphasized that "rote learning is negatively related to fact retention among scientists" (Entwistle & Waterston, 1988, p. 262). In other words, students who had a surface approach had less retention of read factual material than those who had a deep approach. This finding is supported theoretically by the idea that facts are held more effectively when there are more meaningful linkages than when they are stored with one linkage as is done in rote learning.

Edmondson and Novak (1993) focused on research dealing with students' epistemological views and their learning strategies. Those with positivist views of science believe that science can be learned by objective observation. Those with a constructivist approach believe that knowledge is constructed using previous knowledge as a base. The authors emphatically endorsed the adoption of a constructivist epistemological order to advocate meaningful learning. A high level of integration is not possible when two or more systems of knowledge do not intersect. This parallelization invites rote learning as the most efficient method of learning if knowledge is absolute. This research indicated that typical elementary and college science courses tend to reinforce the positivistic epistemological view which further fuels rote orientations. The authors suggest that teachers make epistemological issues explicit and emphasize the active role of the learner in construction of knowledge just as real scientists do. The hypothesis is that students tend to gravitate toward a learning approach that is consistent with their epistemology. Therefore, in order to change their learning orientation, one must ensure a constructivist epistemology. These recommendations support both treatments proposed in this study.

Dickie (1994) examined college physics students' approaches to learning, the intellectual demand of assessment items, and the relationships between students' approaches to learning, the intellectual demands of assessment, and the students' performance in the course. He found that students "approached physics with the intention of memorizing formulas rather than understanding concepts" (Dickie, 1994, p. 33). Only 5.6% of the students had a deep approach to learning on the pretest, while most had a surface or achieving approach (Dickie, 1994). However, after two semesters of physics instruction, the percentages of the students having surface approaches and deep approaches increased while the percentages of those having achieving approaches decreased. Still, only 20% of students reported they tried to understand physics concepts (Dickie, 1994). Furthermore, t-tests comparing the pretest and posttest approach to learning means revealed a significant ($p < .08$) increase in surface approaches, no significant differences in the deep approach, and a significant ($p < .03$) decrease in the achieving approach. Hence, two semesters of physics had increased students' surface approaches and decreased their achieving approaches.

Using a modified version of Bloom's taxonomy, Dickie categorized the intellectual demands of assessment items. Correlations between students' physics understanding as measured by course assessment items and the achieving approach were positively correlated, while the deep approach was negatively correlated with physics understanding. He explained that only 6.6% of the assessment items for that course were categorized at the comprehensive level. Students were not rewarded on assessment items for possessing a deep approach; hence, they abandoned it. For the second semester, over one third of the items were at the comprehension level. This finding agreed with the shift of students' approach away from a surface approach in the second semester. Although statistical analyses were not calculated, he found that, in general, students with a deep or deep achieving approach were more successful than students with a surface approach (Dickie, 1994).

Dickie (1994) also examined the relationship of grade in the course and approach to learning. The only significant correlation between approach to learning and grade on the final examination was a negative correlation between achievement on the final examination in the second course and having a surface approach. Perhaps a more significant finding was the relationship between students' approach to learning and their scores on the Force Concept Inventory (FCI). Students with a deep approach scored significantly higher on the FCI than those with a surface ($p < .012$) or achieving approach ($p < .001$) and higher also than those with a deep achieving approach ($p < .005$) or a surface achieving approach ($p < .003$). Thus, the approach to learning measure was able to select those students who had an accurate conceptual understanding of Newton's laws of force since the FCI required "conceptual understanding rather than rote application of Newton's laws" (Dickie, 1994, p. 55). Based upon these findings, he suggests educators adopt strategies and assessment items that encourage meaningful learning, for meaningful learning means improved understanding. He also used a variety of measures on different levels of Bloom's taxonomy scale to measure meaningful learning. This study provides the basis for my use of high-level questions and problem-solving to measure meaningful understanding. The study also supports the use of meaningful learning orientation as a variable to predict meaningful understanding of physics concepts. To add further credibility to the aims of this proposal, Dickie emphasizes the fact that meaningfully-oriented students are more successful in physics than rotely-oriented students.

Consequently, a treatment that would cause students to approach learning in a more meaningful way would be of great value.

Cavallo and Schafer (1994) found that students' prior knowledge of meiosis and their meaningful learning orientation were significant predictors of high school biology students' meaningful understanding of the Punnett-square method and meiosis as well as the relationships between the two topics. Prediction strength was independent of that explained by aptitude and achievement motivation. The interaction of meaningful learning and prior knowledge significantly predicted meiosis understanding, process and conceptual relationship understanding, and understanding measured by relationship statements about meiosis and the Punnett-square method. They found no significant differences, except for those students who were midrange on the meaningful learning continuum, on meaningful understanding between generative and receptive treatments. The findings of this study support the inclusion of prior knowledge and meaningful learning orientation to predict meaningful understanding.

Cavallo (1996) measured high school biology students' meaningful learning orientation, reasoning ability, genetics meaning, genetics problem solving, and mental model knowledge of genetics. She determined that there was no significant relationship between high school students' meaningful learning orientation and reasoning ability ($r = .08$, $p < .05$). Furthermore, students' reasoning ability was not significantly correlated with their mental model scores, a measure of meaningful understanding. Cavallo (1995) examined the variables that best predicted performance on three tests (test of genetics meaning, test of genetics problem solving, and mental models). She described mental modeling as "an open ended assessment method that reveals the extent and nature (conceptual knowledge or procedural knowledge) of students' understanding of a given topic" (p. 12). She also found that students' meaningful learning orientation and reasoning ability predicted scores on genetics meaning, but meaningful learning orientation was the better predictor. The students' reasoning ability and meaningful learning orientation predicted students' achievement on tests of genetics problem solving, but reasoning ability was the better predictor. Cavallo (1996) compared the students' mental models with the mental models of students in a previous study and found that the two groups of students had very similar mental model frequencies. She introduced the use of mental models and problem solving to measure meaningful understanding of genetics. Further study should be conducted that investigates the use of similar measures in physics.

Lawson and Thompson (1988), Renner, Abraham, Grzybowski, and Marek (1990), and Williams and Cavallo (1995) found that students with higher reasoning ability had greater understandings or fewer misconceptions. The findings by Williams and Cavallo (1995) about reasoning ability and meaningful learning orientation contradict those of Cavallo (1996). Further research should be conducted with different meaningful understanding measures to determine if reasoning ability and not meaningful learning orientation are better predictors of meaningful understanding of physics concepts.

Westbrook and Marek (1991) found that none of their 7th-graders, 10th-graders, or university students of biology possessed a complete understanding of the diffusion concept. Concept evaluation statements were evaluated to determine the students' understanding of the concept of diffusion. They found the students were not appreciably different in the degree of understanding of diffusion despite the disparity in age. In fact, 55% of the 7th-graders had misconceptions about diffusion, whereas 65% of the 10th-graders and 61% of the college students had misconceptions about diffusion. It seems that greater exposure to diffusion only gave the more advanced students more terms to misuse rather than increasing their understanding.

A similar study by Westbrook and Marek (1992) examined the three age groups of students' understanding of the concept of homeostasis. The results were very much the same: There was very little understanding of the concept of homeostasis across the three age levels examined. Only 3% of the 7th-graders had partial understanding while the rest of them had no understanding or did not respond to the question. None of the 10th-graders had complete understanding and only 12% had partial understanding. Roughly, one-third of the college students had a complete or partial understanding of homeostasis. A great many of each age-level exhibited misconceptions (46%, 54%, and 64% respectively). A lack of understanding was pervasive across the grade levels. There was a trend toward greater understanding for those with greater cognitive reasoning. In spite of having studied the concept of homeostasis multiple times, students still could not grasp the formal concept.

Studies on Concept Maps or Vee Diagrams

Concept maps were defined as concepts (perceived relationships within a group of objects or events) and linking words (Heinze-Fry & Novak, 1990). Novak (1984) provided examples of concept maps and described their use. Concept maps must contain concepts, propositions, hierarchy, examples, and cross links. The hierarchical organization of a concept map requires the student to determine the most inclusive concept for a topic (superordinate). Students' concept maps are evaluated by assessing the propositions, hierarchy, and cross-links. Propositions indicate the relationships among concepts which is indicative of the degree of differentiation of concepts. The number of hierarchies indicate the extent of the differentiation. Examples are critical in meaningful learning since they aid students in anchoring new knowledge to prior knowledge. The number of cross links indicate the degree of integrative reconciliation. According to this model, meaningful understanding can be promoted and assessed using concept maps.

Novak (1984) complained that students in typical science laboratories rarely attend to the phenomena being observed and rarely question themselves as to what concepts, principles, or theories were important in understanding the laboratory concepts. Hence, laboratory work and lectures became separate knowledge entities. Novak suggests that educators instruct students not only in the key elements of the Vee, but also in its use as a tool to interpret laboratory work. Vee diagrams were defined as heuristic devices that represent the interplay between concepts, principles, and theories with observations and recorded data. The Vee consists of the key elements of: theory, principles, concepts, events, records or data, transformation of data, and knowledge claims. Novak claims the Vee allows students to conceptualize their laboratory work.

Novak, Gowin, and Johansen (1983) found that seventh and eighth grade students could successfully construct concept maps, but that many lacked cross-linkages. Perhaps instruction on concept maps did not properly emphasize the importance of cross-links. On the other hand, the lack of cross-linkages may indicate the students' failure to utilize integrative reconciliation because this age level may learn material in discrete bits. Students who used the Vee and concept maps scored significantly higher than the non-mapping students on solving novel problems. Since the correlation between achievement and mapping performance was low, mapping must measure a different ability than the typical achievement tests do. Mapping could broaden the teacher's arsenal of evaluation tools.

Novak (1993) described a previous study (Bacones & Novak, 1985) in which students who did concept maps had significantly (F=480) fewer misconceptions than students who did regular problem sets. Evidence suggests that concept maps assist students in the meaningful learning needed for the elimination of misconceptions and subsequent meaningful understanding.

Heinze-Fry and Novak (1990) examined the concept mapping and student attitudes in an auto tutorial college biology course. Students with higher SAT scores tended to benefit the most from mapping, although it was hypothesized that the lower SAT students might benefit from longer term mapping treatment. Analyses revealed that mapping tended to increase students' clarity, integration, and retention. Comments or attitudes about mapping content were generally positive, although some expressed frustration when new concepts did not fit into their old existing structures.

Trowbridge and Wandersee (1994) examined questionnaires, instructor interviews, and the concept maps of students enrolled in a college course on evolution to determine if evidence for critical junctures might be found. Also, the research sought to determine if concept mapping is viable in a college course on evolution. They defined critical junctures as "a conceptual watershed that divides students into two groups on the basis of their prior understanding of fundamental concepts relevant to those currently being taught" (Trowbridge & Wandersee, 1994, p. 461). In other words, a critical juncture is the point in a science course at which students must possess essential understanding of previous concepts before new concepts may be understood. Critical junctures were found by noting the confusion and uncertainty students had in identifying superordinate concepts. One third of the instructor comments to students about concept maps were regarding the lack of linking words. Seventeen percent of the instructor comments were statements calling for more examples. Instructors may use concept maps to determine whether or not meaningful learning has occurred by the evaluation of concept maps after critical junctures. Poorly constructed maps indicate little meaningful learning has occurred. Other findings revealed students spent considerable time constructing maps and thus, spent more time attempting meaningful learning. They also admitted spending 37% more time studying for the course (Trowbridge and Wandersee, 1994).

These studies on concept mapping and Vee diagrams suggest that: (1) low ability students can construct concept maps and Vee diagrams; (2) concept maps and Vee diagrams measure something different than traditional achievement tests measure; (3) those who make concept maps have fewer misconceptions; and (4) concept map use increases clarity, integration, retention, study time, and understanding.

Studies about Other Tools/Means that Increase Meaningful Learning Orientation, Meaningful Understanding, or Meaningful Learning

Other tools such as: audio-tutorial lessons, advance organizers, and questions have been studied with regard to their ability to increase some aspect of meaningful learning. The following describe characteristics of meaningful learning activities that have been found to increase meaningful learning.

Novak and Musonda (1991) developed audio-tutorial lessons (AT) for first and second grade students that would build upon one another so past lessons would serve as advance organizers for new material. One group of children participated in the AT lessons in first and second grade, while another group received no instruction. The children in this study were interviewed to assess changes in science concepts. Concept maps were made from the interviews. Novak and Musonda (1991) found a significant ($p < .015$) increase in the valid notions of students from grades two through twelve. The AT instructed students had higher concept map scores at every grade level. Thus, the 60 AT lessons served as advance organizers for the students when they enrolled in science courses later. Advance organizers assist students in resolving conflicting conceptions which promotes meaningful learning. This only occurs when knowledge becomes intertwined, hence, to resolve misconceptions is to learn meaningfully.

Purdom and Kromrey (1992) examined the effects of instructor intervention in cooperative learning on the achievement of elementary education majors in college who were enrolled in a curriculum course. One group had no instructor assistance; in another group, advance organizers were given by the instructor before cooperative learning; and in another group, the instructor conducted question and answer sessions after cooperative learning. They concluded that advance organizers improve learning more than post-session discussions or cooperative learning alone.

Rubin and Tamir (1988) found that familiar advance organizers combined with application-laboratory tasks improve students' understanding of the rules of scientific inquiry. Students having the advance organizers significantly ($p < .001$) outperformed the control students on tests of process skills in which they were required to analyze research and identify the hypothesis, the variables controlled, and conclusions. They also outperformed the control group on practical tests of problem solving and the advance organizers helped the weaker students most. Students' attitudes toward investigative laboratories were more positive than those attitudes toward verification laboratories.

Glover, Bullock, and Dietzer (1990) examined the type of delay between advance organizer use and the subsequent reading of text to understand conditions that optimize advance organizer use. They found that when as much as 10 minutes of inactivity or activity in another subject was placed between the reading and paraphrasing of the advance organizer, the subjects recalled significantly ($p < .01$) more of the text than when the advance organizer was immediately followed by the reading of the text without the delay. It was hypothesized that the delay provided sufficient time for the exact form of the advance organizer text and previous knowledge links to be forgotten. This causes extra processing which should enhance meaningful learning since prior knowledge is re-anchored to new ideas or concepts.

Armbruster, Anderson, Armstrong, Wise, Janisch, and Meyer (1991) claim that factual, memory-type of questions "are not likely to promote conceptual understanding and meaningful learning" (p. 37). Teachers should ask higher-order cognitive level questions to have students apply learning. Too often teachers ask low-level cognitive-level questions to check recall of knowledge. Other authors, Menke and Pressley (1994), had similar findings: Meaningful learning can be promoted by questioning activity which leads the students to tie new information to prior knowledge. This questioning, called elaborative interrogation (EI), requires students to generate elaborations which facilitates learning even if their responses to the questions are poor. Questions force learners to connect prior knowledge with new facts.

Piagetian Theory

Piaget believed that learners construct knowledge. However, Piaget differs from Ausubel on how that knowledge is constructed. According to Piaget, when a learner encounters input from the environment, the learner's schemes or mental structures incorporate the experiences or data. He called this cognitive process assimilation. Assimilation is a quantitative and qualitative change in existing schemes or mental structures. A scheme is "whatever is repeatable and/or generalizable in an action" (Renner & Marek, 1988, p. 30). In other words, schemes are "mental data processing procedures" (Renner & Marek, 1988, p. 30). The scheme is the basic unit of cognitive structure; whereas, the integration of schemes form what are called cognitive or mental structures. If and when newly assimilated information conflicts with previously formed mental structures, the result is called disequilibrium (Marek & Cavallo, 1997). Disequilibrium serves to motivate the learner to seek equilibrium. Without disequilibrium, schemata would not qualitatively change. Regaining equilibrium or cognitive harmony results in what Piaget called accommodation. Accommodation is in the development of new mental structures. This "accord of thought with things" was what Piaget called adaptation (Piaget, 1963, p. 8). Thus, assimilation and accommodation represent the learner's adaptation to the environmental input.

For Piaget, learning is still incomplete. The learner must then organize the new or newly modified mental structure with previously existing mental structures. Piaget called this process organization, or in his words: "the accord of thought with itself" (Piaget, 1963, p. 8). In organization, structure placement or the interconnectedness are examined and modified so they are in accord with one another. The processes of assimilation, accommodation, and organization are called functional invariants of intelligence. By functionally invariant, Piaget meant that all learners go through the same order of processes regardless of age.

Piaget emphasized that the types of mental structures and content (i.e. concrete or hypothetico-deductive) vary with the learner's age. Piaget described four cognitive stages of development: sensori-motor, preoperational, concrete operational, and formal operational (Renner & Marek, 1988). In the sensori-motor stage (from about 0-2 yrs.) the child uses sensory experience to construct schemes and learn to attach sounds to experiences, thus language develops. During this stage children develop object permanence from their experiences. There is no internal representation of objects or events in this stage. In the preoperational stage (about 2-7 or 8 years of age) the child is capable of seeing and reporting. Thus, the child has acquired the ability to internally represent objects and events. However, the child is egocentric (cannot take others' viewpoints), cannot reverse thinking, centers on aspects of perception, cannot see stages in a transformation, uses transductive reasoning, and cannot conserve various quantities. In the concrete operational stage (about 7-11+ yrs.), the learner can do all of the mental operations listed above that he or she was not capable of as a preoperational learner. According to Piaget, the concrete operational learner is bound to the world of experience and concrete objects. Thought is logical, but not yet optimally so in that the learner can not consider all possibilities and hypothetical situations. The formal operational stage (begins around 11-15+ yrs of age) embraces hypothetical-deductive reasoning, scientific-inductive reasoning, and reflective abstraction (Wadsworth, 1989). Formal operational thought is the pinnacle of reasoning. Piaget believed that such reasoning was independent of all subject matter and that formal reasoning followed the rules of propositional logic (Inhelder & Piaget, 1958). Formal reasoning is determined by the acquisition of five abilities: proportional logic, probabilistic reasoning, the separation of variables, combinatorial logic, and correlational reasoning (Tobin & Capie, 1981).

Piaget (1970) stressed that the development of the intellect is dependent upon natural processes and that it may be accelerated by education, but that it is not derived from that education. Piaget stated that experience, social interaction, equilibration, and maturation are the factors that affect cognitive development (Marek & Cavallo, 1997). Learning occurs best in an environment which allows and stresses self regulation, experience, and social interaction. Piaget suggests educators provide children with activities in which they may explore concepts at their stage of development. This acts to build the strongest foundation for the succeeding stages rather than acting blindly to accelerate stage development (Labinowicz, 1980).

Research in Piagetian Theory-Piagetian Stage Studies

Many researchers have found that the transition to formal operations or reflective thinking is not occurring, or has not developed by the time many students enter college. Resnick and Ford (1981) cited that the people in a few cultures never become reflective or formal operational thinkers. McKinnon and Renner (1971) found that 50% of the college freshmen tested were concrete operational or intuitive and that another 25% were not fully formal. Schwebel (1975) found that 17% of the college freshmen tested were concrete operational; 63% were at the lower formal level; while only 20% were at the upper formal level. The results of a seven-college study (Renner, et al., 1976) are no more encouraging. The percentage of fully reflective college students ranges from 12% to 61% among the seven institutions studied. Chiappetta (1976) compiled a table of studies of secondary and college age students. He concluded that most have not yet reached the reflective or formal operational stage.

Billeh and Khalili (1982) investigated cognitive development and the relationship between cognitive development and physics comprehension of 11th-grade Jordanian students. They found that only 17% of their sample was formal operational. They found that cognitive level is a significant factor in the comprehension of concrete concepts on the achievement test. That is, the higher the cognitive level, the better the comprehension of concrete concepts. They found formal operational ability aids in the understanding of formal as well as concrete concepts.

Renner (1986) reported that it appears the numbers of concrete operational thinkers leaving our schools is increasing. More recently, Trifone (1991) found that after using the Test of Logical Thinking (TOLT) in the assessment of developmental level that more than 75% of high school freshmen and about 60% of high school sophomores were still intuitive. Based upon finding high percentages of intuitive or concrete thinkers in high school, Trifone cautioned against teaching formal concepts to concrete thinkers because of an increased risk of creating misconceptions. Simply being concrete operational means that the possession of hypthetico-deductive reasoning is absent and without it the student cannot compare competing hypotheses. These studies span many decades and indicate that many American students are not able to make use of the formal thought structures. This is of concern in this study since Williams and Cavallo (1995) found reasoning ability to be a better predictor of meaningful understanding of physics concepts. Reasoning ability must be examined in order to assess its relationship to meaningful learning orientation and meaningful understanding in physics.

Lawson's Modified Version of Piagetian Stage Theory

Piaget's stage model is perhaps the most arguable part of his theory. "A long line of research indicates clearly that, although advances in reasoning performance do occur during adolescence, no one, including professional logisticians, reasons with logical rules divorced from the subject matter" (Lawson, 1995, p. 102). Therefore, Lawson suggests a modified version of Piagetian stage theory. Lawson (1995) chooses to view the patterns of "if... and... then" (p. 107) thinking across each age. In what Piaget called the sensori-motor stage, children's behavior follows the if... and ...then behavior. The child has the ability to empirically represent what was experienced. Thus, Lawson called this stage: stage one of preverbal deductive thinking. Lawson called what Piaget called the preoperational stage the second stage of preverbal deductive thinking. The child still thinks with the if...and...then pattern, but the child has the ability to initiate hypothetical mental representations. In other words, the child can represent something that has not been experienced. Piaget's concrete operational stage is Lawson's stage three of verbal deductive thinking. In this stage, Lawson claims the child verbally applies the if...and...then pattern to empirical propositions. Representations initiate their empirical thinking which is inductive in nature. He calls those in stage three intuitive thinkers. The Piagetian formal operational stage parallels Lawson's stage four called verbal deductive thinking. Once more, the if...and...then pattern is applied as it has been throughout development. Only hypothetical representations initiate thinking which is abductive in nature. The stage four child is "reflective, self-contained, and proactive" (Lawson, 1995, p. 112). Just as Piaget claimed, stage three children's thinking begins with the real, while stage four adolescents' thinking begins with the possible. Lawson (1995) states, "although Piaget's characterization of adolescent thought in terms of formal operations appears to be incorrect, his characterization of adolescent thought in terms of its hypothetical, as opposed to empirical, nature appears right on target" (p. 103).

Researchers (Renner & Marek, 1988) have found that concrete operational learners do not learn formal concepts. Likewise, preoperational learners do not learn concrete concepts. In theory, it is the student's attempt to learn concepts that are above his or her reasoning ability that results in misconceptions. Concrete learners are capable of reasoning with the concrete aspects of a concept, so when they attempt to reason with the formal aspect of a concept they often form misconceptions (Renner & Marek, 1988). The mental structures of the various stages are indeed, qualitatively different. Yet, the structures eventually become quantitatively more complex until the learner advances to the next stage. Changes occur in the way that the learner can apply a particular thinking pattern. A novel way of applying a particular thinking pattern brings with it more sophisticated reasoning which, over time, readies the learner's ability to apply yet another novel thinking pattern. This process of development is continuous, yet distinct reasoning patterns occur within the continuum of overall development.

The Learning Cycle

The learning cycle consists of three phases: exploration, conceptual invention (or term introduction), and application (formerly expansion) (Marek & Cavallo, 1997). During exploration students interact with materials under teacher guidance, but yet in a structured way designed to promote assimilation and disequilibrium. Piaget believed that learners must experience in order to get the information or essence of something into their cognitive structures. The exploration provides the opportunity for experience and social interaction as students gather data associated with the concept to be assimilated.

In the conceptual invention phase of the learning cycle, the teacher uses the data from all students in a class and, by asking probing questions of the students, leads them to recognize the pattern or regularity in the data. Once the students construct the regularity or pattern (concept), the teacher attaches the proper terminology if the students do not know the terminology. The conceptual invention phase of the learning cycle provides for the accommodation of Piaget's model of intelligence. The conceptual invention provides an opportunity for experience in manipulating data and interacting with others as students discuss data and construct the concept. It also provides an opportunity for equilibration.

Just as Piagetian theory did not end with the process of accommodation, the learning cycle does not end with conceptual invention. The third phase of the learning cycle, the expansion or concept application, requires the students to use the newly learned concept and the new terminology in different situations or with different materials. The expansion allows students the opportunity to organize their thoughts. This phase provides for the organization process of the Piagetian model. Therefore, the learning cycle explicitly provides the opportunity and activities for assimilation, accommodation, and organization through providing experiences, social interaction, and time for equilibration.

Why should the learning cycle be used to teach science? Renner and Marek (1990) proport that the learning cycle is an effective science teaching procedure since it is based on a sound theory base which "must include educational purpose, the discipline of science, and a model for learning" (p. 241). According to the Educational Policies Commission (1961), schools' purpose should be to teach students to think. The learning cycle meets this requirement since it relies upon building students' rational powers: recalling, imagining, classifying, generalizing, comparing, evaluating, analyzing, synthesizing, deducing, and inferring. With respect to being consistent with the discipline of science, students (during a learning cycle) perform activities that let them quest for knowledge which <u>is</u> science. With regard to the model of learning, the learning cycle was derived from the Piagetian model. In other words, the learning cycle is based upon a sound educational theory base.

<u>The Learning Cycle and Similarities of Piagetian Theory to Ausubelian Theory</u>

The Piagetian theory of learning as incorporated in the learning cycle is very similar to Ausubel's theory of meaningful learning. In organization the "new structure is placed among all of the other structures" (Renner & Marek, 1988, p. 32). Recall, also, that the expansion or concept application phase of the learning cycle provides for organization by allowing the learner to relate the new concept to other known concepts or to examine different aspects of the newly learned concept. The learner must detect similarities, differences and other relationships between the new and old structures. This process of organization seems very close to Ausubel's meaningful learning. Ausubel defined meaningful learning as relating the elements of a task "in a non-arbitrary, substantive fashion to what the learner already knows" (Ausubel, 1963, p. 18). The meaningful learning and organization definitions appear virtually the same. Perhaps meaningful learning is what occurs during the conceptual application (expansion) phase of a learning cycle? Providing time and activities in expansion to allow students to meaningfully learn, may give more students the opportunity to organize what they know. Theoretically the learning cycle is designed to cause students' meaningful learning. The following research about aspects of the learning cycle describe various advantages of using the learning cycle (improved reasoning ability, achievement, and concept understanding).

Learning Cycle Research

Research on the learning cycle will be summarized and categorized into four areas: studies showing the effects of the learning cycle on (1) reasoning ability, (2) achievement, (3) concept understanding, and (4) meaningful understanding.

Learning Cycle Studies and Reasoning Ability

Renner, et al. (1976) provided two different studies of curriculum that claimed to move the learner from the concrete level to the formal operational level. The first dealt with eighth and ninth-grade junior high school courses. Three courses: Introductory Physical Science (IPS); Time, Space, and Matter (TSM), and Investigating the Earth-The Earth Science Curriculum Project (ESCP) all shared in the primary goal of the development of problem-solving skills while encouraging experimentation and interaction with objects. The IPS (8th and 9th grade) curriculum provided investigations that attempted to develop an understanding of the structure of matter. The TSM (8th grade) course presented problems which could be solved through observations and investigations. The ESCP (8th and 9th grade) course was more content oriented with designed investigations to match the material presented. A comparison study was made of these curriculum courses versus the traditional textbook curriculum. The number of formal learners increased from 6% to 40%. The TSM and the IPS courses were found to account for the largest gain in formal thinkers. The ESCP course was composed of many formal concepts that were above the developmental level of the some students' which might explain its lower success rate. This study shows that the TSM and IPS courses can be used to accelerate the concrete learners into formal thought. Perhaps similar learning cycle treatment can accelerate college physics students' reasoning ability.

Marek and Renner (1979) examined an inquiry-based 10th grade biology class as compared to a non-inquiry class. They found that the students in the inquiry class had a greater increase in intellectual development, content achievement, inquiry skills (i.e. forming hypotheses, designing experiments, interpreting data), and IQ scores than did the control students. They caution that for concrete learners, courses should utilize concrete experiences, concrete content, and concrete teaching procedures.

Marek (1981) found that content achievement was positively correlated with cognitive development, IQ, and inquiry skills achievement ($p > .05$). Formal operational students had greater knowledge than the concrete operational students.

Lawson and Snitgen (1982) cited sources that support the premise that many college students fail to use formal reasoning. This study attempted to determine whether or not a one-semester inquiry-based biology course affects the developmental level of the students, their general intelligence, and their degree of field independence. They found a significant difference in the pretest and posttest means ($p < 0.001$) on the Classroom Test of Formal Reasoning for the pretested group. This supported the premise that inquiry instruction promotes formal reasoning development. The overall posttest mean score for the no pretest group was slightly lower than the overall group mean ($p < .10$). Therefore, simply taking the pretest did slightly improve posttest performance. They suggest the pretest acted somewhat like an advance organizer for reasoning. Analysis of pretest and posttest gains for the items not taught showed no significant differences; thus nonspecific transfer did not occur.

Lawson (1992) presented a brief summary of the findings from biology education research. He concluded that investigative, laboratory-based materials help college biology students acquire reasoning and process skills. Also, gains in reasoning were accompanied by equal or better achievement. He added that these gains appear to be general and long lasting. Such evidence supports the premise that learning cycle instruction improves meaningful understanding once reasoning ability is improved.

Westbrook and Rogers (1991) hypothesized "if the students did not have to involve themselves in hypothesis testing, the separation of variables, or other processes related to scientific investigation, then it seems unlikely that the students would show gains on tests that measure the ability to use those processes" (p. 7). In their studies, three types of learning cycles about simple machines were used. The three types of learning cycles present varying degrees of cognitive difficulty to the student. The control group conducted the descriptive learning cycle. Students observe phenomena and describe it; they do not answer "why" questions or design experiments.

Another group used empirical-abductive learning cycles, which present the students with "why" questions. Students do not perform experiments to answer the questions, but rely upon the data already collected in order to answer the questions. The last group used hypothetico-deductive learning cycles. In these learning cycles a question is posed to which students design and perform experiments that test any hypotheses they set forth. Findings revealed that there were no significant differences among the three treatments on reasoning ability. However, the hypothetico-deductive group significantly outscored the other groups on the science process skills measure as well as on one of the tasks measuring conditional/biconditional logic. Based on these results, Westbrook and Rogers (1991) concluded that providing the opportunity for students to design experiments, generate, and test hypotheses enhanced the use of conditional logic as well as science process skills. In addition, the empirical-abductive and hypothetico-deductive learning cycles are more indicative of the true nature of science than the descriptive learning cycles. They concluded that empirical-abductive and hypothetico-deductive learning cycles are more advantageous to student learning because such learning cycles represent "real science" and they improve students' science process skills and one aspect of their logical thinking. These results suggest the types of learning cycles that should be used in the proposed study.

Adey and Shayer (1990), through the implementation of a two year research project, attempted to accelerate the developmental level of British adolescents. The interventions in physics, chemistry, and biology were designed to be related to ten formal operational schemata. However, no attempt was made to teach the schemata. Two of the schools were middle schools (ages 11+ years). In each school control classes close in age and ability to the experimental classes were chosen. Piagetian reasoning tasks were used to obtain assessment of the developmental level. They were administered as pretests, midtests (after one year of intervention activities), posttests (after two years), and delayed posttests (one year after posttests in laboratory school only).

Adey and Shayer (1990) found that the laboratory students' reasoning scores were significantly higher than the control group at the posttest-pretest comparison ($p < .01$), but also at the delayed-pretest comparison ($p < .05$). So the experimental group continued toward faster developmental advancement without further treatment. The experimental group's cognitive development was statistically greater than the control group's by .21 of a developmental level or by .20 of a standard deviation. Regarding the case for general transfer of reasoning ability, one of the schools was not allowed to use interventions concerned with the probability schema. This school used interventions that dealt with other schema, then Piaget's pendulum task and probability task were administered to these students and the students from the control group. The intervention group having no probability interventions had pretest to posttest gains of 1.07 developmental levels on the Piagetian Pendulum Task and gains of 1.01 developmental levels on the probability task (Adey and Shayer, 1990). Gains on both tasks were significantly greater than the gains of the control group at $p < .01$. Thus, evidence is given for general transfer success since the probability schema was not taught. They concluded that success on the probability schema must have come from changes in cognitive ability due to the other interventions.

In a related study, (Shayer & Adey, 1992) examined the ability of the Piagetian tests to predict science achievement scores and found that increased cognitive development is not necessarily a condition for higher than normal science achievement. Residualized gain scores (rgs) are the difference of the grade achieved and the grade predicted. Large and positive rgs are indicative of a successful intervention. The correlation between the Piagetian posttests residualized gain scores (rgs) and the achievement science rgs was .34. They found that the boys obtained 40% more grades of C or higher in science than the control group. About 40% of the boys and 25% of the girls science effect sizes were two standard deviations above the control group, but the other 60% of the boys and 75% of the girls' scores did not differ from the control group. The interventions appeared not to be domain-specific improvements as both boys and girls showed significantly higher achievement in English on the science achievement test over the control group. The effect size for the boys scores was .32 of a standard deviation, whereas the effect size for the girls was .44 of a standard deviation. Males in the experimental group also showed an improvement over the control group in math with an effect size of .60 of a standard deviation. Finding increases in science, math, and English achievement after science interventions support their hypothesis that these increases were caused by increases in developmental level.

Such interventions must begin at the developmental level of the learner and allow exploration, activity, and active development of concepts for cognitive growth to occur. Some cases of success have been reported here, although in varying degrees. The degree of success depended upon the degree to which "optimal conflict" was achieved. Train a subject quickly for one task, and conflict will only occur in the same situation, with little or no generalization. Teach a subject to think about his or her own thinking in all situations, and generalization is greatest. These results indicate it is possible, although to varying degrees, to accelerate development of a concrete thinker into a more formal thinker.

Learning Cycle Studies and Achievement

Renner and Paske (1977) compared a learning cycle physics course with the traditional lecture class. The learning cycle group had greater content achievement gains, had greater satisfaction with instruction, and made greater gains on the Watson-Glaser critical thinking measure. Results were mixed on reasoning ability. Concrete students benefited more from learning cycle instruction than traditional formal instruction while the low-level formal students benefited from both forms of instruction. The relevance of this study stems form the direct application of a learning cycle to physics instruction. The findings of increased reasoning ability and increased content achievements are supportive of using a learning cycle treatment.

Purser and Renner (1983) examined the influence that one hour of exposition versus learning cycle has upon 8th/9th grade achievement of concrete and formal concepts. They found the learning cycle group scored significantly higher ($p < .001$) on concept achievement of biology concepts which are concrete than did the exposition group. There were no significant differences between groups on concept achievement of biology concepts which are formal. Thus, when teaching formal concepts to 8th or 9th grade students, the instructional practices <u>do not matter because students in this grade level do not achieve conceptual understanding of formal concepts</u>. These conclusions apply directly to the type of concepts that should be part of learning cycles.

Saunders and Shepardson (1984) examined the effect of formal versus concrete instruction upon science achievement and the reasoning ability of sixth grade students. Formal instruction used lectures, discussions, written and reading assignments, films, quizzes, and exams. No laboratory was implemented for this group. Concrete instruction made use of the learning cycle. Both treatments were implemented for nine months. Saunders and Shepardson (1984) found the concrete instruction group had a significantly ($p < .01$) higher posttest and delayed posttest science achievement score than the formal instruction group had. In addition, the concrete instruction group had more increased reasoning ability than the formal group.

Learning Cycle Studies and Understanding/Meaningful Understanding

Since learning cycles improve reasoning ability, it follows that better reasoners should have greater understandings. Note these studies don't necessarily examine meaningful understanding. Schneider and Renner (1980) examined 9th grade physical science students' understanding and reasoning. One group received one hour of exposition while the other group received one hour of learning cycle. Both treatments lasted for 12 weeks. The learning cycle group outscored the exposition group on content achievement. Further statistical analysis revealed that neither IQ nor reasoning ability was responsible for the significant differences found between the treatments. In addition, the learning cycle group showed greater gains in reasoning ability than the exposition group. These gains were also retained over the reasoning ability post-posttest administered three months after treatment.

Stepans, Dyche, and Beiswenger (1988) compared the effectiveness of expository instruction and learning cycle instruction in promoting improved understanding about sinking/floating concepts in students enrolled in a science class for elementary education majors. Results of interviews revealed neither group had more than 50% of the answers with explanations correct. The authors explained that this may be due to the problems reported teaching formal concepts to concrete operational students. Both exposition and learning cycle improved the college students' understanding of sinking/floating concepts. However, the learning cycle group had a higher percentage of correct responses than the expository group. They suggest using the learning cycle to teach science concepts for which students typically exhibit misconceptions. This is because to rid oneself of misconceptions, one must interconnect various ideas, concepts, or events. Once a student examines these with reference to one another, he or she must either accommodate or reorganize in order to resolve the mismatch uncovered. Such a process was described as meaningful learning (Dickie, 1994).

Lawson and Weser (1990) examined the degree to which nonscientific beliefs about life (creationism, orthogenesis, the soul) were held in comparison to reasoning level. The sample consisted of university, nonmajor, biology students. The learning cycle was used in the laboratory section of the course. They found that students with higher reasoning ability tended to move away from misconceptions about life toward valid conceptions and understanding. Thus, the learning cycle could be said to improve conceptions also. Meaningful understanding is often described as having valid conceptions, not misconceptions.

Marek and Methven (1991) examined the students of teachers who completed a science in-service workshop designed to teach teachers the use of the learning cycle. They compared their students to the students of teachers who did not complete the in-service and who taught by exposition. They examined the elementary students' conservation reasoning as measured by Piagetian conservation tasks and the language they used to describe several objects. They found the students in learning cycle classes had significantly ($p = .05$) greater gains in conservation reasoning than the students in the expository classes. They concluded the improvement in conservation reasoning was the result of learning cycle experience. The students' descriptive language statements were examined qualitatively and quantitatively. They found the language of students from the learning cycle classes had higher quality descriptions of objects than those given by students from expository classes. In addition, the former group also had significantly ($p < .05$) higher gains in the average number of words they used to describe the objects. They concluded the gains in the numbers of descriptive words could be attributed to the learning cycle or the direct experiences in them. Hence, an understanding of the scientific concept of property was greater in learning cycle classes than in expository classes.

Meichtry (1992) recommended the use of learning cycle instruction to promote the scientific literacy of middle school students. She cautioned teachers to sequence learning cycle activities to accommodate the four levels of concept understanding. For example, a descriptive understanding is necessary for a qualitative understanding. Similarly, a qualitative understanding is necessary for a quantitative understanding which is a prerequisite for symbolic understanding. According to Meichtry (1992) middle school students who are required to learn concepts with a symbolic understanding before they have the other prerequisite understandings "often become frustrated by their inability to understand the content and compensate by memorizing the information to appease the teacher" (p. 440). She claims the results of such memorizing are students with poor understanding and with decreased motivation. In addition, the learning cycle fosters more positive attitudes, increased problem-solving and decision making, as well as improved communication and cooperative skills. All of the above are necessary for scientifically literate citizens. This study is relevant to the proposed study since it found the learning cycle increased problem solving. The understanding required for problem solving will be a sub-measure of meaningful understanding in the proposed study. Based on this evidence, the learning cycle seems likely to increase the understanding required for problem solving.

Marek, Cowan, and Cavallo (1994) used a learning cycle and an expository lecture on diffusion to determine the misconceptions prevalent before and after instruction in the high school biology students. They found that none of the students had an understanding of diffusion before instruction. However, 94% of the learning cycle class's concept evaluation statements demonstrated an understanding of the diffusion concept while only 58% of the expository class' statements demonstrated an understanding. The authors point out that in order to understand a concept rather than to hold on to misconceptions, a connection of related ideas and facts must be linked to other known concepts. This study suggests that this linkage must be made by the student during activity such as learning cycles, not by the teacher during exposition. The authors point out that 58% of the expository class did, however, make the connections to allow them to understand the concept of diffusion. Why or what is it about these students that allowed them to make the transition from misunderstanding to understanding? The authors suggest that further research into meaningful learning orientation be conducted to test this hypothesis.

Sunal, et al. (1992) described a K-8 curriculum about natural resource science. It was "designed to address the concerns with the environment and stewardship of the planet via teaching of higher order thought processes, and fostering meaningful learning" (p. 1). The learning cycle approach was the chosen procedure. Concept maps were also a part of the curriculum. This was the only study found in the literature that associated the learning cycle and meaningful learning. However, no research studies of the effects of this curriculum were reported to substantiate their claim of meaningful learning.

CHAPTER 3

Methodology

Design

A quasi-experimental design using a non-equivalent control-group was used in this research. Such a design is characterized by the non-random assignment of subjects to groups and the administration of pretests and posttests to each group. Pretests and posttests of students' reasoning ability, their meaningful learning orientation, and their meaningful understanding was administered to each group. In the following text, LC represents the learning cycle treatment and MVRL represents the meaningful verbal reception learning treatment.

Sample

The sample consisted of college students enrolled in two sections of an algebra-based, first semester, freshmen level, physics course. Initial total enrollment in the two sections combined was normally about eighty students. The class met three hours per week for "lecture" and two hours per week for "laboratory" for 16 weeks. The sample was from a university in the Midwest having an enrollment of 3500-4500 students. The university serves a somewhat rural community. The city in which the university is located has a population of about 18,000.

One of the two sections was randomly chosen to receive the learning cycle treatment, while the other section received the meaningful verbal reception learning treatment. Because of conflicts with student schedules, it was not possible to randomly assign individual students into treatment groups. Statistical methods should eliminate any initial differences between the two groups due to non-randomization. Previous departmental analyses of the two sections over the past six years has not yielded any major differences in students' academic achievement between the two sections.

The researcher taught both sections of the lectures and all labs which minimized any effect of teacher variable. This researcher/instructor is an assistant professor of physics with a masters degree in physics. She has taught the course primarily as a lecture (3 hrs) and laboratory (2 hrs) course for ten years and has received very good evaluations from both students and administrators.

Instructional Treatments

Physics concepts taught were the same for each treatment. Students were instructed in the traditional topics typically taught in General Physics I: motion, forces, work, energy, momentum, circular motion, gravitational law, Archimedes' Principle, density, Pascal's principle, pressure, heat, phase changes, linear expansion, and the gas laws.

The learning cycle (LC) activities allowed the students to interact with materials that provide the data which they used to formulate their own concept. In theory, learning cycles allow students to learn concrete and formal concepts only if the students are in transition between intuitive and reflective thinking or are completely reflective thinkers. Descriptive and empirical-abductive learning cycles were modified or written for use in the learning cycle treatment. Learning cycle explorations took place in the laboratory section with occasional explorations during the "lecture" time because of the greater number of lecture periods a week. Sometimes these explorations were carried out in the classroom and other times a laboratory room was available for student use. The "lecture" time was used for conceptual invention (if not completed in lab), expansion of the concept activities, or testing. Appendix C contains the learning cycles used in the LC treatment. Expansion of the idea activities often were problems from *College Physics.*, 4th edition by Serway and Faughn (1995) and problems given by the instructor. Note the treatments were numerically coded for analysis.

In MVRL, students were taught how to construct concept maps from the ideas presented in *Learning How to Learn* by Novak and Gowin (1984). MVRL students covered the same material as the LC group, however it was covered in a different order. Topics and concepts were taught from the most general (energy and matter) to the most specific (i.e. acceleration and specific heat) according to Ausubel who stated that students must have more general knowledge initially to which more specific knowledge can be attached (subsumption). Students were given information about the various concepts from the researcher through verbal instruction, advance organizers, and the textbook *College Physics*., 4th edition by Serway and Faughn (1995). Students then organized this information when they constructed concept maps. For example, MVRL students were given assignments such as, "read pages 303 to 305 and construct a concept map on thermal expansion". The MVRL laboratories were also taught using concept maps and advance organizers even though a traditional lab book (Weems (1990)) was used. Appendix D contains concept maps that guided study in the course (done by researcher) and a sample of student concept maps.

Three concepts were chosen for analysis in this study: forces, Archimedes' Principle/density, and heat. Of course, a great many more concepts were covered in the course. All topics in the course were taught according to the prescribed treatment so students were accustomed to the treatment style.

Variables and Data Analysis

The variables of the study were categorized by research questions and are described below. Descriptions of the data analysis are provided for each question.

Question 1: What are the magnitude and direction of any measurable significant differences in meaningful understanding of physics concepts and meaningful learning orientation between students with learning cycle instruction and those with meaningful verbal reception learning instruction? First, the question about differences on meaningful understanding was addressed. The learning cycle treatment (LC) was one independent variable of the study and the meaningful verbal reception learning treatment (MVRL) was also an independent variable. The reasoning abilities of the learners, their prior knowledge, and their meaningful learning orientation were covariates for the determination of differences on meaningful understanding. The dependent variable was the students' meaningful understanding and allowed the examination of treatments as covariates significantly altering students' meaningful understanding.

In order to determine if any differences exist between the LC treatment and the MVRL treatment on the meaningful understanding variable, an analysis of covariance (one-way ANCOVA) was used. The effects of students' reasoning ability, prior knowledge, and meaningful learning orientation (all pretest measures) were covaried so that their effect upon their meaningful understanding was controlled. In this way any significant differences between the groups were attributed to the treatment (LC or MVRL).

Also, the ANCOVA adjusted for any initial differences between groups on measured variables present because of non-randomized samples. However, if there were no initial differences between the groups and there were no effects on meaningful understanding because of reasoning ability, prior knowledge, or meaningful learning orientation, then the statistical analysis became a simple one-way analysis of variance. Attrition caused the two groups to have unequal number of members in two of the concepts tested, so one member from one group was randomly removed from the larger sample to use the ANCOVA method of analysis which required equal groups. Thus, forces sample had 25 members for each treatment, while the density/Archimedes' Principle and heat samples had 24 members for each treatment. Non-normality of data was not a problem because the ANOVA and ANCOVA were robust to the assumption of normality. In other words, only large departures from normality would force nonparametric measures to be used.

Next, the question about differences in students' meaningful learning orientation was addressed. The reasoning abilities of the learners and their prior knowledge were covariates for the determination of differences on meaningful learning orientation. These covariates were measured so any effect they might have were controlled statistically with respect to the independent variable of concern (LC or MVRL treatments). The dependent variable was the students' meaningful learning orientation. This allowed the determination of whether or not the treatments significantly alter students' meaningful learning orientation.

In order to determine if any differences exist between the LC and MVRL treatments on the meaningful learning orientation variable, a one-way ANCOVA was used. The effects of students' reasoning ability and their prior knowledge (pretest measures) were covaried so that any significant differences in meaningful learning orientation (dependent variable) between the groups were attributed to the treatments (LC or MVRL). However, if there were no initial differences between the groups and there were no effects on meaningful learning orientation because of reasoning ability and prior knowledge, then the statistical analysis becomes a simple one-way ANOVA.

Question 2: What are the magnitude and direction of any measurable significant differences in meaningful understanding of physics concepts as measured by the: (1) conceptual questions, (2) problem-solving, and (3) mental models between students from the LC and MVRL groups? This part of the study determined, for example, if the LC treatment improved students' scores on problem solving more than the MVRL treatment. The procedure will be much the same as was done in question one, except that it must be done for each of the three measures of understanding. The LC and MVRL are independent variables of the study. The learners' reasoning abilities, their prior knowledge, and their meaningful learning orientation are covariates for the determination of differences on each individual measure of meaningful understanding. The dependent variable, students' meaningful understanding individual subscores, will allow the examination of treatments as covariates altering students' meaningful understanding on an individual measure of meaningful understanding.

A one-way ANCOVA was used to determine if any differences exist between the LC and MVRL treatments on the meaningful understanding as measured by each instrument. The effects of students' reasoning ability, prior knowledge, and meaningful learning orientation (pretest measures) can be covaried so that their effect upon their meaningful understanding on one measure can be controlled. In this way any significant differences between the groups can be attributed to the treatment (LC or MVRL).

Question 3: Which variable-- reasoning ability, meaningful learning orientation, prior knowledge, or instructional treatment-- is the best predictor of overall meaningful understanding of physics concepts? To determine which variable best explained students' overall meaningful understanding of physics concepts, a stepwise multiple regression was performed with students' reasoning ability measured by the TOLT, their meaningful learning orientation measured by the LAQ, prior knowledge measured by the overall physics understanding score, and instructional treatment (LC or MVRL). These variables were entered as predictor variables in the regression analysis.

Question 4: Which variable-- reasoning ability, meaningful learning orientation, prior knowledge, or instructional treatment-- is the best predictor for each sub-measure of meaningful physics understanding? To determine which variable best explained students' sub-scale meaningful understanding of physics concepts, a stepwise multiple regression was performed with students' reasoning ability measured by the TOLT, their meaningful learning orientation measured by the LAQ, prior knowledge measured by the overall physics understanding score, and instructional treatment (LC or MVRL). Four variables were entered in the regression analysis to predict student understanding on three understanding measures. These variables were (1) high level conceptual questions, (2) problem-solving, and (3) mental model scores. For example, the regression analysis allowed the determination of the variable most important for the understanding required for problem solving.

Measures

Reasoning Ability Measure

All of the instruments may be found in Appendix B. The Test of Logical Thinking (TOLT) was used to determine the students' reasoning ability. The TOLT is a 10 question instrument measuring formal or reflective reasoning. Each item requires the correct response and justification for the response. Scores on the TOLT range from 0 to 10. The reliability of the TOLT was reported as .85 and the internal consistency was reported as ranging from .56 to .82 for each two part subtest (Tobin & Capie, 1981). The predictive validity of the TOLT was reported as .74, while the criterion validity between the TOLT to Piagetian interview was .80 (Tobin & Capie, 1981).

Meaningful Learning Orientation Measure

The Learning Approach Questionnaire (LAQ) is a Likert scale instrument that was used to measure students' approach to learning and their view of science (Entwistle & Ramsden, 1983; BouJaoude, 1992; Cavallo & Schafer, 1994). This study used only those items that queried students on their approach to learning. The higher the score on the LAQ, the more meaningful is the student's approach to learning. Likewise, the lower the score, the more the student's tendency is toward rote learning. The LAQ was given as a pretest measure of students' meaningful learning orientation, as has been done by Dickie (1994), and as a posttest measure of students' meaningful learning orientation. The Cronbach-alpha internal consistency for the LAQ has been reported as .77 (BouJaoude, 1992). The split half internal consistency was found to be .71 for data from a previous study (Williams & Cavallo, 1995).

Meaningful Understanding Measure

The students' meaningful understanding of physics topics was measured using high level questions, problem solving, and mental model scores.

Conceptual understanding.

Okebukola (1990) found that meaningful understanding may be assessed through the use of multiple choice questions that are at the comprehension level and above. For his research, he used a 40 item test in which "40% of the items for each test were at the comprehension level, 30% at the application level, 10% at the analysis level, and 5% at the synthesis level, and 5% at the evaluation level" (Okebukola, 1990, p. 496). Dickie (1994) has examined physics assessments previously. Therefore, this researcher relied upon his categorizations to modify and create a measure suitable for measuring meaningful understanding of physics concepts. The conceptual tests were given as a pretest and as a posttest measure at the end of the conceptual unit.

The forces test of conceptual understanding used was the Force Concept Inventory (Hestenes, Wells, and Swackhamer, 1992). The FCI is one of the most widely used instruments in physics. The FCI is a 29-item multiple choice instrument designed to identify Newtonian physics misconceptions. The KR reliability for the FCI was .86 for the pretest and .89 for the posttest (Hestenes, Wells, and Swackhamer, 1992). The face and content validity of the items have been established by the authors as well. Questions 20 and 21 were omitted from the FCI as the students found the questions confusing and the split-half reliability was found to be r =.744 for this 27 question version of the FCI. As far as the percentages on Bloom's scale, 18.5% of the questions were at the comprehension level, 44.4% were at the application level, 18.5% were at the analysis level, 11.1% at the synthesis level, and 7.4% at the evaluation level.

A 17 question multiple choice exam on Archimedes' Principle and density was constructed to assess heat conceptual understanding. The split-half reliability was .768. On Bloom's scale, 11.8% were at the comprehension level, 23.5% at the application level, 35.3% at the analysis level, 11.8% at the synthesis level, and 17.6% at the evaluation level.

A 17 question multiple choice exam on heat was constructed to assess heat conceptual understanding. The heat split-half reliability was found to be .823. It was found that 23.5% were at the comprehension level, 29.4% at the application level, 23.5% at the analysis level, 5.9% at the synthesis level and 17.6% at the evaluation level of Bloom's taxonomy.

Problem solving.

Students' meaningful understanding of physics problem solving was measured by their score on a pretest exam and a posttest exam on solving novel problems. Dickie (1994) stated problems that are unfamiliar to the solver, but are structurally similar to familiar ones can be used to measure meaningful understanding of physics. Since problems are typically given for exams in the course, six similar problems were chosen to assess their problem solving understanding. The force exam split-half reliability was .635, the Archimedes/density reliability was .834, and the heat reliability was .740.

Mental models.

Cavallo and Schafer (1994) describe mental models as an open-ended assessment method that reveals student understanding. Students were asked to write everything that they knew about three physics topics: forces, density and Archimedes' Principle, and heat. Students' papers were examined for correctness only after being numbered to make them anonymous to the scorer. The original student sheets contained their names since the correctness of the essays counted as part of their exam (for posttest only). Only correct information was used in the scoring analysis for mental models. This information from student sheets was transferred by hand onto templates similar to that used by Mosenthal and Kirsch (1992). A template is found in Appendix B. Each sentence was transferred to one line of the grid with the categories: agent, action, object, receiver, goal or explanation, effect (points of reference), and time, location, and condition (points of observation). Mosenthal and Kirsch (1992) suggest that the growth in understanding of a student can be measured using a single knowledge model (mental model) of one concept or topic. The more categories, details in each category, and relationships that are included in a mental model indicate greater meaningful understanding of the topic than when fewer of these items are included. The mental model tests were scored by the researcher based upon a numerical assessment of categories. Scores may range from zero (no understanding) to some integer (more meaningful understanding). This integer may vary on different mental models topics for some physics topics have greater detail, more categories, and more linkages than other physics topics. The mental model measures were also given as a pretest and a posttest measure. One point was given for each category included in the model per sentence. (Note that this is not the traditional mental model method of scoring.) For example, if a student said, "the ball hit the tree when I threw it", the "ball" would be considered the agent, "hit" the action, "tree" the object, and the condition "when I threw it"; thus a student would be given a score of four for that sentence. One very common response: "for every action there is an equal and opposite reaction"; the condition category contains "for every action", the effect category contains "there is an equal and opposite reaction force". Thus, this sentence would get a score of 2. Two physics teachers unfamiliar with the mental models checked the placement of items into categories for a sample of students. Once on the templates (anonymous once placed on the templates), the templates were checked three times by the researcher over a period of months to ensure uniformity of placement of like and similar items.

A student's overall physics understanding score was obtained by summing the student's conceptual question score, problem solving score, and mental model score. This overall score was obtained for pretest and posttest. Pretest scores were used as covariates or as measures of prior knowledge.

CHAPTER 4

Results

Statistical analyses were performed to answer the four research questions. This chapter will provide the results of these analyses and will be organized by research questions 1 - 4. Descriptive statistics and correlations are in Appendix E. Significance level was taken to be $p < .05$ throughout.

Question 1

What are the magnitude and direction of measurable significant differences in meaningful understanding of physics concepts and meaningful learning orientation between students with learning cycle instruction and those with meaningful verbal reception learning instruction?

Three one factor analyses of covariance (ANCOVA) were performed to answer each part of question one for each of the three concept areas tested (forces, density/Archimedes' Principle, and heat). Note that one ANCOVA was performed for forces, one for density/Archimedes' Principle, and one for heat data to measure differences in meaningful understanding and in meaningful learning orientation. The results are found in Tables 1 through 6. The independent variable is in bold type. The other variables are covariates.

Table 1: Force Data ANCOVA

Source	*df*	*SumofSquares*	*Mean Square*	*F-ratio*	*P-value*
Treatment	**1**	**1412.314**	**1412.314**	**3.239**	**.079**
Learning Approach	1	15.477	15.477	.035	.851
Reasoning Ability	1	20.487	20.487	.047	.829
Force Understanding	1	4.900	4.900	.011	.916
Error	45	19622.498	436.056		

(dependent variable = overall force understanding)

Table 2: Density/Archimedes' Principle Data ANCOVA

Source	*df*	*Sum of Squares*	*Mean Square*	*F-ratio*	*P-value*
Treatment	1	**546.494**	**546.494**	**2.871**	**.097**
Learning Approach	1	57.937	57.937	.304	.584
Reasoning Ability	1	73.643	73.643	.387	.537
Density Understanding	1	192.151	192.151	1.009	.321
Error	43	8186.185	190.376		

(dependent variable = overall density/Archimedes' Principle understanding)

Table 3: Heat Data ANCOVA

Source	*df*	*Sum of Squares*	*Mean Square*	*F-ratio*	*P-value*
Treatment	1	**194.368**	**194.368**	**.807**	**.374**
Learning Approach	1	356.160	356.16	1.478	.231
Reasoning Ability	1	118.665	118.665	.492	.487
Heat Understanding	1	1.970	1.970	.008	.928
Error	43	10361.030	240.954		

(dependent variable = overall heat understanding)

Table 4: Force Data ANCOVA

Source	*df*	*Sum of Squares*	*Mean Square*	*F-ratio*	*P-value*
Treatment	1	**10.484**	**10.484**	**.279**	**.600**
Reasoning Ability	1	325.427	325.427	8.667	.005
Force Understanding	1	116.168	116.168	3.094	.085
Error	46	1727.277	37.550		

(dependent variable = meaningful learning orientation)

Table 5: Density/Archimedes' Principle Data ANCOVA

Source	*df*	*Sum of Squares*	*Mean Square*	*F-ratio*	*P-value*
Treatment	1	**1.696**	**1.696**	**.047**	**.830**
Reasoning Ability	1	78.374	78.374	2.159	.149
Density Understanding	1	78.267	78.267	2.157	.149
Error	44	1596.911	36.293		

(dependent variable = meaningful learning orientation)

Table 6: Heat Data ANCOVA

Source	*df*	*Sum of Squares*	*Mean Square*	*F-ratio*	*P-value*
Treatment	1	**78.325**	**78.325**	**1.342**	**.253**
Reasoning Ability	1	213.000	213.000	3.649	.063
Heat Understanding	1	56.293	56.293	.964	.331
Error	44	2568.580	58.377		

(dependent variable = meaningful learning orientation)

Table 1 shows that the students from the two treatments did not significantly (.05 level) differ in their overall meaningful understanding of forces (conceptual question score + problem solving score + mental model score). However, the learning cycle class had higher overall mean meaningful understanding force scores. The learning cycle class mean was 58.511, while the meaningful verbal reception learning class mean was 47.649.

Similarly, Table 2 shows that the students from the two treatments did not significantly differ (at the .05 level) in their overall meaningful understanding of density and Archimedes' Principle. As with forces, the LC treatment had higher numerical scores than the MVRL treatment since the overall mean density/Archimedes' Principle meaningful understanding score was 34.450 while the MVRL students' mean score was 27.425. Table 3 shows that the LC and MVRL students did not significantly differ in their overall meaningful understanding of heat.

Thus, from these analyses, the answer to the first part of the Question 1 is that there were no measurable significant (at the .05 level) differences found between LC and MVRL instruction in the students' overall meaningful understanding of these three physics topics.

Table 4 shows that the treatments for force concepts did not differ significantly in their affect on the students' meaningful learning orientation. The MVRL students' meaningful learning orientation mean (66.707) was only slightly higher than that of the LC students' (65.773).

Table 5 also shows that the LC and MVRL students did not differ significantly in meaningful learning orientation for the density/Archimedes' Principle concept. Once more, the MVRL students' learning orientation mean (65.737) was only slightly higher than that of the LC students' (65.346).

Table 6 illustrates the same lack of difference in treatment effect. However, this time, the LC students' meaningful learning orientation mean

(68.098) was slightly higher than the MVRL students' mean (65.402). Thus, for all topics studied, the LC and MVRL treatments did not differ significantly in their ability to change the students' meaningful learning orientation.

Question 2.

What are the magnitude and direction of measurable significant differences in meaningful understanding of physics concepts measured by (1) conceptual questions, (2) problem-solving, and (3) mental models between LC students and MVRL students?

Three ANCOVA's were performed to answer each part of Question 2 for each of the three topics tested (forces, density/Archimedes' Principle, and heat). Note that three ANCOVAS were performed for forces, density/Archimedes' Principle, and heat to measure differences in meaningful understanding in terms of the sub-measures of understanding: concept, problem solving, and mental model. The results are found in Tables 7, 8 and 9 below.

Table 7

ANCOVAS from Force Data

Source	df	Sum of Squares	Mean Square	F-ratio	P-value
Treatment	**1**	**8.175**	**8.175**	**1.313**	**.258**
Concept Score	1	140.898	140.898	22.627	.000
Reasoning Ability	1	56.980	56.980	9.151	.004
Learning Approach	1	.015	.015	.002	.962
Error	45	280.208	6.227		

Source	df	Sum of Squares	Mean Square	F-ratio	P-value
Treatment	**1**	**8.946**	**8.946**	**3.236**	**.079**
Problem Score	1	.029	.029	.010	.919
Reasoning Ability	1	21.890	21.890	7.918	.007
Learning Approach	1	.078	.078	.028	.867
Error	45	124.409	2.765		

Source	df	Sum of Squares	Mean Square	F-ratio	P-value
Treatment	**1**	**1225.936**	**1225.936**	**2.966**	**.092**
Model Score	1	260.915	260.915	.631	.431
Reasoning Ability	1	52.979	52.979	.128	.722
Learning Approach	1	77.107	77.107	.187	.668
Error	45	18597.318	413.274		

(dependent variable = specific understanding type; i.e. concept, problem, model)

Table 8

ANCOVAS from Density/Archimedes' Data

Source	df	Sum of Squares	Mean Square	F-ratio	P-value
Treatment	**1**	**17.504**	**17.504**	**2.161**	**.149**
Concept Score	1	43.460	43.460	5.365	.025
Reasoning Ability	1	37.485	37.485	4.627	.037
Learning Approach	1	5.459	5.459	0.674	.416
Error	43	348.354	8.101		
Treatment	**1**	**21.740**	**21.740**	**8.195**	**.006****
Problem Score	1	8.240	8.240	3.106	.085
Reasoning Ability	1	1.118	1.118	.422	.520
Learning Approach	1	5.252	5.252	1.980	.167
Error	43	114.077	2.653		
Treatment	**1**	**173.462**	**173.462**	**1.057**	**.310**
Model Score	1	22.115	22.115	.135	.715
Reasoning Ability	1	3.772	3.772	.023	.880
Learning Approach	1	13.116	13.116	.080	.779
Error	43	7058.008	164.140		

** $p < .005$ **(dependent variable = specific understanding type; i.e. concept, problem, model)**

Table 9

ANCOVAS from Heat Data					
Source	*df*	*Sum of Squares*	*Mean Square*	*F-ratio*	*P-value*
Treatment	1	.161	.161	.027	.871
Concept Score	1	3.122	3.122	.515	.477
Reasoning Ability	1	10.676	10.676	1.761	.192
Learning Approach	1	12.034	12.034	1.984	.166
Error	43	260.755	6.064		
Treatment	1	11.087	11.087	5.961	.019*
Problem Score	1	.862	.862	.464	.500
Reasoning Ability	1	7.073	7.073	3.803	.058
Learning Approach	1	.279	.279	.150	.700
Error	43	79.974	1.860		
Treatment	1	153.395	153.395	.735	.396
Model Score	1	22.140	22.140	.106	.746
Reasoning Ability	1	304.103	304.103	1.458	.234
Learning Approach	1	209.914	209.914	1.006	.321
Error	43	8971.703	208.644		

* $p < .05$ (dependent variable = specific understanding type; i.e. concept, problem, model)

Table 7 shows the ANCOVAS for the dependent variable of meaningful understanding of forces when the understanding score is either a conceptual, a problem solving, or a mental model understanding score. From Table 7 it is apparent that the students' force concept scores, their problem solving scores, or their mental model scores did not differ significantly according to treatment. In other words, students in a LC class did not have significantly better problem solvers or better concept understanding or better mental model builders than those in the MVRL treatment, and vice-versa. Though the differences were not significant at the .05 level, they were significant at the .1 level for problem solving and mental models. In both cases, the LC presentation of forces created a slightly higher mean problem solving score (3.344) and mental models (42.251) than did the MVRL treatment on forces (2.456 and 32.229, respectively).

Table 8 shows the ANCOVAS for the dependent variable of meaningful understanding of density/Archimedes' Principle when the understanding score used is either a conceptual, a problem solving, or a mental model score. This time the analyses were mixed. There were no significant differences in the students' conceptual and mental model building understanding of density/Archimedes' Principle between the LC and MVRL treatments. Although in both cases the LC students had slightly greater mean scores in both areas compared to the MVRL students. However, the LC and MVRL students did significantly differ in their problem solving. The LC students had a greater mean understanding in density/Archimedes' Principle problem solving than did the MVRL students. The LC problem solving mean was 4.079 while the MVRL treatment mean for problem solving was 2.587. Thus, the magnitude of the difference was 1.492, or roughly 1.5 problems which represents a 25% improvement over the MVRL treatment mean.

Table 9 shows the ANCOVAS for the dependent variable of meaningful understanding of heat when the understanding score used is either a conceptual, a problem solving, or a mental model score. As with density, the results were mixed. There were no significant differences in the LC versus the MVRL treatments in conceptual and mental model understanding. However, the LC and MVRL treatments were significantly different in problem solving understanding ($p = .019$). However in this case, the MVRL were greater problem solvers than did the LC students. The MVRL problem solving mean was 2.736 while the LC problem solving mean was 1.764. Thus, the magnitude of the difference was .972, or almost one problem greater which represents a 16% improvement over the LC treatment mean.

Hence, the answer to Question 2 is complex. Based upon this research, if forces was the topic being studied, it made no difference which treatment (LC or MVRL) was used. The understanding was not significantly different. Understanding scores on concept tests, problem solving, and mental models were practically the same.

However, if density/Archimedes' Principle was the topic being studied, the results of this research demonstrates that there was no significant difference between the treatments in terms of producing concept and mental model understanding. However, a 25% improvement in problem solving over that by the MVRL group was made by the LC group . Recall also that the students in the learning cycle treatment also had slightly higher means (although not significant) on concept and mental model understanding measures. Thus, the LC treatment was better at producing understanding in problem solving when density/Archimedes' Principle was the topic studied.

When heat was the topic studied, the MVRL treatment was 16% better than the LC treatment at producing understanding in problem solving. Also, the students in the MVRL treatment had slightly higher means (although not significant) on conceptual and mental model understanding. Thus when the topic being studied was heat, a MVRL treatment was best at producing understanding in problem solving.

Question 3.

Which variable (reasoning ability, meaningful learning orientation, prior knowledge, or instructional treatment) is the best predictor of overall meaningful understanding of physics concepts?

To determine the variable that best predicts students' overall meaningful understanding of physics concepts, a stepwise multiple regression was performed with reasoning ability (TOLT), meaningful learning orientation (LAQ), prior knowledge (overall meaningful understanding score which is sum of concept, problem solving, and mental model scores), and treatment (LC or MVRL) entered as predictor variables.

For overall meaningful understanding of the force concept (posttest), treatment was the best predictor although it was not significant at the .05 level (r = -.263, F = 3.561, df = 48, p = .065) [r = correlation; F = F statistic; df = degrees of freedom; p = probability] . For posttest overall understanding of density/Archimedes' Principle, treatment was the best predictor (r = -.198, F = 1.878, df = 46, p = .177). However, it was excluded from the regression model since $p > .05$. Thus, for density, there was no significant predictor of overall meaningful understanding. For posttest overall meaningful understanding of heat, the students' meaningful learning orientation was the best predictor (r = .157, F = 1.155, df = 46 p = .288). It was excluded from the regression model since $p > .05$. Based upon these three findings, Question 3 may not be formally answered as none of the entered variables added any more to the prediction of overall understanding in the regression model. Neither reasoning ability, learning approach, prior knowledge, nor treatment were significant predictors of overall meaningful understanding. Therefore, it is not possible to answer Question 3 from the data of this study.

Question 4.

Which variable (reasoning ability, meaningful learning orientation, prior knowledge, or instructional treatment) is the best predictor for each sub-measure of meaningful understanding of physics?

Three stepwise multiple regression analyses were done for each sub-measure (concept, problem solving, mental model) of meaningful understanding. In other words, for concept understanding, a regression analysis was done for forces, density/Archimedes' Principle, and for heat.

For concept understanding it was found that for forces, prior knowledge

(r=.587, F = 21.861, df = 48, p = .000) was the most significant predictor in the model. However, reasoning ability (r = .451, F = 9.720, df = 48, p = .003) was the next best predictor of force concept understanding. Together, reasoning ability and prior knowledge of force concept explain 45.6% of the variance in posttest understanding of force concepts.

For density/Archimedes' Principle concept understanding, prior knowledge of density/Archimedes' Principle was the better predictor of students' posttest density concept understanding (r = .406, F = 6.479, df = 46, p = .014). Reasoning ability was the second best significant predictor (r = .387, F = 5.570, df = 46, p = .023) of students' density concept scores. Together reasoning ability and prior knowledge explain 25.7% of the variance in students' density concept scores.

For heat concept understanding, reasoning ability was the only significant predictor of students' heat concept scores (r = .348, F = 6.355, df = 46, p = .015). Reasoning ability thus explains 12.1% of the variance in students' heat concept scores.

In summary, students' conceptual understanding was best predicted by students' prior knowledge scores for forces and density/Archimedes' Principle. However, students' heat concept understanding was best predicted by their reasoning ability. Recall also that students' reasoning ability was also a significant predictor for force and density/Archimedes' Principle conceptual understanding, although it was of slightly lesser importance in the regression model.

For predicting students' problem solving score for forces, the stepwise multiple regression revealed that the students' reasoning ability was the only significant predictor (r = .391, F = 8.681, df = 46, p = .005). Reasoning ability explained 15.3% of the variance in force problem solving. Treatment was the second strongest predictor although its probability was slightly greater than

.05 ($r = -.269$, $F = 3.666$, $df = 46$, $p = .062$). Note that for forces, the negative on the correlation means to be in a LC class indicated higher problem solving posttest scores.

For density/Archimedes' Principle problem solving, treatment was the only significant predictor of students' problem solving scores ($r = -.277$, $F = 8.283$, $df = 46$, $p = .006$). This negative correlation means that being in a MVRL treatment correlated with decreased problem solving scores. The LC treatment correlated with increased problem solving scores. Treatment explained 7.7% of the variance in density/Archimedes' Principle problem solving scores.

The students' reasoning ability was the better significant predictor of heat problem solving ($r = .356$, $F = 6.507$, $df = 46$, $p = .014$). Treatment was the next best significant predictor of students' heat problem solving ($r = .338$, $F = 5.803$, $df = 46$, $p = .020$). For the topic of heat, the positive correlation means that being assigned to a MVRL class correlates with greater problem solving scores. Together these two variables predicted 22.6% of the variance in heat problem solving scores.

Thus, for forces and heat topics, students' reasoning ability was the most effective predictor of students' problem solving scores. For heat topics, treatment was the next best predictor of students' problem solving scores. For density/Archimedes' Principle however, treatment was the only significant predictor of students' problem solving. However, the 'ideal' treatment varied by topic being studied: density/Archimedes' Principle or heat. Being in a LC class when studying density/Archimedes' Principle correlated with higher problem solving scores, yet being in a LC class for heat topics correlated with lower problem solving scores.

To find the best predictor of students' mental model scores, three stepwise multiple linear regressions were performed. None of the predictor variables (reasoning ability, learning approach, prior knowledge, or treatment) were significant and entered into the regression model. Thus, it is not possible to gain insight into predicting mental model scores from this work.

CHAPTER 5

Discussion and Conclusions

Due to the length of the discussions and the number of research questions, the discussion of the results and conclusions drawn from these results will be organized by research questions 1 through 4. For example, question 1 will be discussed immediately followed by the conclusions drawn from the results of question 1.

Discussion of Question 1: Overall Meaningful Understanding.

The ANCOVA results were similar for the three physics concepts examined. No measurable differences in meaningful understanding ($p > .079$ and higher) were found for forces, density/Archimedes' Principle, or heat. That is, the LC students had virtually the same overall meaningful understanding on the three items tested as did the MVRL students. Separate t-tests comparing pretest and posttest scores of overall understanding for each group revealed a significant ($p < .000$) increase in meaningful understanding of the three physics concepts (Williams, 1997). Therefore, the LC and MVRL college physics students improved their meaningful understanding of forces, density/Archimedes' Principle, and heat.

What does this mean? The students from the different treatments had nearly equal overall (conceptual + problem solving + mental model) meaningful understandings. Students in this sample were in transition or were reflective (or formal operational) thinkers. The LC and MVRL results were similar because Piagetian and Ausubelian theories specified similar criteria for meaningful learning. <u>Both theories explain learning but in different terminology</u>. Following are a description of Piagetian theory explaining learning within the LC treatment and a description of Ausubelian theory explaining learning in the LC treatment. Figure 14 illustrates both theories.

Some students in this study were given "physics" experiences through the learning cycle. According to the research results, they took this experience, constructed the concepts of forces, density/Archimedes' Principle, and heat and formed greater meaningful understanding of these physics concepts. According to Piaget's (1963) theory , the concrete experience allowed assimilation (incorporation of experiences into mental structures) which led to disequilibrium (conflict between mental structures). During the conceptual invention phase of the learning cycle, accommodation (change or development of new structures) occurred. Piaget called the processes of assimilation and accommodation adaptation. The student adapted to the input from the exploration. During conceptual expansion, the student organized the new mental structure with structures previously developed. Piaget called this process organization. Thus, the students increased their meaningful understanding of the concept.

Ausubelian theory can also be applied to explain students' learning during the LC. In the Ausubelian interpretation, the concrete experiences during the exploration provided the relevant prior knowledge necessary for meaningful learning. The exploration also provided the opportunity for subsumption during which new information was related to more general ideas, making the task potentially meaningful to the student. During the conceptual invention phase, the researcher encouraged the students to make links between data or observations. Students were also encouraged to orient their learning toward meaningful learning rather than rote. Students were encouraged to link new terminology to the phenomena observed during the exploration. In this manner, the students linked other items to the phenomena, or concept, being studied. Ausubel (1963) called making such new links progressive differentiation. During the expansion phase, students related the phenomena with the new links and terminology with new concepts or ideas. Superordinate learning (new links cause one idea to subsume a previous one) and integrative reconciliation (new links form between the old and new ideas) occurred during the conceptual invention phase of the LC. In each process, the learner formed links between the new ideas and other concepts or ideas for which no links previously existed.

Piagetian	LC	Ausubelian
	Exploration	
assimilation		gives prior knowledge
disequilibrium		subsumption
	Concept Invention	
accommodation		progressive differentiation
	Concept Expansion	
	(or application)	
organization		superordinate learning
		integrative reconciliation

Figure 14. The learning cycle and Piagetian and Ausubelian explanations of how each phase led to overall meaningful understanding.

Similarly, each theory can be used to explain how the MVRL treatment led to students' meaningful understanding. Following are a description of Piagetian theory explaining learning with the MVRL treatment and a description of Ausubelian theory explaining learning in the MVRL treatment. Figure 15 illustrates both theories.

The MVRL treatment had several phases. Material was presented through verbal instruction followed by advance organizers. Ideally, the students were to construct concept maps from the advance organizers before the laboratories. The students completed laboratories that utilized concept maps to introduce the underlying theory in the laboratory. More advance organizers, verbal instruction and concept maps followed the laboratory.

According to Piagetian theory (Piaget, 1963), the students who were in transition or who were formal operational assimilated the input from the verbal instruction. Concrete operational students do not assimilate abstract concepts and require concrete experience. According to Piagetian theory, concrete operational students do not learn formal concepts. However, if concrete experiences were provided, they might learn concrete aspects of the concept. In this study, none of the students were concrete. Therefore, according to Piagetian theory these formal students had the ability to learn formal concepts although they might not choose to operate at a formal level. Thus, the use of verbal instruction and advance organizers does not prevent the application of Piagetian theory for this sample. However, care must be taken when applying Piagetian theory to younger samples who are cognitively less developed.

After the verbal instruction, students were told to construct concept maps relating various aspects of the concept(s). The construction of the concept maps were usually based upon reading passages from the textbook. During the construction of the maps, the students took charge of their own learning. Students struggled with ways to relate the items in the passages from the textbook for additional assimilation. The laboratories provided the opportunity for the students to become disequilibrated and to accommodate to the data. Students usually attended laboratories before the concept maps were collected for grading. Therefore, the processes of disequilibrium and accommodation probably occurred in the laboratory rather than during the construction of concept maps. The process Piaget called organization occurred as the students read more advance organizers and constructed more concept maps. Organization occurred during the students' efforts to construct a concept map that related their thoughts about additional concepts to their thoughts about the new phenomena or concept studied.

According to Ausubel (1963), prior knowledge and subsumers for concepts were provided by verbal instruction. Students were encouraged to orient their learning away from rote when they were asked to construct concept maps. Laboratories and concept maps also promoted subsumption and progressive differentiation as new links were created. More advance organizers or verbal instruction caused the students to link items to other, less specific items (superordinate learning according to Ausubel). Furthermore, integrative reconciliation was accomplished as additional maps were constructed or revised by the student.

Piagetian	MVRL	Ausubelian
	verbal instruction	
assimilation*		prior knowledge
		subsumption
	advance organizers &	
	concept maps	
assimilation*		subsumption
		progressive differentiation
	laboratories	
disequilibrium		subsumption
accommodation		progressive differentiation
	advance organizers &	
	concept maps	
organization		superordinate learning
		integrative reconciliation

* for formal operational sample only.

Figure 15. Meaningful verbal reception learning and Piagetian and Ausubelian explanations of how each phase led to overall meaningful understanding.

Conclusions from Question 1: Overall Meaningful Understanding.

College physics students from each treatment achieved nearly the same overall meaningful understanding on each of the three physics concepts examined. Piagetian *and* Ausubelian theory can explain how the students in each treatment achieved overall meaningful understanding. It appears that

Piaget *and* Ausubel have viable theories of learning. Piagetian theory can be used to explain meaningful learning in the learning cycle as well as meaningful learning in meaningful verbal reception learning. Ausubelian theory can be used to explain meaningful learning in the learning cycle as well as learning in meaningful verbal reception learning. The two theories appear to explain learning in different terms. More research needs to be conducted to validate this premise.

Further research could determine if the sequence of the phases of MVRL could be altered to obtain better student meaningful understanding. Usually concept maps were assigned on Mondays, laboratories were on Tuesdays, and concept maps were collected on Wednesdays. Students who procrastinated could have done their maps on Tuesday night after the laboratory. It needs to be determined if the order of these activities in the MVRL sequence is associated with a change in students' meaningful understanding.

One weakness of this study is that the order of the LC concepts was from general to specific within *each* concept, not course wide. Whereas, this order (general to specific) was followed for the entire MVRL treatment. The LC curricula should be organized so that the concepts are covered in order from those that are more general to those that are more specific. According to Ausubel, this organization should favor meaningful learning, but research should be done to investigate this.

Research should be done that compares these two treatments to the typical college physics lecture/lab treatment. The majority of college professors will never consider abandoning their lecture/lab physics unless statistics indicate greater success by using one or both of these curricula.

Discussion of Question 1: Meaningful Learning Orientation

The remaining part of Question 1 is the meaningful learning orientation of the students in the two treatments. Recall that for forces, density/Archimedes' Principle, and heat data, the LC and MVRL students' meaningful learning orientation did not differ significantly. Could it be that students from each treatment were drawn away from rote means of learning by roughly the same significant amounts? This was not the case in this study. Ad hoc t-tests showed that there was not a significant change in meaningful learning orientation scores (pretest to posttest) for *either* treatment. Neither group of students increased or decreased their tendency to learn meaningfully. This was a single four-hour, sixteen-week course in the students' college career. Perhaps this is evidence that it is not possible to change the learning orientation of college physics students during such a short treatment. A shift in learning would possibly be observed if the course was offered over a longer period of time, if all science courses that students have taken previously were taught in the same manner, or if all instructors taught using procedures that do not reward rote learning.

Conclusions from Question 1: Meaningful Learning Orientation

Students in this study from the LC group did not alter their tendency to learn meaningfully, nor did the students from the MVRL group alter their tendency to learn meaningfully. Perhaps if all classes in students' schedules were taught in the same manner, students' learning orientations would change. Based upon my knowledge of my colleagues' courses, this was probably the only course in the students' week that did not reward rote learning. A concerted effort of all professors might correlate with a positive change in meaningful learning orientation. Such a curriculum study should be done at the college level. Theoretically, according to Piaget and Ausubel, great strides in meaningful understanding may be accomplished by students actively taking part in their learning. Such understanding should greatly outweigh that obtained by hearing lectures. This research has already shown that greater understanding occurred after each treatment. Theoretically, even greater understanding could occur if students' tendency to learn meaningfully increased.

A study comparing the change in meaningful learning orientation for the LC and MVRL treatments to that of a traditional lecture/lab class should be conducted. Dickie (1994) found that students' tendency to learn by rote *increased* after a college physics class. Perhaps the students from the treatments in this study left the courses with a greater tendency to learn meaningfully than if they had been in a course that was taught traditionally by lecture/lab.

Discussion of Question 2.

Each student was assessed for each concept (forces, density/Archimedes' Principle, and heat) on three submeasures of meaningful understanding: conceptual understanding, problem solving, and mental models. Results of ANCOVA's revealed that there were no significant differences between the LC and MVRL treatments for students' concept understanding ($p > .149$) of forces, density/Archimedes' Principle, and heat. The ANCOVA results for understanding measured by mental models also showed that there were no measurable significant differences in meaningful understanding as measured by mental models ($p > .092$). Thus, the students in the LC and MVRL treatments had roughly equal conceptual and mental model understanding on all three items. Students from each treatment were encouraged to improve their conceptual knowledge and mental model understanding. These findings provided more evidence for the idea that Piagetian and Ausubelian theories are similar theoretically if their end-products (students' conceptual understanding and mental model knowledge) are not significantly different.

According to results of ANCOVA's, there were no statistically significant differences among treatments on the problem solving for forces. According to results of ANCOVA's for density/Archimedes' Principle and heat data, the problem solving differed in direction among the two treatments. For density/Archimedes' Principle data, the LC students had a 25% improvement in problem solving over the MVRL students' mean scores ($p < .006$). For heat data, the MVRL students had a 16% improvement in problem solving over the LC students ($p < .019$). This may simply indicate weaknesses in curricula for the two treatments. For forces, the curricula appears to be equal for both treatments. For density/Archimedes' Principle, the LC exploration was a problem solving activity similar to the problems on the assessment instrument. The LC students actually measured the mass of the water that poured out of the cup when a cylinder was put in the cup of water. They determined that this quantity was the same mass as the apparent mass difference (buoyant force) of the cylinder in and out of water. That particular LC activity was an ideal opportunity to watch the students construct their ideas about density/Archimedes' Principle.

The weakness of the MVRL curricula for density/Archimedes' Principle could be explained in Ausubelian terms. The verbal instruction on density/Archimedes' Principle did not to provide suitable anchors to other structures, thus creating less problem solving ability by its students. A Piagetian explanation for the MVRL curricular weakness for the density/Archimedes' Principle topic might be that there was no assimilation because of a lack of previous experience. I have noticed many times over the years that students are unaware that the volume of water that comes out of a cup when a cylinder is inserted, is the same as the volume of the cylinder. A lack of experience could possibly have caused the MVRL students to lag behind in density/Archimedes' Principle problem solving.

The heat problem solving difference may indicate a weakness in the

LC curriculum and a strength for the MVRL curriculum. From day one in the MVRL treatment, students were relating concepts to energy and heat. These students simply may have thought about heat more and made more connections which increased their problem solving ability. Perhaps students already had concrete experience with heat. The LC curriculum did not stress heat from the beginning of the semester. The LC curriculum of this study was modeled after one used in local school systems since 1985. Now, it is thought that LC curriculum must be planned so that "the concepts learned in earlier learning cycles can serve as anchors for linking concepts of later learning cycles" (Marek and Cavallo, 1997). This means that more general topics such as heat and energy must be introduced first before specific items such as motion and speed. The LC students did not have an earlier LC to provide anchors about heat, whereas the density LC prior to the Archimedes' Principle LC did provide anchors. Thus, the LC students had less experience with heat according to Piaget or less prior knowledge about heat according to Ausubel. Whether explained in Piagetian terms (no assimilation occurred) or in Ausubelian terms (no subsumers were available), the LC students solved fewer problems on the heat concept than the MVRL students did.

Why the same differences between treatment due to treatment weakness or strength did not appear on the conceptual and mental model assessments are unknown. Possibly because the mental model and conceptual questions had a greater number of maximum points, there was more room for students' meaningful understanding scores to fluctuate without being significantly different as a group. Note the problem solving scores had a possible score of six. The maximum possible conceptual scores were at least seventeen, and the mental model scores were much greater. Perhaps increasing the point value for problem solving, allowing for partial credit might prove fruitful in a similar future investigation.

Conclusions from Question 2

According to the results of Question 1, Ausubelian and Piagetian theories used different terms to explain the construction of meaningful understanding. Also, manners of achieving meaningful understanding have been based upon each theory. With well-planned and well-written curricula and assessment instruments having the same maximum point-value, no differences should be expected between LC and MVRL treatments if indeed the two theories simply use different terminology to explain meaningful learning.

Discussion of Question 3.

Based upon regression analyses, neither treatment, nor reasoning ability, nor meaningful learning orientation, nor prior knowledge were significant predictors of overall physics (concept + problem solving + mental model) understanding at the .05 level. For forces and density/Archimedes' Principle, the students' treatments were the best predictor, while for heat the students' learning orientation scores were the best predictor. Thus for the three concepts studied, none of the predictors were significant; and for the three topics the most significant predictor of overall physics understanding was different. These findings further complicate our understanding of the most important variable in meaningful understanding. It may possibly mean that all predictor variables are necessary or in some way interconnected. Or perhaps these instruments are not accurate measures. As was mentioned in Chapter 2, past research has been contradictory on this matter as well. All variables must be examined in future research to determine what is most important to overall meaningful understanding of physics. Such research is critical for further understanding of meaningful learning and education in general.

Conclusions from Question 3.

Very little may be concluded from the results of Question 3 aside from the fact that more research must be conducted to determine what variables are the strongest predictors of overall physics understanding. Perhaps research with other instruments and well-tested curricula will yield more valuable results. The results of question 3 indicate and reinforce that meaningful understanding is complex.

Discussion of Question 4.

The results of a stepwise multiple regression to find the best predictor for forces, density/Archimedes' Principle, and heat conceptual understanding proved more fruitful than did the analyses for overall understanding. For forces and density/Archimedes' Principle data, students' prior knowledge was the best predictor of student conceptual understanding while reasoning ability was the next best predictor. For heat, reasoning ability was the only significant predictor of heat concept scores. Without prior experience, conceptual understanding decreased substantially for forces and for density/Archimedes' Principle. That is to be expected by both Piagetian and Ausubelian theories, for without assimilation or subsumers, meaningful learning does not occur. According to Piaget without adequate reasoning ability, abstract concepts such as forces, density/Archimedes' principle, and heat can not be learned. Perhaps this is what Ausubel meant when he used the term 'potentially meaningful' as a criterion for meaningful learning. For Ausubel, the evidence suggests that material classified as not potentially meaningful would include material more abstract than the student's structures.

For problem solving understanding of force and heat concepts, reasoning ability was the best predictor. Thus, students having greater reasoning ability correlated with greater problem solving. This can be explained if Piagetian reasoning ability and the Ausubelian term "potentially meaningful" have similar meaning. If forces and heat were presented in a potentially meaningful way, then according to Ausubel meaningful learning measured by solving problems could occur. If forces and heat were presented to formal operational learners, then according to Piaget the construction of problem solving understanding could occur.

For heat, the next best predictor of problem solving was treatment, with MVRL treatment correlating with greater heat problem solving. For density/Archimedes' Principle, the best predictor was treatment, with the LC treatment correlating with greater density/Archimedes' Principle problem solving. This finding is consistent with the findings and discussion of Question 2. This may be explained by the apparent weakness of the MVRL treatment to present the density/Archimedes' Principle concept combined with the strength of the LC to present the density/Archimedes' Principle concept and the apparent strength of the MVRL presentation of heat combined with the apparent weakness of the LC presentation of heat. In short, the two curricula produced different levels of problem solving understanding for different concepts depending upon the relative strength of the curricula.

None of the predictor variables (reasoning ability, prior knowledge, learning approach, or treatment) were significant predictors of the knowledge measured by mental models. The inexperience of the researcher with mental models may be the cause of this finding. Mental models may be only valid as understanding measures if the researcher has great deal of experience with them. Mental models should be examined further as tools to measure meaningful understanding of college physics students.

<u>Conclusions from Question 4</u>.

The analysis of predictor variables for concept understanding and problem solving further support the idea that Piagetian and Ausubelian theory are similar in their explanation of how learning occurs. All variables mentioned in theories by Piaget and Ausubel were not significant predictors for concept understanding or problem solving, so exact correlations of the theories are not yet possible based on the findings of this research. Question 4 analyses should be repeated with a LC curricula based on a top down approach, the MVRL phases sequenced in the most beneficial order, and more reliable instruments. Once these corrections are made more insight will be gained into these two theories of learning.

In summary according to this research, there were no significant differences between the Piagetian-based learning cycle and the Ausubelian-based meaningful verbal reception learning for college students' meaningful understanding of physics concepts. What the results of this research suggested is that although Piaget and Ausubel used different terminology to explain learning, these theories are very similar. This research attempted to blend the two theories; illustrating that the theories did not explain meaningful understanding in significantly different ways. In doing so, there were far more questions raised than have been answered. For example, where is the disequilibrium in Ausubel's theory? What is the motivating factor in Ausubel's theory that compares to the disequilibrium in Piaget's theory? Is the learning orientation sufficient to motivate the learner to make the necessary connections? If it is, what is the motivating force for organization in Piagetian theory? Further research is necessary to obtain answers to these questions.

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APPENDICES

APPENDIX A: Student Permission Letter

The University of Oklahoma

SCIENCE EDUCATION CENTER
Physical Sciences Building, Room 323
Norman, Oklahoma 73019

Agreement to participate

This letter is to obtain your consent to participate in a research project by Karen Williams, Asst. Professor at ECU & PhD student at OU, under the sponsorship of Dr. Ed Marek a professor of science education at OU (OU, Science Education Center, Physical Sciences Bldg, Rm 323, Norman, OK 73019, phone 405/325-1498). The research is to be conducted at ECU, but under the auspices of the University of Oklahoma-Norman Campus. Please read all of this agreement carefully and sign if you agree to participate. Because both sections of GPI taught this semester are given specialized treatment this semester, if you do not agree to participate in the *course format* as is taught, you must drop this course and enroll again at a later time without any prejudice against you. If you want to participate in the course *as taught, but without your scores being used*, you may remain enrolled in the course without prejudice to you and I will not use your scores in the study.

The purpose of this research is to determine the effects that a learning cycle style physics class and a meaningful verbal reception style physics class have upon your understanding of physics concepts and your approach to learning. Learning cycles are labs designed to allow concept learning. In reception learning, the teacher provides an outline of material to which s/he later attaches more specific material. Then students organize this material into diagrams of how the material is related. The participants of the study will be asked before and after instruction to complete, multiple choice exams, work 6 problems, and tell all s/he knows about particular physics concepts (i.e. forces). As with any physics exam that assesses knowledge, these exams will count in the calculation of your grade as described in the syllabus. Such exams have been given in "ordinary physics courses" previously taught by the instructor that were not involved in any study. In addition to the physics tests, the participants reasoning ability and approach to learning will be assessed primarily through multiple choice exams. These two exams will not affect your grade.

I sign this (________________________) as evidence that I do not foresee any mental or physical risks to any of the participants of this study that do not also exist in any normal physics course taught at ECU by K. Williams.
On the other hand, participants in both classes may benefit by greater physics understanding as well as having gained a vigorous approach to learning that will be invaluable throughout your education. Neither I nor past research can tell you which class (if one is really better than the other) will provide the best understanding. Thus there is no known disadvantage or advantage at this time to being in one section as opposed to the other.

This is to certify that I, ______________________________, hereby agree to participate as a (print full name) volunteer in a scientific investigation as a part of an authorized research program of the University of Oklahoma Science Education Center. I understand that this allows my scores to be used in research, but that my name will not be used in association with such scores reported in research.

I understand and was told that I am free to refuse to participate in any part of this project without prejudice or detriment to me. I understand that by signing this form, I agree to participate in this research. However, this does not waive my legal rights. I understand that the OU Science Ed. Center or K. Williams will answer any questions I have relating to the research procedures.

____________________ ____________________

Date Subject's signature

APPENDIX B: Instruments

Test of Logical Thinking (TOLT)

Learning Approach Questionnaire (LAQ)

Forces: Conceptual Questions

Forces: Problems

Forces: Mental Model

Density/Archimedes' Principle: Conceptual Questions

Density/Archimedes' Principle: Problems

Density/Archimedes' Principle: Mental Model

Heat: Conceptual Questions

Heat: Problems

Heat: Mental Model

Mental Model Template

Test of Logical Thinking (TOLT)

WRITE ONLY ON THE ANSWER SHEET PROVIDED.

Item 1: Orange Juice

I. Four oranges are squeezed to make six glasses of juice. How much juice can be made from six oranges?

A. 7 glasses
B. 8 glasses
C. 9 glasses
D. 10 glasses
E. other

II. Reason

A. The number of glasses compared to the number of oranges will always be in the ratio of 3 to 2.
B. With more oranges, the difference will be less.
C. The difference in the numbers will always be two.
D. With four oranges the difference was 2. With six oranges the difference would be two more.
E. There is no way of predicting.

Item 2: Orange Juice

I. Given the information in Item 1, how many oranges are needed to make 13 glasses of juice?

A. 6 1/2 oranges
B. 8 2/3 oranges
C. 9 oranges
D. 11 oranges
E. other

II. Reason

A. The number of oranges compared to the number of glasses will always be in the ratio 2 to 3.
B. If there are seven more glasses, then five more oranges are needed.
C. The difference in the numbers will always be two.
D. The number of oranges will be half the number of glasses.
E. There is no way of predicting the number of oranges.

Item 3: The Vegetable Seeds

I. A gardener bought a package containing 3 squash seeds and 3 bean seeds. If just one seed is selected from the package what are the chances that it is a bean seed?

A. 1 out of 2
B. 1 out of 3
C. 1 out of 4
D. 1 out of 6
E. 4 out of 6

II. <u>Reason</u>

A. Four selections are needed because the three squash seeds could have been chosen in a row.
B. There are six seeds from which one bean seed must be chosen.
C. One bean seed needs to be selected from a total of three.
D. One half of the seeds are bean seeds.
E. In addition to a bean seed, three squash seeds could be selected from a total of six.

Item 4: The Flower Seeds

I. A gardener bought a package of 21 mixed flower seeds. The package contained seeds for:

3 short red flowers	4 tall red flowers
4 short yellow flowers	2 tall yellow flowers
5 short orange flowers	3 tall orange flowers

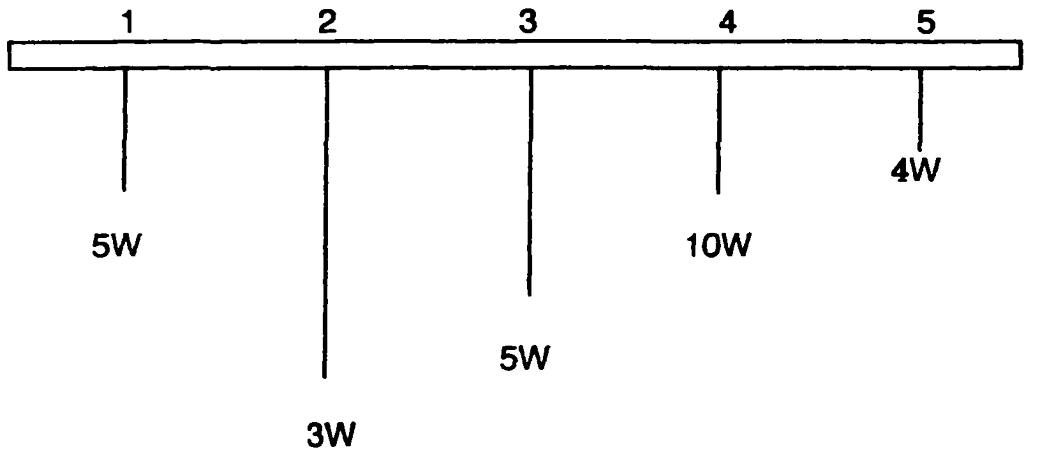
If just one seed is planted, what are the chances that the plant that grows will have red flowers?

A. 1 out of 2 B. 2 out of 3 C. 1 out of 7
D. 1 out of 21 E. other

II. <u>Reason</u>

A. One seed has to be chosen from among those that grow red, yellow, or orange flowers.
B. 1/4 of the short and 4/9 of the tall are red.
C. It does not matter whether a tall or a short is picked. One red seed needs to be picked from a total of seven red seeds.
D. One red seed must be selected from a total of 21 seeds.
E. Seven of the twenty-one seeds will produce red flowers.

Use the diagram below to help you answer Items 5 and 6. The diagram shows five pendulums of various lengths. The number at the bottom of each pendulum is the number of large steel washers (W) attached to the end of the pendulum.



Item 5: The Pendulum's Length

I. Suppose you wanted to do an experiment to find out if changing the length of a pendulum changed the amount of time it takes to swing back and forth. Which pendulums would you use for the experiment?

A. 1 and 4 B. 2 and 4 C. 1 and 3 D. 2 and 5 E. all

II. <u>Reason</u>

A. The longest pendulum should be tested against the shortest pendulum.
B. All pendulums need to be tested against one another.
C. As the length is increased the number of washers should be decreased.
D. The pendulums should be the same length but the number of washers should be different.
E. The pendulums should be different lengths but the number of washers should be the same.

Item 6: The Pendulum's Weight

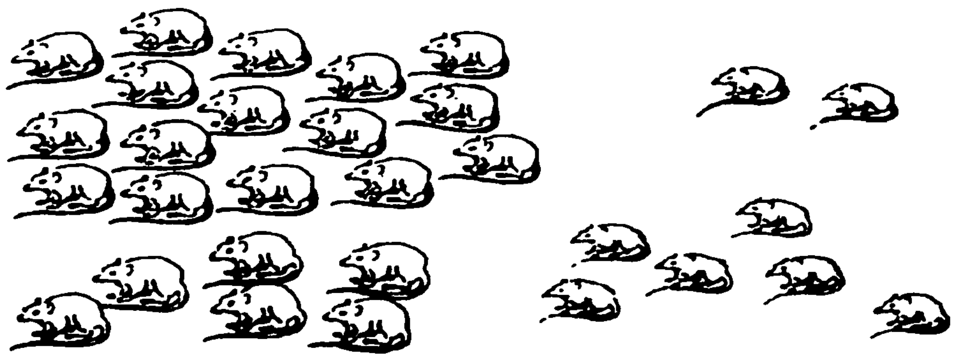
I. Suppose you wanted to do an experiment to find out if changing the weight on the end of the string changed the amount of the time the pendulum takes to swing back and forth. Which pendulums would you use for the experiment? (refer to previous diagram)

A. 1 and 4 B. 2 and 4 C. 1 and 3 D. 2 and 5 E. all

II. Reason

A. The heaviest weight should be compared to the lightest weight.
B. All pendulums need to be tested against one another.
C. As the number of washers is increased the pendulum should be shortened.
D. The number of washers should be different but the pendulums should be the same length.
E. The number of washers should be the same but the pendulums should be different lengths.

Item 7: The Mice



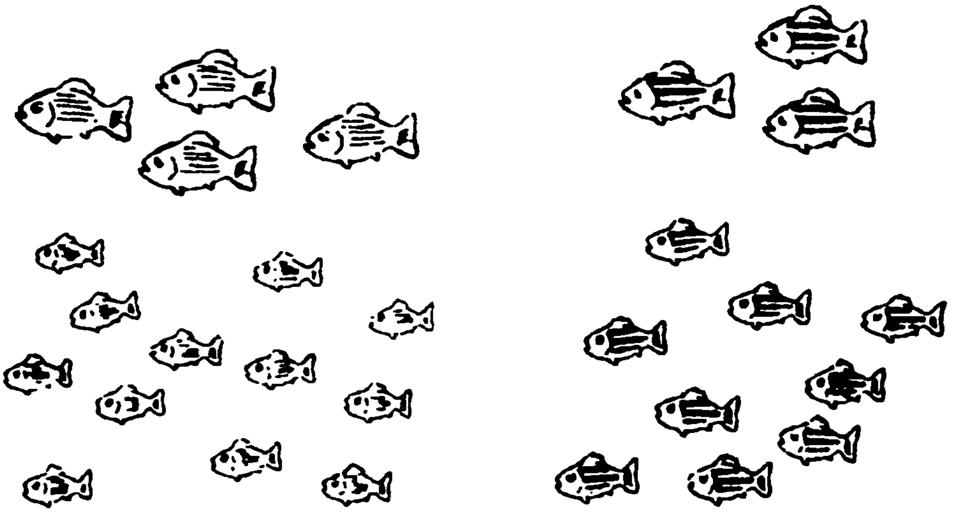
I. The mice shown above represent a sample of mice captured from a part of a field. Are large mice more likely to have black tales and small mice more likely to have white tails?

A. Yes B. No

II. <u>Reason</u>

A. 8/11 of the large mice have black tails and 3/4 of the small mice have white tails.
B. Some of the large mice have white tails and some of the small mice have white tails.
C. 18 mice out of 30 have black tails and 12 have white tails.
D. Not all of the large mice have black tails and not all of the small mice have white tails.
E. 6/12 of the white tailed mice are large.

Item 8: The Fish



I. The fish shown above represent a sample of fish captured from a part of a lake. Are large fish more likely to have broad stripes than small fish?

A. Yes B. No

II. Reason

A. Some large fish have broad stripes and some have narrow stripes.
B. 1/4 of the fish are large
C. 12/28 are broad striped and 16/28 are narrow striped.
D. 3/7 of the large fish have broad stripes and 9/21 of the small fish have broad stripes.
E. Some fish with broad stripes are small and some are large.

Item 9: The Student Council

Three students from each of grades 10, 11, and 12 were elected to the student council. A three member committee is to be formed with one person from each grade. All possible combinations must be considered before a decision can be made. Two possible combinations are Tom, Jerry, and Dan (TJD), and Sally, Anne, and Martha (SAM). List all other possible combinations in the spaces provided on your answer sheet. More spaces are provided than you will need.

Grade 10	Grade 11	Grade 12
Tom (T)	Jerry (J)	Dan (D)
Sally (S)	Anne (A)	Martha (M)
Bill (B)	Connie (C)	Gwen (G)

Item 10: The Shopping Center

In a new shopping center, 4 store locations are going to be opened on the ground level. A BARBER SHOP (B), a DISCOUNT STORE (D), a GROCERY STORE (G), and a COFFEE SHOP (C) want to move in there. Each one of the stores can choose any one of four locations. One way that the stores could occupy the four locations is BDGC. List all other possible ways that the four stores can occupy the 4 locations in the spaces provided on your answer sheet. More spaces are provided than you will need.

Learning Approach Questionnaire (LAQ)
Learning in Science and in School (Learning Approach Questionnaire)

Write your name, your birth date, and your sex on the scantron provided.

The questions in this booklet are about how you study and learn ____________.

Respond to every question by completely filling in the letter you choose on the scantron provided. Please use a #2 pencil.

Do not mark in this booklet.

Work quickly through the questions, your first answer is usually your best.

There are no right or wrong answers.

Simply respond according to how you think and feel.

Please be assured that your answers are confidential.

Thank you very much for your cooperation in answering the questions.

1. Age: a. 15-19 b. 20-24 c. 25-29 d. 30-39 e. 40+

2. Ethnic Origin: a. American Indian b. Asian c.White/Caucasian d. African/American e. other

3. Mother's Highest Level of Education Completed:
   a. less than high school b. high school graduate
   c. some college d. college graduate
   e. beyond college (graduate work, medical school, law school, etc.)

4. Father's Highest Level of Education Completed:
   a. less than high school b. high school graduate
   c. some college d. college graduate
   e. beyond college (graduate work, medical school, law school, etc.)

5. What is your classification so far?
   a. Fr b. So. c. Jr. d. Sr. e. Grad.

6. What is your grade in this physics class?
   a. A b. B c. C d. D e. F

7. What grade would you give yourself on your reading ability?
   a. A b. B c. C d. D e. F

8. What grade would you give yourself on your ability to express yourself in writing?
   a. A b. B c. C d. D e. F

9. Do you plan to take any more science courses after this one?
   a. Yes, definitely b. yes, probably c. no, probably
   d. No, definitely e. I don't know

The following questions refer to how you study and learn about _______ in this class. For each item there is a five point scale ranging from "Always True" to "Never True". On the scantron provided, fill in the letter that best fits your immediate reaction. Do not spend a long time on each item; your first reaction is probably the best one. Answer every question. Don't worry about projecting a good image. There are no correct answers and your answers are confidential!

	Always True---Never True				
	A	B	C	D	E
10. I generally put a lot of effort into trying to understand things which at first seem difficult.	0	0	0	0	0
11. I have a fairly good grasp of the main ideas of a topic but my knowledge of the details is rather weak.	0	0	0	0	0
12. I try to relate new material, as I am learning it, to what I already know on that topic.	0	0	0	0	0
13. I prefer to follow all "tried out" ways to solve problems rather than trying anything too adventurous.	0	0	0	0	0
14. While I am studying, I often think of real life situations to which the material I am learning would be useful.	0	0	0	0	0
15. I find I tend to remember things best if I concentrate on the order in which the teacher presented them.	0	0	0	0	0
16. I find I have to concentrate on memorizing a good deal of what I have to learn.	0	0	0	0	0
17. I go over important topics until I understand them completely.	0	0	0	0	0

		Always True---Never True				
		A	B	C	D	E
18.	I find it best to accept the statements and ideas of my lectures and question them only under special circumstances.	0	0	0	0	0
19.	I prefer courses to be taught in a way that is clearly structured and highlyorganized.	0	0	0	0	0
20.	Teachers shouldn't expect students to spend significant amounts of time studying material everyone knows won't be examined.	0	0	0	0	0
21.	In reporting laboratory work, I like to try to work out several different ways of interpreting the findings.	0	0	0	0	0
22.	I often find myself questioning things that I hear in lectures or read in books.	0	0	0	0	0
23.	In trying to understand new topics, I explain them to myself in ways that other people don't seem to understand.	0	0	0	0	0
24.	I find it useful to get an overview of a new topic for myself, by seeing how the ideas fit together.	0	0	0	0	0
25.	Teachers seem to delight in making the simple truth unnecessarily complicated.	0	0	0	0	0
26.	After a lecture or lab, I reread my notes to make sure that I understand them.	0	0	0	0	0
27.	I set out to understand thoroughly the meaning of what I am asked to read or learn in class.	0	0	0	0	0

		Always True---Never True				
		A	B	C	D	E
28.	I tend to like subjects with a lot of factual content rather than theoretical kinds of subjects.	0	0	0	0	0
29.	I try to relate what I have learned in one subject to that in another.	0	0	0	0	0
30.	I feel that I am more cautious than others in drawing conclusions, unless they are well supported by evidence.	0	0	0	0	0
31.	The best way for me to understand what technical terms mean is to remember the textbook definition.	0	0	0	0	0
32.	I am very aware that teachers know a lot more than I do, and so I concentrate on what they say as important rather than rely on my own judgment.	0	0	0	0	0
33.	Puzzles and problems fascinate me, particularly where you have to work through the material to reach a logical conclusion.	0	0	0	0	0
34.	I usually don't think about the implications of what is taught in class or how it relates to my life.	0	0	0	0	0
35.	I learn some things by rote, going over and over them until I know them by heart.	0	0	0	0	0
36.	When I'm starting a new topic, I ask myself questions about it which the new information should answer.	0	0	0	0	0
37.	I spend a lot of my free time finding out more about interesting topics which have been discussed in class.	0	0	0	0	0

		Always True---Never True A B C D E
38.	I often have to read things in physics without really understanding them.	0 0 0 0 0
39.	Although I generally remember facts and details, I find it difficult to fit them together into an overall picture.	0 0 0 0 0
40.	When I am reading an article or listening to other's ideas in class, I generally examine the evidence carefully to decide whether the conclusion is justified.	0 0 0 0 0
41.	I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.	0 0 0 0 0
42.	What I have learned in this class has changed my views about some things in life (for example: politics, religion, philosophy of life)	0 0 0 0 0

Forces

Conceptual Questions

Place the letter of the correct answer on the scantron sheet.

1. Two metal balls are the same SIZE, but one weights twice as much as the other. The balls are dropped from the top of a two story building at the same time. The time it takes the balls to reach the ground below will be:

a. about half as long for the heavier ball.
b. about half as long for the lighter ball.
c. about the same time for both balls.
d. considerably less for the heavier ball, but not necessarily half as long.
e. considerably less for the lighter ball, but not necessarily half as long.

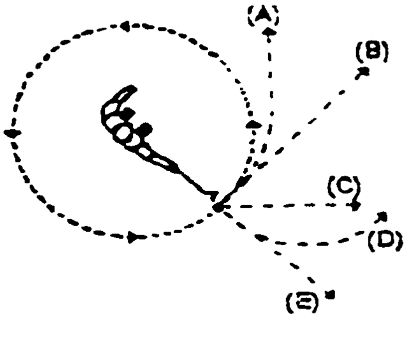
2. Imagine a head-on collision between a large truck and a small compact car. During the collision,

a. the truck exerts a greater amount of force on the car than the car exerts on the truck.
b. the car exerts a greater amount of force on the truck than the truck exerts on the car.
c. neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
d. the truck exerts a force on the car, but the car doesn't exert a force on the truck.
e. the truck exerts the same amount of force on the car, as the car exerts on the truck.

3. Two steel balls, one of which weighs twice as much as the as the other, roll off a horizontal table with the same speeds. In this situation;

a. both balls impact the floor at approximately the same horizontal distance from the base of the table.
b. the heavier ball impacts the floor at about half the horizontal distance from the base of the table than does the lighter.
c. the lighter ball impacts the floor at about half the horizontal distance from the base of the table than does the heavier.
d. the heavier ball hits considerably closer to the base of the table than the lighter, but not necessarily half the horizontal distance.
e. the lighter ball hits considerably closer to the base of the table than the heavier, but not necessarily half the horizontal distance.

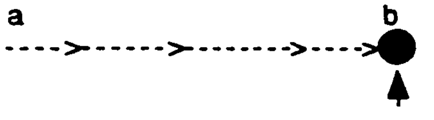
4. A heavy ball is attached to a string and swung in a circular path in a horizontal plane as illustrated in the diagram on the right. At the point indicated in the diagram, the string suddenly breaks at the ball. If these events were observed from directly above, indicate the path of the ball after the string breaks.



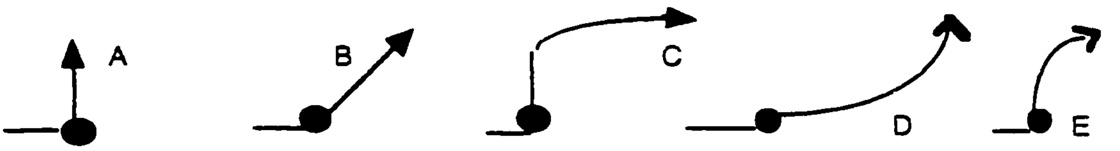
5. A boy throws a steel ball straight up. Disregarding any effects of air resistance, the force(s) acting on the ball until it returns to the ground is(are):

a. its weight vertically downward along with a steadily decreasing upward force.
b. a steadily decreasing upward force from the moment it leaves the hand until it reaches its highest point beyond which there is a steadily increasing downward force of gravity as the object gets closer to the earth.
c. a constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point, after which there is only the constant downward force of gravity.
d. a constant downward force of gravity only.
e. none of the above, the ball falls back down to the earth simply because that is its natural action.

Use the statement and diagram below to answer the next four questions: The diagram depicts a hockey puck sliding, with constant velocity, from point "a" to point "b" along a frictionless horizontal surface. When the puck reaches point "b", it receives an instantaneous horizontal "kick" in the direction of the heavy print arrow.



6. Along which of the paths will the hockey puck move after receiving the "kick"?



7. The speed of the puck just after it receives the "kick"?

a. Equal to the speed "Vo" it had before it received the "kick".
b. Equal to the speed "V" it acquires from the "kick", and independent of the speed "Vo".
c. Equal to the arithmetic sum of the speeds "Vo" and "V".
d. Smaller than either of speeds "Vo" or "V".
e. Greater than either of the speeds "Vo" or "V", but smaller than the arithmetic sum of these two speeds.

8. Along the frictionless path you have chosen, how does the speed of the puck vary after receiving the "kick"?

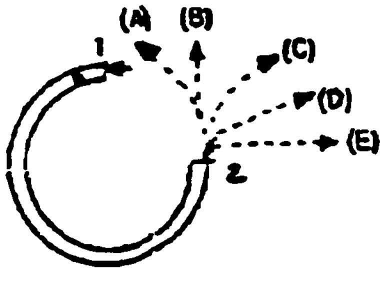
a. No change.
b. Continuously increasing.
c. Continuously decreasing.
d. Increasing for a while, and decreasing thereafter.
e. Decreasing for a while, and increasing thereafter.

9. The main forces acting, after the "kick", on the puck along the path you have chosen are:

a. the downward force due to gravity and the effect of air pressure.
b. the downward force of gravity and the horizontal force of momentum in the direction of motion.
c. the downward force of gravity, the upward force exerted by the table, and a horizontal force acting on the puck in the direction of motion.
d. the downward force of gravity and an upward force exerted on the puck by the table.
e. gravity does not exert a force on the puck, it falls because of the intrinsic tendency of the object to fall to its natural place.

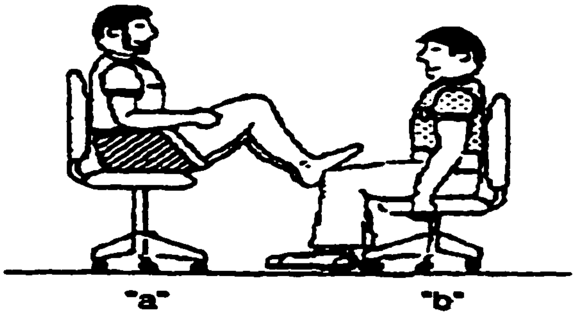
10. The accompanying diagram depicts a semicircular channel that has been securely attached, in a horizontal plane, to a table top. A ball enters the channel at "1" and exits at "2".

Which of the path representations would most nearly correspond to the path of the ball as it exits the channel at "2" and rolls across the table top?



11. Two students, a student "a" who has a mass of 95 kg and a student "b" who has a mass of 77 kg sit in identical office chairs facing each other. Student "a" places his bare feet on student "b'"s knees, as shown below. Student "a' then suddenly pushes outward with his feet, causing both chairs to move.

In this situation,



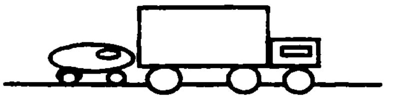
a. neither student exerts a force on the other.
b. student "a" exerts a force on "b", but "b" doesn't exert any force on "a".
c. each student exert a force on the other but "b" exerts the larger force.
d. each student exert a force on the other but "a" exerts the larger force.
e. each student exerts the same force on the other.

12. A book is at rest on a table top. Which of the following force(s) is(are) acting on the book?

1. A downward force due to gravity.
2. The upward force by the table.
3. A net downward force due to air pressure.
4. A net upward force due to air pressure.

a. 1 only   b. 1 and 2   c. 1,2, and 3   d. 1,2, and 4
e. none of these, since the book is at rest there are no forces acting on it.

Refer to the following statement and diagram while answering the next two questions. A large truck breaks down out on the road and receives a push back into town by a small compact car.



13. While the car, still pushing on the truck, is speeding up to get up to cruising speed,

a. the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
b. the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
c. the amount of force of the car pushing against the truck is greater than that of the truck pushing back against the car.
d. the car's engine is running so it applies a force as it pushes against the truck, but the truck's engine is not running so it can't push back against the car, the truck is pushed simply because it is in the way of the car.
e. neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

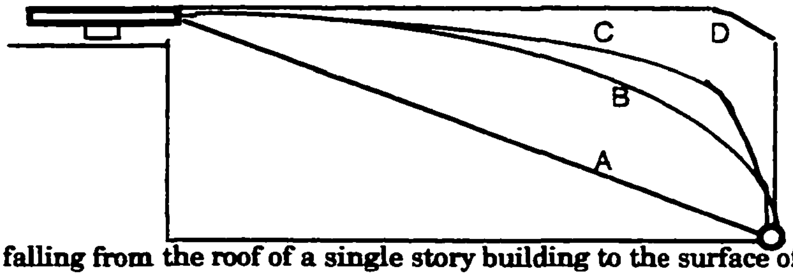
14. After the person in the car, while pushing the truck, reaches cruising speed at which he/she wishes to continue to travel at constant speed;

a. the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
b. the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
c. the amount of force of the car pushing against the truck is greater than that of the truck pushing back against the car.
d. the car's engine is running so it applies a force as it pushes against the truck, but the truck's engine is not running so it can't push back against the car, the truck is pushed simply because it is in the way of the car.
e. neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

15. When a rubber ball dropped from rest bounces off the floor, its direction of motion is reversed because;

a. energy of the ball is conserved.
b. momentum of the ball is conserved.
c. the floor exerts a force on the ball that stops its fall and then drives it upward.
d. the floor is in the way and the ball has to keep moving.
e. none of the above.

16. Which of the paths in the diagram to the right best represents the path of the cannon ball?

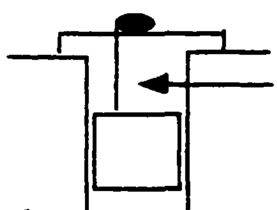


17. A stone falling from the roof of a single story building to the surface of the earth;

a. reaches its maximum speed quite soon after release and then falls at constant speed thereafter.
b. speeds up as it falls, primarily because the closer the stone get to the earth, the stronger the gravitational attraction.
c. speeds up because of the constant gravitational force acting on it.
d. falls because of the intrinsic tendency of all objects to fall toward the earth.
e. falls because of a combination of the force of gravity and the air pressure pushing it downward.

When responding to the following question, assume that any frictional force due to air resistance are so small that they can be ignored.

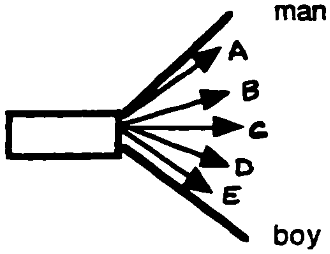
18. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving up the shaft at constant velocity;



ascending at constant speed

a. the upward force on the elevator by the cable is greater than the downward force of gravity.
b. the amount of upward force on the elevator by the cable is equal to that of the downward force of gravity.
c. the upward force on the elevator by the cable is less than the downward force of gravity.
d. it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
e. the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.

19. Two people, a large man and a boy, are pulling as hard as they can on two ropes attached to a crate as illustrated in the diagram on the right. Which of the indicated path (A-E) would most likely correspond to the path of the crate as they pull it along?

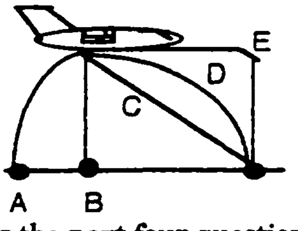


20. A golf ball driven down a fairway is observed to travel through the air with a trajectory (flight path) similar to that in the depiction below. Which of the following force(s) is(are) acting on the golf ball during its entire flight?

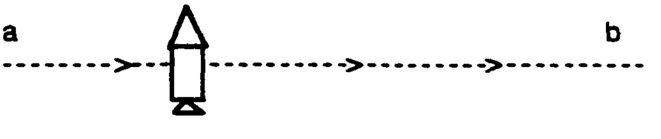
1. the force of gravity 2. the force of the "hit" 3. the force of air resistance

a. 1 only b. 1 and 2 c. 1,2, and 3 d. 1 and 3 e. 2 and 3

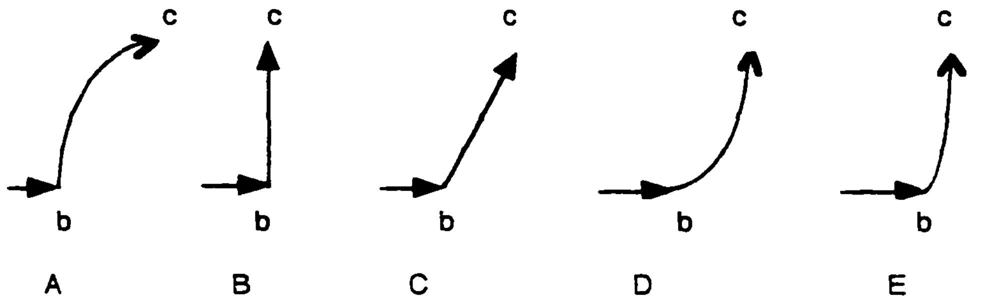
21. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction. As seen from the ground, which path would the bowling ball most closely follow after leaving the airplane?



When answering the next four questions, refer to the following statement and diagram. A rocket, drifting sideways in outer space from position "a" to position "b" is subject to no outside forces. At "b", the rocket's engine starts to produce a constant thrust at right angles to the line "ab". The engine turns off again as the rocket reaches some point "c".



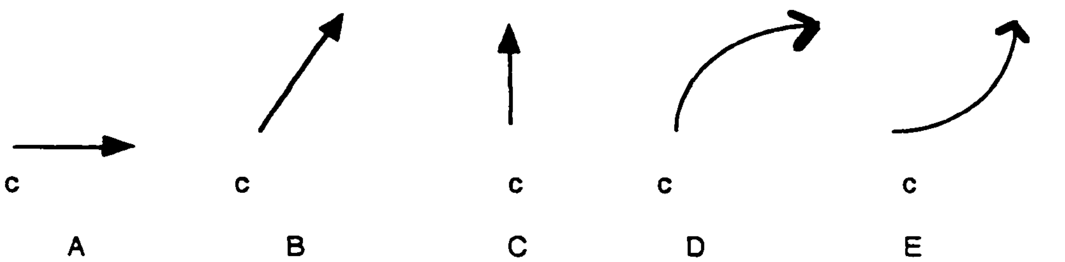
22. Which path below best represents the path of the rocket between "b" and"c"?



23. As the rocket moves from "b" to "c", its speed is

a. constant.
b. continuously increasing.
c. continuously decreasing.
d. increasing for a while and constant thereafter.
e. constant for a while and decreasing thereafter.

24. At "c" the rocket's engine is turned off. Which of the paths below will the rocket follow beyond "c"?



25. Beyond "c", the speed of the rocket is ;

a. constant.
b. continuously increasing.
c. continuously decreasing.
d. increasing for a while and constant thereafter.
e. constant for a while and decreasing thereafter.

26. A large box is being pushed across the floor at a constant speed of 4.0 m/s. What can you conclude about the forces acting on the box?

a. If the force applied to the box is doubled, the constant speed of the box will increase to 8.0 m/s.
b. The amount of force applied to move the box at a constant speed must be more than its weight.
c. The amount of force applied to move the box at a constant speed must be equal to the amount of the frictional force that resists its motion.
d. The amount of force applied to move the box at a constant speed must be more to the amount of the frictional force that resists its motion.
e. There is a force being applied to the box to make it move but the external forces such as friction are not "real" forces they just resist motion.

27. If the force being applied to the box in the preceding problem is suddenly discontinued, the box will;

a. stop immediately.
b. continue at a constant speed for a very short period of time and then slow to a stop.
c. immediately start slowing to stop.
d. continue a constant velocity.
e. increase its speed for a very short period of time, then start slowing to a stop.

Forces: Problems. Show all work.

Name:______________Student #: _____Class Lecture time: ___

1. Two perpendicular forces, one of 45 N directed due North and the second, 60 N directed due East, act simultaneously on an object with mass of 35 kg. What is the resultant acceleration of the object?

2. A block having a mass of 5.0 kg rests on a horizontal surface where the coefficient of sliding kinetic friction between the two is 0.2. A string attached to the block, is pulled horizontally resulting in a 2 m/sec^2 acceleration by the block. What is the tension in the string?

3. A 15 kg block and a 5.0 kg hanging mass are connected by a light string over a massless frictionless pulley. What is the acceleration of the system when released?

4. A horizontal force of 750 N is needed to overcome the force of static friction between a level floor and a 250 kg crate. What is the coefficient of static friction?

5. A 300 kg crate is placed on an adjustable inclined plane. As one end of the incline is raised, the crate begins to move downward just as the angle of inclination reaches 25 degrees. What is the coefficient of static friction between the crate and incline surface?

6. A puck is given an initial speed of 8 m/sec after being hit by a hockey stick. It continues to move in a straight line path for a distance of 16 m before coming to rest. What is the negative rate of acceleration? What is the force on the puck? (mass of puck= 100. g)

Forces: Mental Model

Name:____________ Student #: ____ Class Lecture Time: ___

Write everything that you know about forces. Include anything that may help illustrate your knowledge of forces. You may use this page and continue on the back of this page. Additional paper will be provided if you need it, just raise your hand.

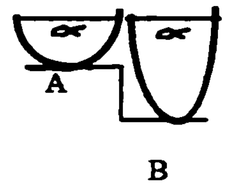
Density/Archimedes': Conceptual Questions

Place the letter of the correct answer on the scantron sheet.

1. A 10 kg object has twice the density of water. Compared to 10 kg of water, its volume is
   a. as much b. half as much c. twice as much d. less

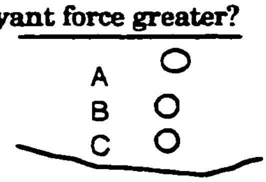
2. When the above mentioned object is suspended in water its mass will appear to be
   a. 3.33 kg b. 5 kg c. 10 kg d. none of these

3. Two vases of different shapes each contain a fish. In the position shown, the fish that will feel the greatest pressure is
   a. A b. B c. both experience the same pressure d. can't tell



4. The answer to #3 above is because:
   a. the weight of water is greater in vase B
   b. fish A is nearer to the bottom of the vase
   c. both fish are at the same depth
   d. A's tank is at a higher level

5. A pebble is sinking to the bottom of the lake. When is the buoyant force greater?
   a. A b. B c. C d. buoyant force is equal at all levels



6. This follows from the fact that
   a. pressure increases with depth
   b. the same weight of water is displaced at any depth
   c. the water is more compressed with increasing depth
   d. B provides a moderate answer- sort of an average

7. A certain force is required to keep a block 2 m beneath the surface of water. What force is required to keep it 4 m deep?
   a. zero b. the same c. twice a much d. four times as much

8. This is because
   a. pressure increases with increased depth
   b. it displaces the same weight of water at any depth
   c. the block floats
   d. surface tension doesn't act beneath the surface

9. A cubic meter of lead which weighs 10^5 N is submerged in water. The buoyant force acting on it is about 10^4 N
   a. the block loses half its apparent weight when suspended in water
   b. the block displaces 10^5 N of water
   c. the volume of water displaced is one cubic meter
   d. block loses twice its apparent weight when in water

10. Part of a wrick from a ship weighs 500 N. It displaces 200 N of fluid. The buoyant force acting on it is 200 N. From this we can see that the buoyant force acting on it is equal to the
    a. weight of the submerged object
    b. volume of fluid displaced
    c. difference between the weight of the object and the weight of the fluid
    d. weight of fluid displaced

11. A rock is submerged in water and displaces a volume of water which is
a. greater than volume of stone
b. less than the volume of stone
c. equal to the volume of the stone
d. zero

12. The standard kilogram is a platinum-iridium cylinder 39 mm in height and 39 mm in diameter. What is the density of the material in g/cm^3?
a. 21.4
b. 19.3
c. 13.6
d. 10.7

13. In a large tank containing a liquid, the hydrostatic pressure at a given depth is a function of which of the following?
a. depth
b. surface area
c. liquid density
d. A and C

14. A ping pong ball has an average density of 0.084 g/cm^3 and a diameter of 3.8 cm. What force would be required to keep the ball completely submerged under water?
a. 1000 N
b. 0.788 N
c. 0.516 N
d. 0.258 N

15. When ice floats in water, about 10% of the ice floats above the surface of the water. There is some ice floating in a glass of water. What will happen to the water level as the ice melts?
a. The water level will rise 10% of the volume of the ice that melts.
b. The water level will rise, but not as much as the 10% indicated.
c. The water level will remain unchanged.
d. The water level will become lower.

16. Atmospheric pressure is 1.0×10^5 N/m^2 and the density of air is 1.29 kg/m^3. If the density of the air were constant as you go up, calculate the height of the atmosphere needed to produce this pressure.
a. 7850 m
b. 77,000 m
c. 1260 m
d. 10,300 m

17. A large stone is resting on the bottom of a swimming pool. The normal force of the bottom of the pool on the stone
a. is equal to the weight of the stone.
b. is equal to the weight of the water displaced.
c. is equal to the sum of the weight of the stone and the weight of the displaced water.
d. is equal to the difference between the weight of the stone and the weight of the displaced water.

Archimedes'/Density: Problems. Show all work.

Name:______________Student #: ____Class Lecture time: __

1. A piece of metal, with a density of 4.69 g/cm^3 and a mass of 1500 g, is submerged in a container of oil, with a density of 0.75 g/cm^3. What volume of oil does the metal displace?

2. A spring balance which registers in units of grams is attached by a string to the piece of metal with a density of 4.69 g/cm^3 and a mass of 1500 g submerged in a container of oil with a density of 0.75 g/cm^3. The balance will register what reading when the metal is submerged.

3. A block of wood, with a mass density of 0.50 g/cm^3 and mass of 1500 g floats in a container of oil, with a density of 0.75 g/cm^3. The balance will register what reading when the wood is submerged.

4. What volume of water is displaced by a submerged 4.0 kg cylinder made of solid iron? (iron density = 7.86×10^3 kg/m^3 and water density = 1.0×10^3 kg/m^3)

5. Legend says that Archimedes, in determining whether or not the king's crown was made of pure gold, measured its volume by the water displacement method. If the density of gold is 19.3 g/cm^3 and the crown's mass is 600 g, what volume of water would be necessary to prove that it is pure gold?

6. A solid rock, suspended in air by a spring scale, has a measured mass of 9.0 kg. When the rock is submerged in water, the scale reads 3.3 kg. What is the density of the rock? (water density = 1000 kg/m^3)

Archimedes'/Density: Mental Model

Name: ________________ Student #: _____ Class time: _____

Write everything that you know about Archimedes' Principle and density. Include anything that may help illustrate your knowledge. Use this page and continue on the back of this page. If you need more paper, raise your hand and it will be provided.

Heat: Conceptual Questions

Place the letter of the correct answer on the scantron sheet.

1. Which of the following best describes a substance in which the temperature remains constant during an inward heat flow?
   a. gas b. liquid
   c. solid d. substance undergoing change of state

2. Heat flow occurs between two bodies in thermal contact when they differ in what property?
   a. mass b. specific heat c. density d. temperature

3. A falling 500 kg object is attached by a rope through a pulley to a paddle wheel shaft which is placed in a well-insulated tank holding 25 kg of water. The object, in being allowed to fall, causes the paddle wheel to rotate to churn the water. If the object falls a vertical distance of 100 m at constant speed, what is the temperature change of the water? (1 kcal = 4186 J)
   a. 19600 ^{o}C b. 4700 ^{o}C c. 4.7 ^{o}C d. 0.8 ^{o}C

4. A 0.003 kg lead bullet is traveling at a speed of 240 m/s when it embeds in a wood post. If it is assumed that half of the resultant heat energy generated remains with the bullet, what is the increase in temperature of the embedded bullet? (specific heat of lead = 0.03 kcal/kg^{o}C)
   a. 115 b. 137 c. 230 d. 259

5. A waterfall is 145 m high. What is the increase in temperature of the water at the bottom of the falls if all of the initial potential energy goes into heating the water?
   a. 0.16 ^{o}C b. 0.34 ^{o}C c. 0.69 ^{o}C d. 1.04 ^{o}C

6. What is the temperature increase of 4.0 kg of water when heated by a 800 W immersion heater for 10 min?
   a. 56 ^{o}C b. 51 ^{o}C c. 28 ^{o}C d. 14 ^{o}C

7. A 50 g cube of ice, initially at 0 degrees C is dropped into 200 g of water in an 80 g aluminum container, both initially at 30 degrees C. What is the final equilibrium temperature in degrees C? (specific heat for aluminum is 0.215 cal/g^{o}C and L_f = 80 cal/g)
   a. 17.9 b. 9.4 c. 12.1 d. 20.6

8. If heat is flowing from a table to a block of ice moving across the table, which of the following must be true?
   a. The table is rough and there is friction between the table and ice.
   b. The ice is cooler than the table.
   c. The ice is changing phase.
   d. All three are possible, but none is absolutely necessary.

9. As I use sandpaper on some rusty metal, the sandpaper gets hot.
   a. Heat is flowing from the sandpaper into the metal.
   b. Heat is flowing from the metal into the sandpaper.
   c. Friction is creating the heat.
   d. Heat is flowing from my hand into the sandpaper.

10. A 120 g block of copper is taken from a kiln and carefully placed in a beaker containing 300 g of water. The water temperature rises from 15 degrees C to 35 degrees C. Given specific heat of copper is 0.10 cal/g^{o}C, what is the temperature in degrees Celsius of the kiln?
a. 500 b. 360 c. 720 d. 535

11. In a cloud formation, water vapor turns into water droplets which get bigger and bigger until it rains. This will cause the temperature of the air in the clouds to
a. get warmer b. get cooler
c. stay the same d. there is no air in clouds

12. Find the final equilibrium temperature in degrees C when 10 g of milk at 10 degrees C is added to 160 g of coffee at 90 degrees C. (Assume specific heats of coffee and milk are the same as water and neglect the heat capacity of the container).
a. 85.3 b. 77.7 c. 71.4 d. 66.7

13. How much heat energy is required to vaporize a 1 g ice cube at 0 degrees C? The heat of fusion of ice is 80 cal/g. The heat of vaporization of water is 540 cal /g.
a. 620 cal b. 720 cal c. 820 cal d. 1 kcal

14. A container of hydrogen gas has the same temperature as a container of denser nitrogen and denser oxygen gas. The atoms having the greatest average kinetic energy are the
a. hydrogen b. oxygen c. nitrogen d. all the same

15. When an iron ring becomes heated by a flame, the hole becomes larger which follows from the fact that
a. expansion takes place inward toward the center of the ring as well as outward
b. expansion takes place in all directions
c. the surrounding air and the iron expand at different rates
d. the center only expands outward

16. When a solid changes to a liquid and then to a gas, energy is
a. absorbed b. released c. decreased d. latent

17. Dew on the grass results from
a. fast moving molecules
b. evaporation
c. the pressure of the atmosphere on water vapor
d. the slowing down of fast moving water molecules

Heat: Problems. Show all work.

Name:_____________Student #: ____Class Lecture time: __

1. A 20 g object has what specific heat if its temperature increases by 5 ^{o} C when 20 cal of heat are transferred to it?

2. A 200 g mass of metal with a specific heat of 0.30 cal/g^{o}C, initially at 90 degrees C, is placed in a 500 g calorimeter initially at 20 degrees C with a specific heat of 0.10 cal/g^{o}C. The calorimeter is filled with 100 g of water initially at 20 degrees C. Once the combination of metal, calorimeter and water reach equilibrium, what is the final temperature?

3. A 0.003 kg lead bullet is traveling at a speed of 240 m/s when it embeds in a block of ice at 0 degrees C. If all the heat generated goes into melting ice, what quantity of ice is melted? The specific heat of lead is 0.03kcal/kgC, the latent heat of fusion is 80 kcal/kg and 1 kcal = 4186 J.

4. A flat pan container holds 200 g of water. If over a 10 min. period, 1.5 g of water evaporates from the surface, what is the approximate temperature change of the remaining water? (L_v = 540 cal/g)

5. Iced tea is made by adding ice to 1.8 kg of hot tea, initially at 80 degrees C. How many kg of ice, initially at 0 degrees C, are required to bring the mixture to 10 degrees C? (L_f = 80 kcal/kg). Assume the specific heat capacity of tea is the same as that of water.

6. A 100 g piece of copper, initially at 95 degrees C, is dropped into 200 g of water contained in a 280 g aluminum calorimeter; the water and calorimeter are initially at 15 degrees C. What is the final temperature of the system? (specific heats of copper and aluminum are 0.092 and 0.215 cal/g^{o}C, respectively)

Heat: Mental Model

Name: ___________Student #: _____ Class Lecture Time: ____

Write everything you know about heat. Include anything that may help you illustrate your knowledge. Use this page and continue on the back of this page. If you need more paper, raise your hand and it will be provided.

Mental Model Template

Points of Reference							Points of Observation		
Sentence number	Agent	Action	Object	Receiver	Goal/explanation	effect	time	location	conditon

APPENDIX C: Learning Cycles

Graphing

Laws of Motion

Motion of Ball on Incline

Motion of Ball on Steeper Incline

Motion of Falling Ball

Vectors

Friction

Circular Motion

Energy

The Balancing Act

Collisions and the Rules that Govern Them

Density

Archimedes' Principle

Specific Heat in Solids

Graphing

Introduction.

This activity will allow you to gain experience in graphing, in describing graphs, and in using equations to describe graphs.

Exploration.

Part A.
1. Select six integers between 0 and 25. Record these in the x-column.
2. Multiply each of these integers by two. Record these in the y-column.

X	Y

3. Now graph the x-values along the horizontal axis and the y-values along the vertical axis. Label this graph: Graph A: 2x versus x.

4. Describe the shape of the graph.

Part B.
5. Select six integers between 0 and 10. Record in the x-column.

6. Square each of the x-values. Record in the y-column.

X	Y

7. Now graph the x and y values.
8. Describe the shape of the graph.

Part C.
9. Select six integers between 0 and 100 that have integer square roots (such as 49 since square root of 49 is 7). Record the values as x's and their square roots as y's.

X	Y

10. Graph the x and y-values.

11. Describe the shape of the graph.

Part D.
12. Select six integers between 0 and 20. Record as x-values.

13. To obtain the y-values, take the reciprocal of the x-value.

X	Y

14. Graph the x and y-values.

15. Describe the shape of the graph.

Conceptual Invention.

1. Were the graphs from part A, B, C, and D similar? In what ways? Explain.

2. In your own words, describe the $y=2x$ graph.

3. What do you think the shape of a $y=3x$ graph would look like? Graph it on the same piece of graph paper as the $y=2x$ graph.

4. Describe a $y=Nx$ graph? (N is an integer)

5. In your own words, describe a $y=x^2$ graph.

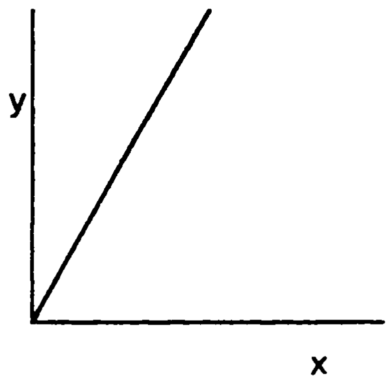
6. In your own words, describe a y= squareroot of x graph.

7. In your own words, describe a $y= 1/x$ graph.

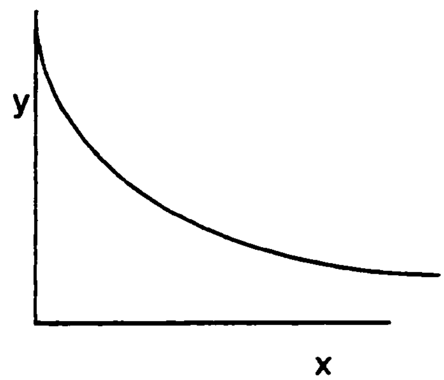
8. Now, if you were to look at a graph (and it was one of these four types), could you intelligently guess at the form of the graph's equation? Explain how or how not.

Expansion.

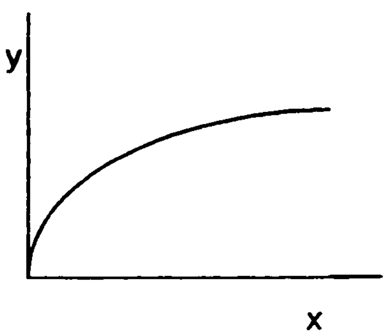
1. For the following: write the form of the equation describing the graph.



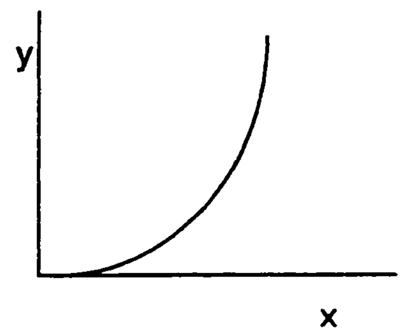
a.



b.



c.



d.

2. Each student must put one paperclip on the electronic scale and record the total mass on the board. Plot the # of paperclips on the horizontal axis and the total mass on the vertical axis. Describe the graph. Write an equation describing the graph.

3. What is the slope of the graph?

4. Look at the graph and then look at the average mass of one paperclip. How does this mass compare to the slope of the graph?

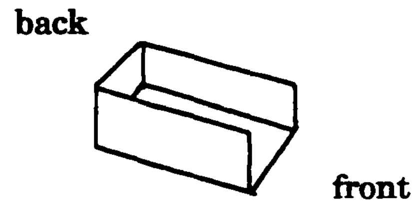
5. In your own words, tell how you can obtain the specific equation of a straight line in terms of x and y only. Be sure to define what x and y are in your equation.

Laws of Motion

Exploration 1.

Equipment: shoebox, scissors, rubber ball

Make a three-sided box out of the milk carton with the scissors.



1. Place the rubber ball in the box next to the back wall. Push the box forward. What happens to the ball when the box is moving?

When the box is moving is the ball moving? How can you tell?

2. Now place the ball near the front of the box. Push the box forward. What happens to the ball as the box begins to move?

What happens to the ball after the motion has begun for some time?

When the box is moving is the ball moving? How can you tell?

3. Now place the ball next to the back wall again. Push the box forward quickly, but stop it suddenly.
What happens to the ball after you stop the box?

Try it again. Does the ball move? If it does in what direction?

4. From your observations, write some general statements about the motion of the ball.

Conceptual Invention 1.

5. What happened to the ball when the box was still for several minutes?

6. What happened to the ball when the box is first pushed forward?

7. After the initial motion of the box, is the ball moving? How can you tell?

If it is moving, how fast is it moving?

8. What happens to the ball when the box is stopped suddenly?

9. In what direction does the ball move when the box is stopped?

Complete the following sentences.

10. A ball at rest continues to be at _______ unless ____.

11. A ball in motion continues to be in __________ in ___ __________ _________ unless ______________________.

12. A push or pull is called a ___________.

13. Sentence 10 and 11 above are statements of _________________.

Expansion 1.

Recall the movement of the ball from question 2. Recall the movement of the ball from question 3. In each case, how does the motion of the ball compare with that of the box? In what direction does each move?

When something has a tendency to resist a change in its motion it is said to have <u>inertia</u>. Inertia is the tendency of an object to resist changes in its motion. Newton's First Law is sometimes called the law of inertia. Now using the new term inertia write a sentence or two explaining the motion of the ball in the box.

Equipment: compass (drawing type), penny, toy car, metric ruler

Draw a circle of radius 10 cm on a piece of paper. This will be the road for our car. Put the coin on top of the car. Quickly push the car around the road.

14. What object or objects feel a force?

15. What is the path of the car?

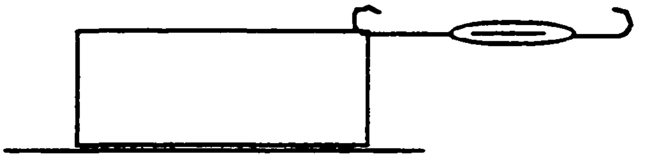
16. When slowly pushing the car suddenly stop the car.
    What objects or objects feel a force?

17. What happens to the coin? What is its path?

18. Write a statement explaining the motion of the coin using Newton's First Law.

Exploration 2a.
Equipment: 3-1kg masses, spring scale, box, scissors.

Poke a hole in the box so that the hook on a spring scale may be attached. (See diagram.)



1. Place one mass in the box. Pull on the spring scale so that the box moves. What happens to the spring scale? What value does it read?

Record this value in the data table provided.

Data Table 1

# of masses	Scale reads
1	______
2	______
3	______

2. Repeat, but pay attention to how fast the box moves. Once you can judge how fast it moves, place another mass in the box. Pull on the spring scale so that the box moves as fast at the end as it did before. Is it harder or easier to pull?

Record the scale reading in Data Table 1.
What happens to the spring scale?

3. Place the third mass in the box and repeat. Record the value of the spring scale. Again, be sure to have the box moving as fast at the end as it was before.

Conceptual Invention 2a.

4. What can you say about the number of masses and the scale readings in questions 1-3 above?

5. What does the spring scale reading represent?

What does the number of masses in the box represent?

6. What can you say about these two things from #5?

Exploration 2b.

7. Now with one mass in the box, pull so that the spring scale is twice what it was before. You may need to practice several times to pull so that the spring scale reads twice what it did. Use the words fast , very fast, very very fast, slow, very slow, or very very slow to describe the motion of the box. Record your descriptions in Data Table 2.

Data Table 2

mass	speed at beginning	speed at end	Scale reading	Speedchange
1	________	________	________	________

Conceptual Invention 2b.

8. How fast was the box and mass moving just as you first began to pull it?

9. Tell how much the speed of the box and the masses changed from the time that you first began pulling on them to the end. Use the terms alot, a little, very little, or none to describe how much the speed changed from beginning to end. Write your descriptions in Data Table 2.

10. What does the scale reading represent?

11. What can you say about the force that you exerted and how much the speed of the masses changed?

Expansion 2.

Equipment: identical books, spring scale, string, scissors

1. Tie a string around one book. Hook the spring scale on the string at the center. Pick up the book with the spring scale. Hold it still and record the value of the spring scale in the data table.

Data Table

# of books	Scale reading	Prediction

2. Predict what the value of the spring scale will be with two books. Record your prediction in the data table. Now place a second book with the first and re-tie the string as before. Raise the book off of the table. Holding it still, record the value of the spring scale. Is it close to your prediction?

3. Now predict what the value of the spring scale will be with three books. Record your prediction. Place a third book with the first two and record the value of the spring scale.

4. What can you say about the number of books you are holding and the value on the spring scale?

5. Is it easier to lift 1 book, 2 books, or 3 books? Why?

What force are you pulling up with when you are holding up one book? Two books? Three books? Why?

For Further Expansion 2.

Equipment: 2 spring scales, book, desk or table, string, scissors

Cut a string so that you can tie it around a book. Tie the string around a book and hook two spring scales on opposite sides of the book. Leave the book on the table. Work in pairs, with one student pulling on one spring scale. Pull with the same force on each spring. Talk to your partner to be sure that you are each pulling with the same force. Describe what happens to the book.

Does it move while you are both pulling with the same force?

What happens if one of you lessens the pulling force or lets go? Write a sentence or two describing what you observed.

Exploration 3.

Equipment: skateboard, 'medicine ball'

Work in pairs so that one is a light student and one is a heavier student. One student carefully stands on the skateboard, this is the thrower. The other stands about 2 m away and is the catcher. The student on the skateboard is to throw the basketball to the other student.

1. Describe what happens to the thrower and the ball.

2. Repeat the throw, but this time throw the ball harder. Describe what happens.

3. Compare this throw with the first one.

4. Switch jobs so that the thrower is the catcher and the catcher is now the thrower. Repeat the above procedure.
What things are the same and what things are different?

Conceptual Invention 3.

5. What can you say about the direction in which the ball went compared with the direction in which the thrower went?

6. What did the thrower do to the ball in the act of throwing it?

7. What caused the thrower to move as he did after the throw?

8. What general statements can you make about the ball and the thrower?

Expansion 3.

Equipment: skateboard, wall

Stand on the skateboard so that you can push on a wall. What happens when you push on the wall?

Are you exerting a force on the wall when you push on it? What made you move as you did?

You are now ready to complete the problems assigned in your text dealing with Newton's Laws.

Motion of Ball on Incline

Introduction:

What is important to be included in a description of the motion of a ball rolling down an incline? This investigation will allow you to learn how to describe such motion using physics terms.

Exploration.

1. Place the wooden V-trim to the incline apparatus (with the "0" at the lower end). Adjust the incline to 30 degrees.

2. Note on the grooved board that there are marks denoting: 60.00 cm, 70.00 cm, 80.00 cm, 90.00 cm, etc.. These are the distances from the end of the ramp.

3. Using your pencil as a stop, release the ball from the 60.00 cm mark and record in the table the time it takes the ball to reach the end of the ramp. To ensure greater accuracy, repeat the process 2 more times. Now average the times and record under the time column.

4. Repeat Step 3 for 70.00 cm, 80.00 cm, 90.00 cm, 100.00 cm and 110.00 cm distances.

Table 1.

distance	time1	time2	time3	time (avg)	?

5. Look at the data for patterns. Write a summary of what you observe from Table 1.

Conceptual Invention.

1. Graph the distance versus the time.
2. What does the graph look like? Describe it.

3. As the time increases, what happens to the distance traveled?

4. From your graph, what is happening to the ball?

5. Go back to Table 1 and calculate the average velocity for each of the ball's trips. Record it in the "?" column in the table.

6. Do your calculations from #5 above agree with your answer to #4?

   Explain.

7. Plot a graph of the average velocity versus the time (avg).
   Describe this graph.

8. After you have drawn the best fit line through the data points, examine the following:

Choose 2 points that have a difference in average velocity of 10 cm/sec. What is the time interval between these 2 points?

Chose 2 other points that have a difference in average velocity of 10 cm/sec. What is the time interval between these 2 points?

9. What can you say about the results of #8 above?

10. Recall what you know about linear graphs. Is there a relationship between the change in average velocity, time, and slope?

If so, write the equation involving all three quantities.

11. What is the name for the slope?

What happened to the ball going down the incline? (Use your new terms.)

Expansion.

1. Calculate the slope of the graph for the ball on the incline.

2. What is the special name for the slope of this graph called?

3. Write a definition for acceleration in terms of this investigation.

4. What are the units for acceleration?

5. Using the equation that you developed from #10 above, solve the following:

   A car is advertised to travel from 0 to 60 mi/hr in 5 seconds.
   What is the acceleration of such a car?

6. In writing and using your new terminology, describe what happened to the car in the problem #5 above.

Motion of Ball on Steeper Incline

Introduction:

Further experimentation will allow you to practice describing the motion of the ball rolling down the incline.

Exploration.

1. Repeat Investigation 1 with the incline set at 45 degrees.
   Record all of your data in Table 2.

Table 2

distance	time1	time2	time3	time (avg)	avg. velocity

2. Plot the average velocity versus the time and obtain the acceleration of the ball rolling down the incline.

Conceptual Invention.

1. Describe how the acceleration of the ball varied from that of previous incline.

2. Why do you think that this is so? What is your evidence?

3. Describe the velocity change in any 0.200 second interval of time. Pick 2 other 0.200 second intervals to check. Be sure to select points ON THE LINE that you drew (NOT data points). Why?

Is the velocity change the same or different?

4. What is changing as the ball rolls down the incline? Describe what happens to the velocity of the ball as it goes down the incline. How does it compare to the velocity of the ball on the previous incline?

Expansion.

1. What do you think would happen to the acceleration of the ball if the incline were inclined at 70 degrees? 90 degrees?

2. From your answer from #1, which ball would be going faster at the bottom of the ramp, one inclined at 70 degrees or one inclined at 90 degrees? Explain why.

3. Use equations to explain your answer in #2.

Motion of a Falling Ball.

Introduction.

You have described the motion of a ball on an incline and even postulated what would happen if the incline were at 90 degrees. Now you will drop the ball and describe its motion.

Exploration:

1. Assemble the timer apparatus as instructed. When the ball is released at the top the timer begins counting. It stops counting when the ball hits the timer pad. Pressing the reset button allows timing for additional trials. Ask your instructor if you need assistance with the apparatus. Hint: Try distances from 40 -140 cm.

2. Using the equipment, obtain the acceleration of the ball. Rely upon your experience from the first two investigations to do so.

Here is a blank table for your data. Be sure to insert headings for the columns.

Table 3.

Conceptual Invention.

1. Explain all the steps you took to obtain the acceleration of the ball.

2. Plot the distance the ball fell (vertical axis) versus the time (avg) of fall squared. What is the slope of this graph? Discuss.

3. Write an equation that illustrates this relationship between distance and time^2.

4. Does the value for the acceleration of the ball seem reasonable compared to what you got from the acceleration of the ball for the two previous investigations? Explain.

5. Since the ball was freefalling, describe the motion of the ball. In other words, explain what happens to the ball as it falls.

6. What do we call the acceleration of a falling ball?

7. Write the formula for the distance, acceleration, and time for an object freely falling from rest.

Expansion.

1. Would you expect a heavy ball and a small ball to fall with the same acceleration?

Collect data to support your answer. Again, here is a blank data table for your use.

Table 4.

What is your conclusion? (Does a heavy ball and a lighter ball fall with the same acceleration?). Justify your answer.

Expansion Problems.

1. A rock is dropped off of a building that is 100 m tall. Find how long it takes it to hit the ground using the accepted value for the acceleration of an object in freefall ($9.8 m/s^2$).

2. If it takes a rock 3 seconds to hit the ground when dropped from the top of a cliff, how tall is the cliff?

You should be ready to do the problems in Ch. 2. Begin working on them!

Vectors

Introduction.

You have probably added numbers linearly, for example: $2 + 3 = 5$, $3 + 4 = 7$. Could $2 + 3$ ever equal the square root of 13? Could $3 + 4$ ever equal 5? You will examine such cases.

Equipment: Ruler, force apparatus, tension scales

Exploration.

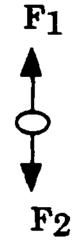
Use a spring scale to pick up a 100g weight. What is the spring scale doing to allow you to lift the weight?

What does the force of the spring scale represent or measure?

If you were to lift 20 lbs, in physics terms what are you doing to the object?

Now set up the force apparatus to look like this.

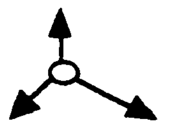
Data 1



Sketch how your apparatus will look for force 1 and force 2, being careful to include the values of F_1 and F_2 as read from the tension scales. Be sure to mark the locations of F_1 and F_2 on your paper. Record the values in Data Table 1.

Now we are going to look at a more complicated example on Data 2 and use three forces. Adjust the pulleys and the angles between the forces so that the ring is exactly in the center. Record the values of F_1, F_2, and F_3. Be sure that you mark the location of these forces on the paper that you place underneath the force scale apparatus.

Data 2



Once the forces are recorded and the positions of the arms are located take a protractor and measure the angle between force 1 and force 2, the angle between force 2 and force 3, and the angle between force 3 and force 1. Record your results in Data Table 1.

Data Table 1

Data	Force in g	Angle between forces
1	force1=	1&2 =
	force2=	2&1 =
2	force1=	1&2=
	force2=	2&3=
	force3=	3&1=

Conceptual Invention.

1. Observe the Data 1 diagram that you drew. Describe how Force 1 and Force 2 are acting on the ring. How are these forces related to one another?

2. Summarize what you think Data 1 is telling you about force 1 and force 2.

3. Describe how force 1, force 2, and force 3, on Data Set 2, are related. Describe how the forces are acting in the directions that they are acting. Be sure to explain the angles involved.

4. Summarize what you think the Data from Set 2 are telling you.

5. In Data set 1 force 1 is pulling upward. In Data set 2 force 1 is pulling upward. In Data set 1 there is a force 2 pulling downward, but in Data set 2 there are 2 forces pulling it at angles away from one another.
How are force 2 and force 3 related to force 1?

Could you call the combination of those some force? If so what is that force?

6. What would be the direction of the combination of force 2 and force 3?

7. How is this combination of force 2 and force 3 related to force 1?

8. Now use Data 1 to draw a scale diagram of those data. For a scale diagram a certain length represents a certain amount of another quantity. For example: 1 cm may represent 200 g of weight, 2 cm may represent 400 g of weight. Using Data 1, draw a scale diagram of force 1 and force 2.

9. How are force 1 and force 2 related to each other?

10. Now draw a scale diagram of Data set 2. With F_1 being the length of force 1 converted into cm, F_2 being the length of force 2 converted into cm, and F_3 being the length of force 3 converted into cm on your scale.

11. Once you have your scale drawing drawn, then draw a parallelogram using F_2 and F_3 as the sides of your parallelogram. Draw the vector from the intersection of the three forces down to the opposite side of the parallelogram.
What do you think this vector represents?

12. Explain why this vector can be called the resultant force of F_2 and F_3.

13. How does this resultant force relate to force 1?

14. Describe what you think a vector is.

Expansion.

Read your text book page 55 thru page 60. Complete questions: 1, 3, 4, 6 on page 75 in the text book. Furthermore, answer the questions below.

1. Explain what it means to say the magnitude of a vector is a scalar.

2. State which of the following are vectors and which are not vectors. For example, classify the following: force, temperature, the amount of water in a can, the weight of a book, the height of a building, the velocity of a sports car, and the age of the universe.

3. Now that you have studied vectors experimentally and have read about vectors experimentally, summarize the steps that you take to add vectors using components. In other words summarize section 3.3 of your text book <u>in your own words</u>. Feel free to choose forces as an example to explain your summarization of the forces.

Friction

Introduction.

You will examine the frictional forces between objects and the constant involved between two objects.

Exploration.

1. Watch a block slide on the lab table as you push it away from you. Describe its motion. Does it matter whether or not you slide it on edge or a different side?

2. Why do you think the motion is such?

3. Mass a block with the spring scale. Record in Data Table 1.

4. Take a block and attach a spring/tension scale so that you can pull the block with the scale so that the block has a constant speed. Record the value in grams from the tension scale in data table 1. Tape 100 g to the top of the block of wood and repeat.

5. Continue too add 100 g to the block and repeat step 4 three more times.

Data Table 1.

Total Mass=M	Tension=T

6. Plot a graph of T versus M.

7. Determine the slope of the graph.

slope = __________

8. Does the slope of the graph have any units?

9. What does it mean if something doesn't have any units? Is it a force, a mass, etc?

Conceptual Invention.

10. What does the force that you read on the tension scale represent? Hint: Would this force change if you pulled the block on ice? On rubber? What do you think?

11. What is the equation of the line that you graphed?

12. What does the slope of the line represent?

13. Use your new terminology in a sentence describing the equation of the line that you graphed.

14. Draw a free body diagram for the situation in which you are applying a force through the tension scale so that the block moves at constant velocity across the table.

Expansion.

15. Find the coefficient of kinetic friction for the block on the floor using the equation (only one data point) instead of obtaining it from a graph. Then find the coefficient of kinetic friction for the block on the floor by the method that made use of the graph. Which one do you think is more accurate? Why?

Coefficient of kinetic friction for wood on tile (eqn. method) = __________

Coefficient of kinetic friction for wood on tile (slope method) = __________

A data table is provided below:

total mass	tension

How do the two coefficients compare?

16. Read the section in your book about friction on an inclined plane as a block just begins to slide. Be sure to draw here the free body diagrams so that you understand how they obtained the expression that the coefficient of starting friction is the tangent of the angle at which it begins to slide.

17. Now incline the lab table and obtain the coefficient of starting friction for the lab table and wooden block. How does it compare to the coefficient of kinetic friction obtained earlier? Compare with members of the class. Is one always larger than the other?

18. Now read the rest of the chapter on friction (Ch. 4) and work the assigned problems.

Circular Motion

Equipment: Circular motion apparatus, string and rubber stopper

Exploration.

1. Slowly rotate the apparatus. Describe what happens to the mass.

2. Remove the spring from the large mass and slowly rotate the apparatus.

3. Describe what happens to the mass.

4. What effect does the spring have on the mass while it is in motion?

5. Now twirl a string with a rubber stopper on the end of it. What effect does the string have on the stopper?

6. State your findings about an object in circular motion. In your explanation, be sure to answer the question: what it is that makes an object move in a circle?

Conceptual Invention.

7. What is necessary for an object to move in circular motion? What is your evidence?

8. Using the new terminology, summarize your findings.

9. In what direction does this force act? How can you tell or how do you know? Tell what the spring and string do.

10. What other variables might affect this force? List them.

11. Discuss/tell how you might test to see if these variables affect the force that makes an object move in a circle.

Expansion.

1. What is it that keeps the clothes in a washing machine moving in a circle? In what direction does this act?

2. What is it that keeps your car moving in a circle as you turn a curve? (Hint: Think about turning a curve when there is ice on the road.)

3. Using your knowledge thus far about circular motion, explain why a pilot pulling out of a steep dive will "black out". (Hint: For the same reason a car on an icy curve will fail to stay in a circular path.)

Centripetal Force

Equipment: Circular motion apparatus, stopwatch, masses, graph paper, scales

Exploration.

1. Tell how you can determine the velocity of the rotating mass. (Hint: How can you find the velocity of a car when the speedometer is broken.

2. State how the centripetal force can be determined.

3. For the radii given, measure the time for 30 oscillations then use it to determine the velocity. Find the mass needed to stretch the spring a distance equal to the given radius. Record in the Data Table 1.

Data Table 1

radius	dist. around once	time around once	velocity	centripetal mass	centripetal force
14cm					
16cm					
18cm					
20cm					

4. Calculate the distance around once for each radius and record in Data Table 1.

5. Calculate the period and record in Data Table 1.

6. Calculate the velocity and record in Data Table 1.

7. Calculate the centripetal force using the centripetal mass and Newton's Second Law.

8. Plot a graph of centripetal force verses velocity.

9. Describe the graph of F_c vs. v.

10. Plot a graph of centripetal force verses velocity squared.

11. Describe the graph of F_c vs. v^2.

Conceptual Invention.

12. What does the graph of F_c vs. v^2 suggest?

13. Use your mathematics knowledge to write an equation for the F_c vs. v^2 graph.

14. Now determine the value of the slope of your graph.
Record it here:___________________.

15. Determine the quotient of the mass of the rotating bob and the avg. radius of the circular orbit.

Record this quotient here:____________________.

16. How does the quotient in #15 above compare with the slope obtained in #14?

17. Write a new equation for the graph of F_c verses v^2 using this information.

18. State in your own words the relationships that you have found between the variables.

Expansion.

Read Section 7.4 thru 7.7 in your text. Work problems: 29,31,34,39.

Energy

Introduction.

Experimentation with these materials should enable you to learn about energy.

Exploration.

1. Take the fun dough and flaten it out so that it is about 3/4 to 1 inch thick. It needs to be 3 to 4 inches square to provide an adequate target.

2. Drop the small steel ball onto the fun dough from a height of about 40 cm above the fun dough. Drop the large steel ball onto the fun dough from the same height. Describe what happens to the dough.

3. Drop the small ball from the ceiling height and the large ball from a height of about 10 cm. Describe what happens to the dough. Now, reverse the two balls (sizes) and repeat. Describe what happens to the dough.

4. Based upon your answers to 2 and 3, how does height affect the amount that the ball indents the dough?

5. Based upon your answers to 2 and 3, how does mass of the ball affect the amount that the ball indents the dough?

6. Predict how the dough will be indented when you drop the large ball from a height of about 40 cm and you throw the large ball from a height of 40 cm above the dough. What is the initial velocity of the ball that is dropped as compared to thrown?

Does this give you an idea as to why you guessed the predicted outcome? Explain.

7. Now be careful (don't hurt your lab partner(s) or break anything) and actually do #6 to see if you were correct in your prediction. Write your conclusions here.

Conceptual Invention.

8. When lifting the small ball as compared to the large ball (to the same height), tell which one requires more exertion (or work) on your part.

9. A ball that is dropped from a height of 40 cm requires _____ times as much work to lift it to that height as a ball that was lifted and then dropped from a height of 80 cm.

10. A ball that is twice as heavy (or massive) as another ball requires ____ times as much work to lift it to 40 cm.

11. Write your definition of work.

12. You did so much work on the steel ball in lifting it, what happened to this work when you let the ball go? What happened to the ball as soon as you let it go? What happened to the dough as the ball hit it?

13. Write the definition of potential energy and kinetic energy in your own words.

14. Compare potential energy and work. In this experiment, how are they related?

(i.e., you gave the ball _____ and it then had _____).

15. Compare the potential energy and kinetic energy as the ball fell. Assume the ball had 10 units of work done on it, and describe what happens to the 10 units as the ball falls.

16. Write the variables that you think affect how much kinetic energy the ball has and how much potential energy the ball has. (think about #2,3,4 & 7 or test others yourself).

17. After the class discussion, can you eliminate any of the variables you listed, or add any that you forgot to include? Explain.

18. Write the equation for kinetic energy and for potential energy

Expansion.

Read Chapter 5 and do the problems assigned.

The Balancing Act

Equipment: meter stick, masses, pivot, knife edge, clamps

Introduction.

To be in balance means the same thing as to be in equilibrium. In this investigation you will study about equilibrium and what is called the balance or teeter totter as it may have been called when you were a child. A fulcrum (F) is just a support pivot point. The fulcrum will pivot on what is called a knife edge or pivot.

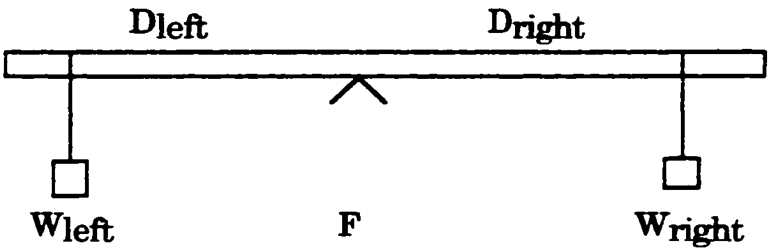


Figure 1

Exploration.

1. Balance the meter stick alone. Adjust the meter stick on the fulcrum so that the meter stick is perfectly horizontal. To distinguish perfectly horizontal measure the distance the right end of the meter stick is from the table and the distance the left end of the meter stick is from the table. If this distance is the same from the meter stick to the table on both ends then the meter stick is perfectly horizontal. The balance point is the location of the knife edge on the meter stick. Indicate the point of natural balance on the Data Table 1.

Data Table 1
Natural balance point of the meter stick=______________

Be sure to tighten the knife edge at this point on the meter stick because you will be using this natural balance point throughout the rest of the investigation.

2. With the pivot on a meter stick at the natural balance point, place a mass on a clamp. Place another mass on another clamp at a location that balances the stick. Repeat 3 times for other masses at different locations. Record in Data Table 2.

Data Table 2.

Trial	Wleft in g	Dleft in cm	Wright in g	Dright in cm

Conceptual Invention.

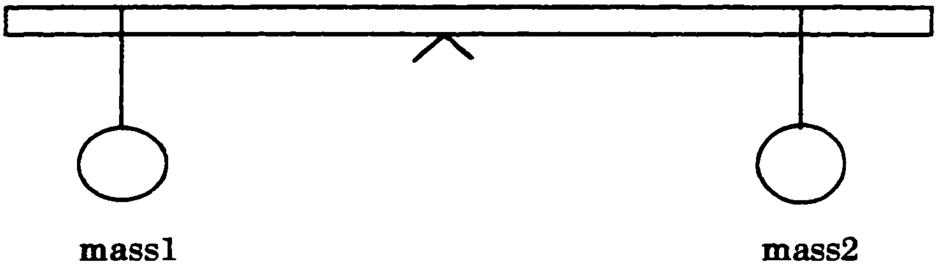
1. Multiply W_{Left} times D_{Left}. Do the same for W_{Right} times D_{Right}. Record in data table below.

Trial	Wleft x Dleft	Wright x Dright

2. From the above data table, can you write a general rule for weights and their distances on a meter stick at its natural balance point.

3. When on a teeter totter, where must you place a big and a small child so that they can teeter totter? Draw a sketch.

4. The product of weight versus distance from the fulcrum is called torque. A torque causes a rotation which has a direction clockwise or counterclockwise. State the direction of the torque or rotation for each of the masses shown. Hint: Ignore all other masses besides the one for which you are determining the torque.



Expansion.

1. Where must one place a 50 g mass if a 200 g mass is placed at 60 cm on a uniform meter stick with a pivot point at 50 cm?

2. Read Section 8.1, 8.2, and 8.4. Do problems #4, 8, 9, 12, 16, 21.

Collisions and The Rules That Govern Them

Exploration.

The following data were gathered by a computer for your use. To obtain the data, car 1 had a mass of 10 kg and car 2 had a mass of 20 kg. When the two cars collided, they stuck together and traveled as one larger car of mass 30 kg. Observe the data and try to come up with some rule regarding the masses and velocities. The rule must work for each case. Note the sign convention used: positive velocities are directed to the right and negative velocities are directed to the left. Draw a sketch noting the directions of the cars to show me you understand.

Sketch showing car's direction/vel.

mass car1=10kg	mass car2=20 kg	cars combined=30kg	before collision	after collision
3.00m/s	0.00m/s	1.00m/s		
2.00m/s	1.00m/s	1.33m/s		
4.00m/s	1.00m/s	2.00m/s		
-2.00m/s	-3.00m/s	-2.67m/s		

Conceptual Invention.

1. What rule can you determine fits each case? Show below how the rule fits one of the cases .

2. Write this rule in algebraic and in sentence form.

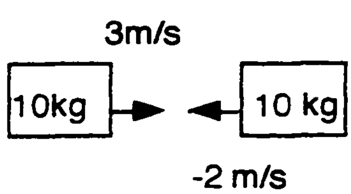
3. Write a sentence using the term momentum in the rule.

4. Look at the kinetic energy of the objects. Does the kinetic energy of all the objects before the collision equal the kinetic energy of all of the objects after the collision?

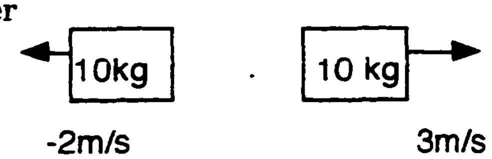
5. Why do you think this is so?

6. The following data were gathered by computer for two cars that collided head-on, but did not stick together. Instead, they bounced off of each other.

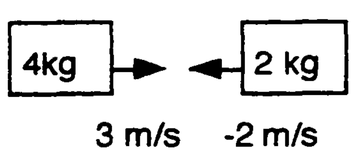
<u>Case 1.</u>
before



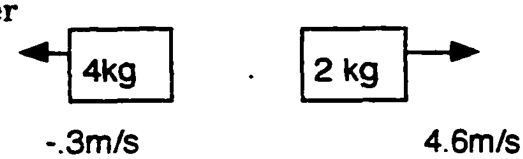
after



<u>Case 2.</u>
before



after



Write a rule including masses and velocities that explains the collision of two objects that bounce off of each other.

7. Is this rule similar to the earlier rule?

8. Check the kinetic energy. Is the kinetic energy of all of the objects before the collision equal to the kinetic energy of all objects after the collision? Why do you think this is so?

Expansion.

9. Summarize your rules for conservation of momentum and conservation of kinetic energy for elastic and inelastic collisions.

10. Work on the momentum problems in your textbook.

Density

Equipment: Aluminum cylinder, lead cylinder, overflow can, balance, graduated cylinder

Exploration.

1. Mass the dry graduated cylinder. Record here: ___________

Measure 30.0 ml of water with a graduated cylinder. This represents the ______________of the water.

2. Mass the 30.0 ml of water in the cylinder.
Record the mass of the water in grams.
________________represents the masses of ____________ml of water.

3. Repeat #1 and #2 above with 25.0 ml and 40.0 ml of water.

Record your results:

25.0 ml water mass=___________________

40.0 ml water mass=___________________

4. What can you determine from the results of the exploration?

5. Do you think this applies to different materials?

Use the aluminum and lead object to find out. Submerge the objects in water to measure their volume, as you did in Archimedes' Principle. Record your findings below.

______ml of aluminum has mass=__________g.

______ml of lead has mass=_______________g.

6. Divide the mass and volume by the number of ml. This will make your answer easier to study.

1.0 ml of aluminum has mass=___________

1.0 ml of lead has mass=________________

Conceptual Invention.

7. Is the mass of 1 ml of any substance the same?

How is it different? Explain.

8. Using the new terminology state your findings about water, aluminum, and lead.

9. Write an equation for density. (Hint: Use, Density=ρ)

10. What did you obtain as the density of the aluminum cylinder?

Of the lead object?

11. Find the accepted value off density from a physics book.
accepted values: _____ for aluminum, and _____ for lead

Calculate % error = ___________ for aluminum

% error = _______________ for lead

Expansion Problems.

12. If a substance has a density of 2 g/cm^3, what is the mass of 1 m^3 of the substance?

13. Explain this in everyday words. Hint if 1 cm^3 of a substance had a mass of 2 g, should a 1 m^3 volume of the same substance be more massive or less massive?

Calculate the mass of the 1 m^3 volume.

14. An cubical object just floats without sinking in a fluid of density 1.40 g/cm^3. If a side of the cube is 1.0 cm long what is the mass of the cube?

Archimedes' Principle

Equipment: Balance on ring stand with rubber band, aluminum cylinder with a string, overflow can, 250 ml plastic cup, water

Introduction.

Do you feel the same, heavier, or lighter in a swimming pool? This investigation will teach you about objects' mass as measured in air and as measured in water.

Exploration.

1. Using the balance with rubber band attachment, determine and record the mass of the aluminum cylinder. Draw a diagram to show how you did this.

Mass of cylinder=________________

2. Similarly, determine and record the mass of the aluminum cylinder when it is totally submerged in water. Fill the overflow can with water so that it is approximately 2 cm below the spout. Now submerge the aluminum cylinder. Do not allow the cylinder to rest on the bottom of the cup. Why should you not allow this?

Mass of cylinder in water= ______________

3. Place the plastic cup under the spout. Fill the overflow can with water until water stops pouring out of the spout. Empty the plastic cup and place it under the spout. What do you think will happen if you pour any more water into the can?

Using a graduated cylinder pour 20.0 ml of water into the can and record your observations. Measure and record the volume of water that poured out. Is this what you expected? Why or why not?

State what will happen if you were to pour 50.0 ml of water into the can. Do it and test your predictions.

In summary, what does the overflow can allow you to do?

4. Now refill the overflow can until water stops pouring out. Carefully place the same dry aluminum cylinder in the overflow can. Allow it to rest on the bottom of the can. Describe what happens.

Why did it happen?

Is this what you predicted?

5. Now record the mass of the water that flowed out.

Mass of water overflow____________________

Conceptual Invention.

6. Was there a difference in the mass of the aluminum cylinder when it was measured in the air (#1) as opposed to the water (#2)?

7. If so, how great was this difference in mass?

8. Why do you think there is a difference? In other words, what does the water do? Draw a diagram to show this.

9. How does this difference in mass compare with the mass of water that poured out of the can?

State your findings in words.

10. What does the mass of water that overflowed represent? (Hint: Why did it overflow?) Now restate your findings to incorporate this relationship and the term buoyant force.

Expansion.

11. Describe an experiment in which you could obtain the volume of your body when in a bathtub.

12. Describe an experiment in which you could obtain the buoyant force of your body when in a bathtub?

13. You buy a ring at a garage sale. In order to determine whether or not it's gold you perform an experiment. Its mass in the air is 3 g. Its mass in water is 2.77 g. Calculate the buoyant force?

Using this, calculate the density of the ring.

Do you think the ring is gold?

Specific Heat in Solids

Introduction.

The student will be able to determine the affect that heat has on different materials in order to determine the specific heat capacity of different materials.

Equipment:

aluminum cylinder	lead weight	string
graduated cylinder	scales	
400 ml beaker	thermometer	
styrofoam cup	hot plate	

Exploration.

In this lab you will be heating metal cylinders and then transferring them to water in a styrofoam cup.

First, we must discuss what things affect how long it takes something to cool off or warm up.

1. Does the amount of matter in an object affect how much heat that you must add to warm it up it to a particular temperature?

If so, how?

Can you cite an example from your personal experience?

2. Does how much you increase the temperature affect how much heat that you must add?

If so, how?

Can you cite an example from your personal experience?

Thus far, you have discovered that the quantity of heat depends upon the mass of the object and the temperature change through which the material must go .

Now you will perform an experiment.

1. Place a pyrex 400 ml beaker filled with about 300 ml of water on a burner to begin heating while you prepare the rest of the experiment.

2. Record the description and material of each metal object in the data table.

3. Record the mass of each object (in grams) in the data table beneath the name of the substance.

4. Attach a string about 30 cm long to each object. Place the metal object in the beaker of hot water. Don't allow the string to touch the heater plate.

5. Using the graduated cylinder, pour 300 g of tap water into a styrofoam cup.

6. When the water has begun to boil, record the temperature of the water as Tmi, but DON'T leave the thermometer on the bottom of the beaker.

7. Why does the temperature of the boiling water represent the temperature of the metal initially?

8. Record the initial temperature of the water (as Twi) in the styrofoam cup just before you are ready to transfer the hot metal cylinder into the cup. Be sure that the metal cylinder is in the boiling water for at least 3 minutes before you transfer it. Lift the cylinder off of the bottom of the beaker for 1 min. before you transfer it to the cup.

9. Transfer the hot metal cylinder to the water in the styrofoam cup. Set the cup on the table and record the temperature of the water in the styrofoam cup until it stops rising and begins to fall again. Record this temperature as Twf and as Tmf.

10. What is the final temperature of the metal object now?

    Why?

11. Repeat the experiment (steps 5,6, and 8) for the other cylinder and record the data in the data table.

Data Table

material	alumnium	lead
mass in g		
Tmetal initially (C)		
Tmetal final (C)		
Change in temp. of metal		
mass x chg. in temp		

material	water	water
mass in g		
Twater initially (C)		
Twater final (C)		
Change in temp. of water		
mass x chg. in temp.		

Conceptual Invention.

10. Calculate mass times the change in temperature for both the metal and water and record above.

11. When you put the hot metal cylinder into the cooler water, what happens?

12. Should the heat lost by the metal cylinder equal the heat gained by the water?

Why?

13. Earlier we reasoned that the amount of heat depends on m and the change in T.
Is the m ΔT of the water equal to the m ΔT of the metal?

What is your evidence?

14. What could be the other factor that makes the m ΔT's different?

15. How could you make the m ΔT's equal (to take this into account)?

Could you multiply by some number to make them equal?

16. Let this number be c. Now if heat is equal to Q, then write an expression for the heat.

17. Call c the specific heat capacity. For convenience let c for water be 1 cal/g ^{0}C. Since we earlier determined that the heat lost by the metal should equal the heat gained by the water, then calculate the specific heat capacity for each of the metals that you used.

18. The specific heat capacity is a constant that depends on ___________.

Expansion.

Complete the problems in the text on heat.

APPENDIX D: Meaningful Verbal Reception Learning Concept Maps

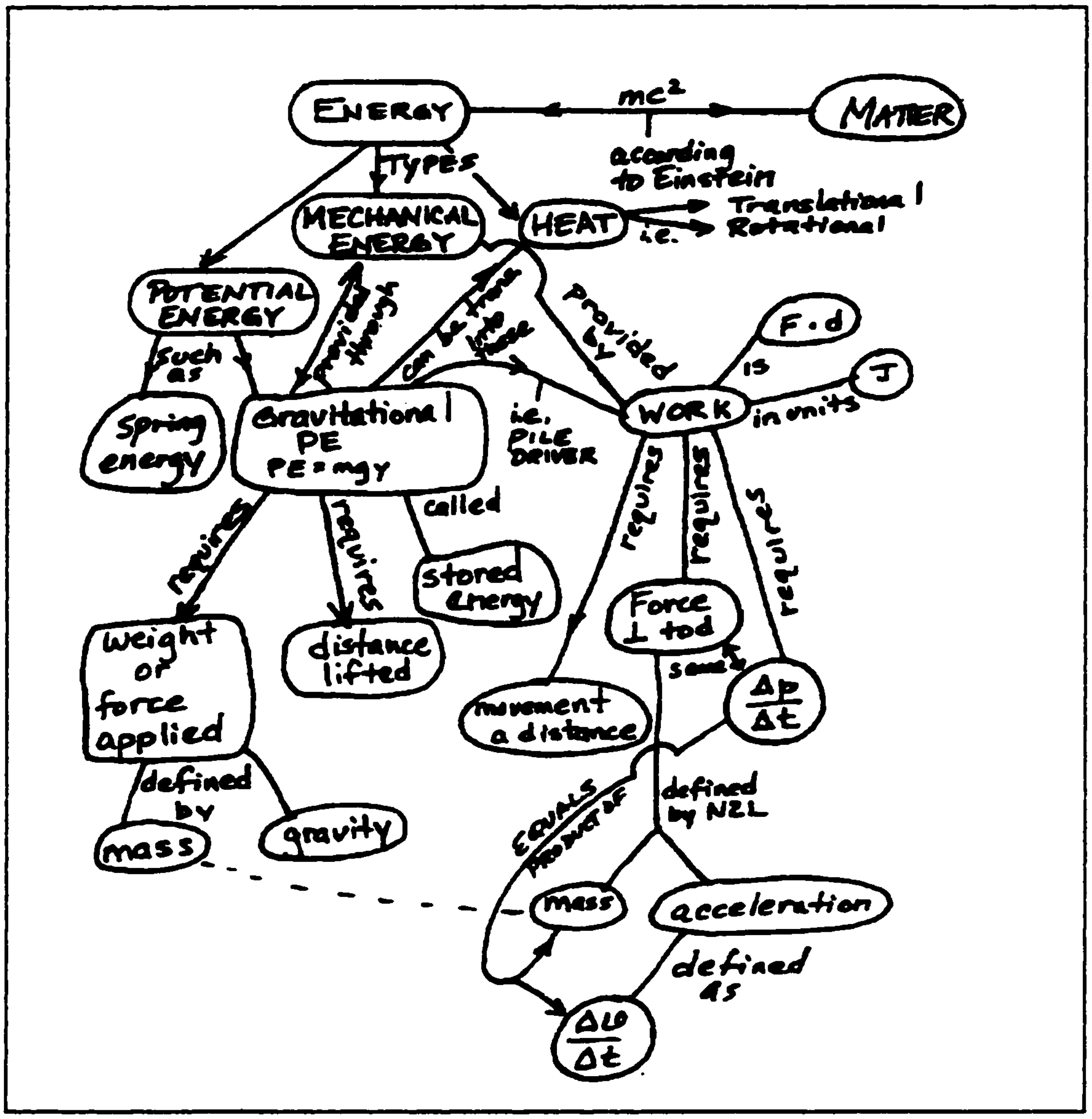


Figure 1. Energy was considered to be one of the most general topics in physics. This concept map roughly guided the course of study for the meaningful verbal reception learning treatment.

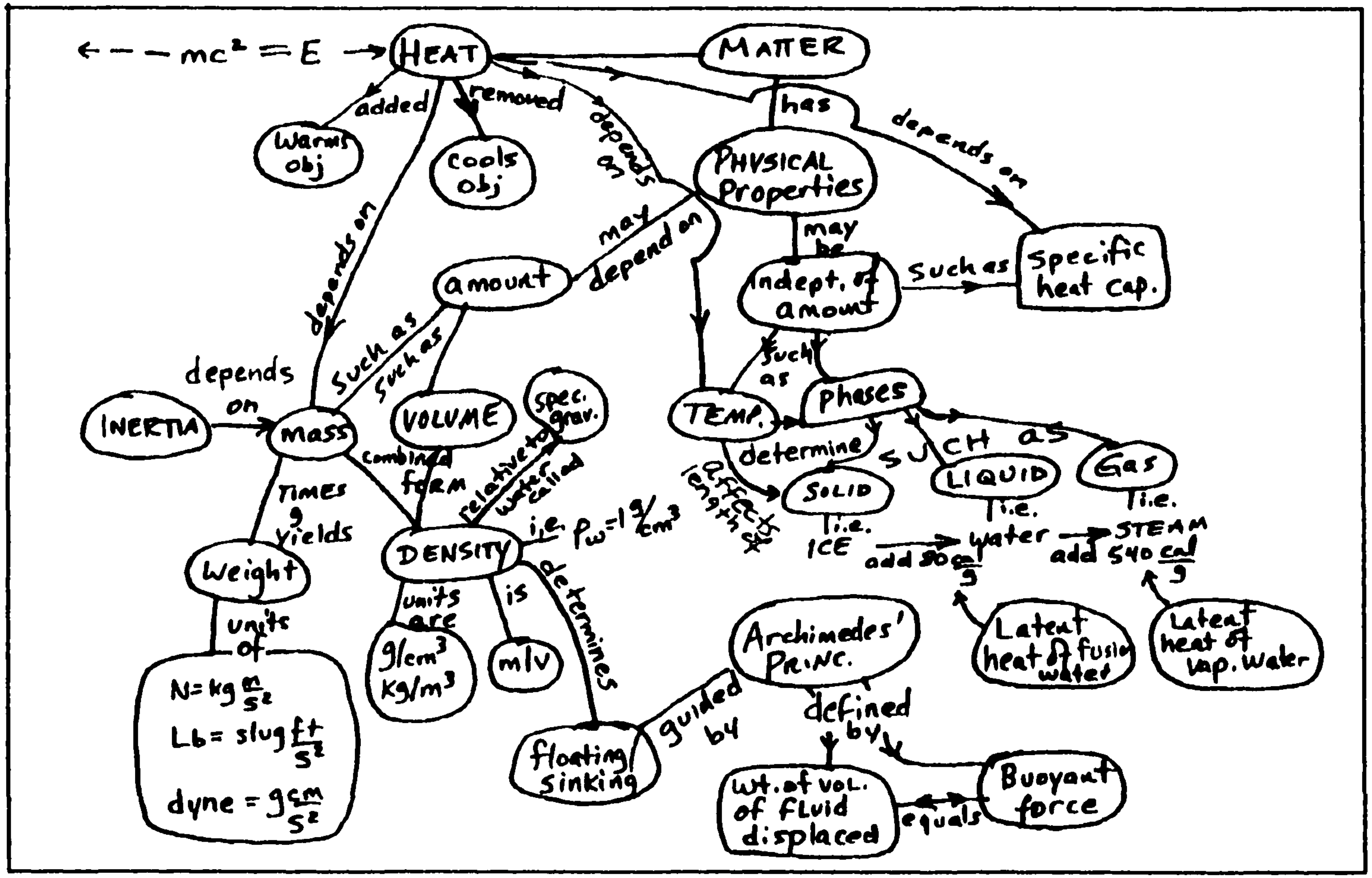


Figure 2. Energy and matter were chosen as the two most general topics in physics. This concept map connects at the upper left to Figure 1. This map as well as the previous one guided presentation of the material in the course for the MVRL students.

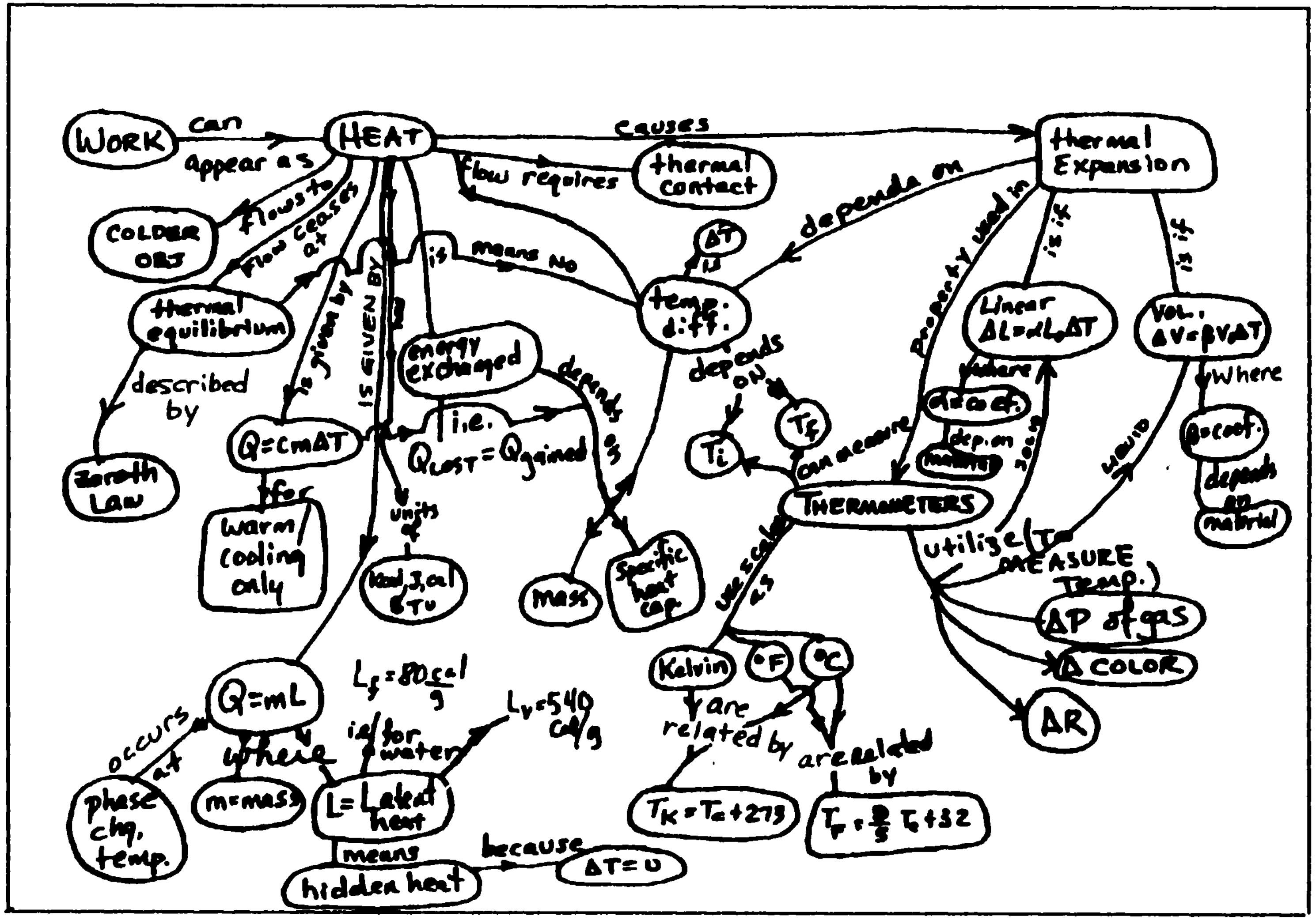


Figure 3. Concept map showing relationship between thermal expansion, heat, and thermometers. Students aided in the construction of this map after reading the text and drawing their own maps.

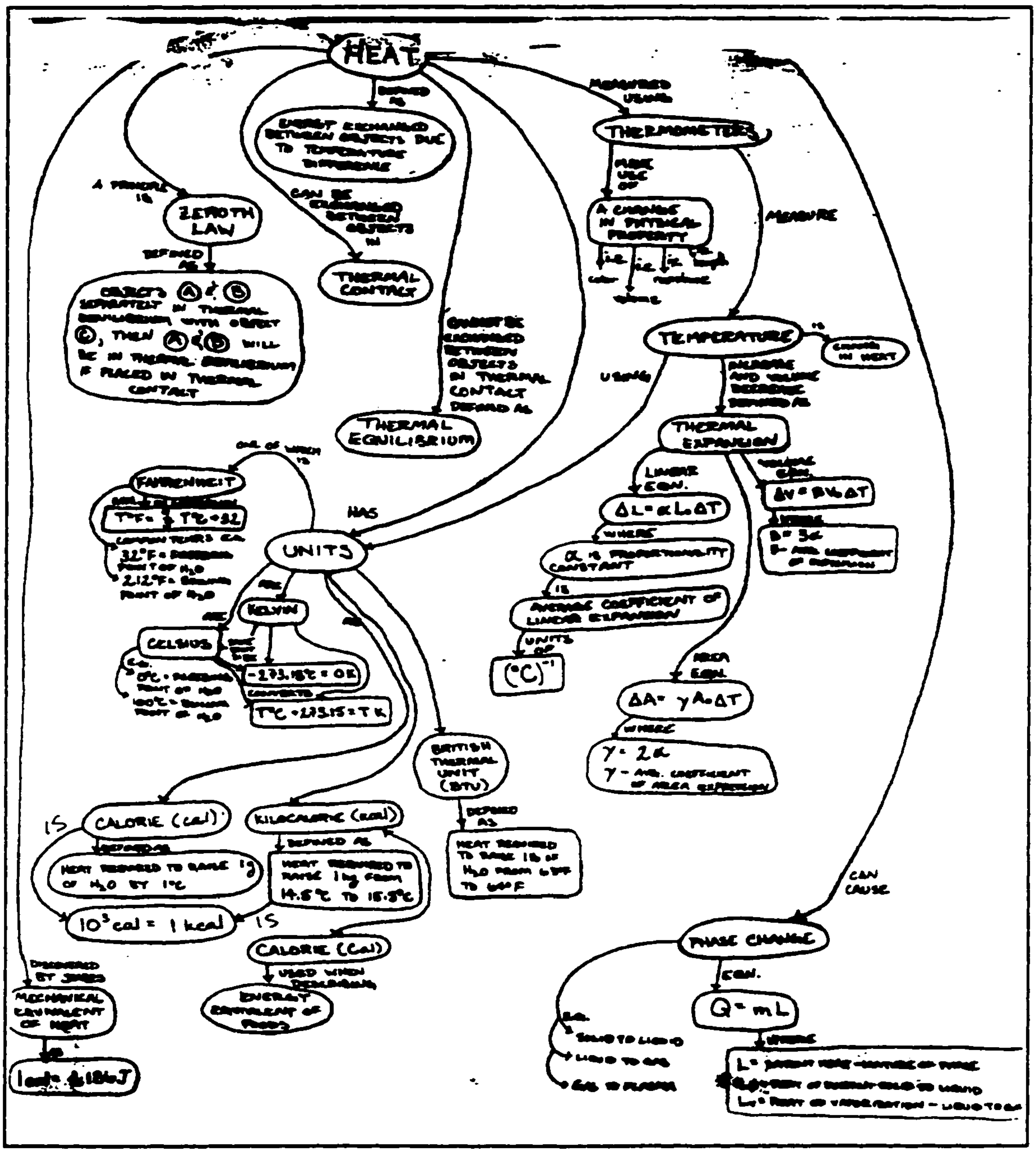


Figure 4. Student constructed concept map (similar to that of researcher in Figure 3) that was considered to be fairly well constructed.

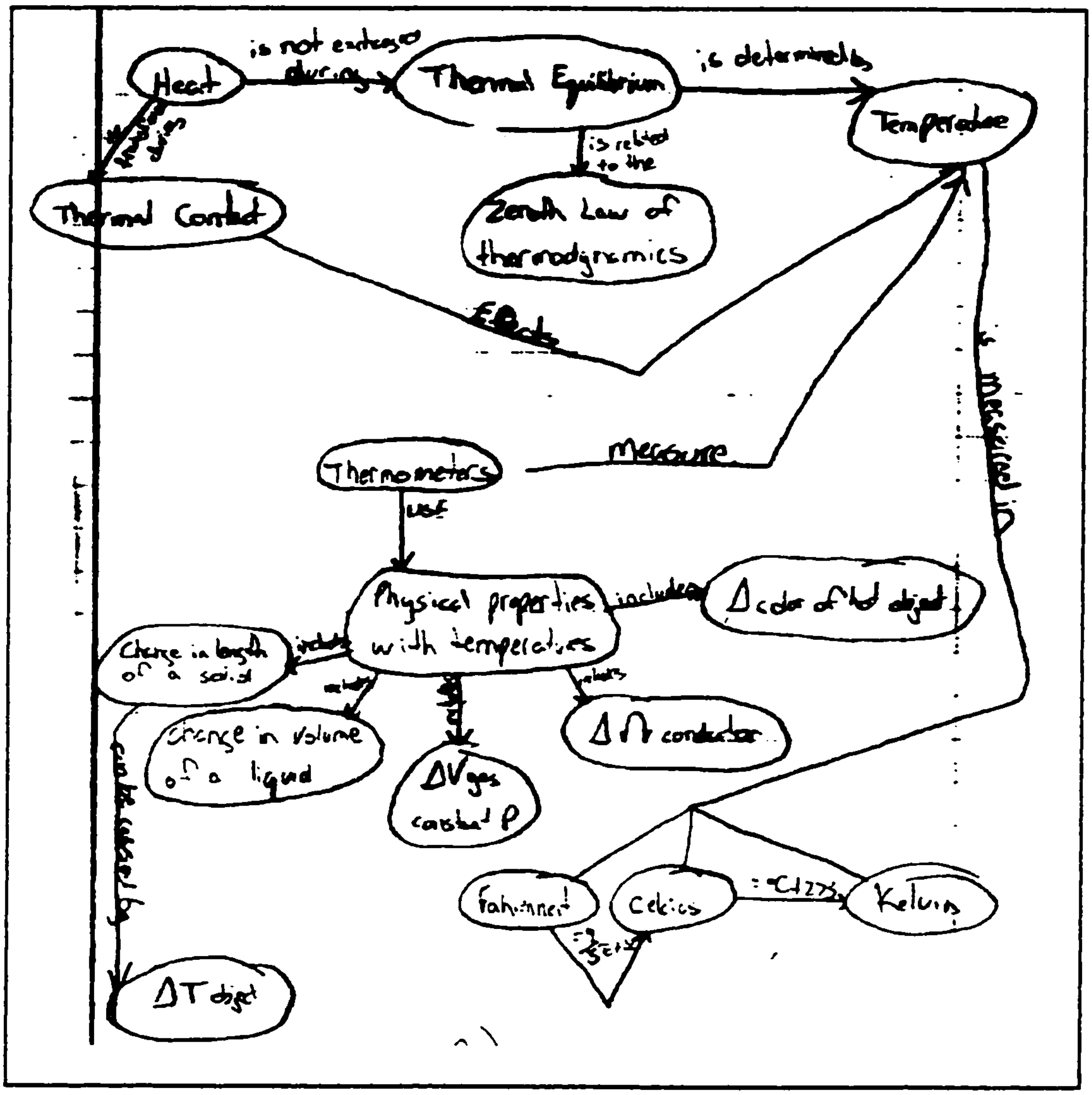


Figure 5. Student constructed concept map similar to Figures 3 and 4 although this one has much fewer linkages.

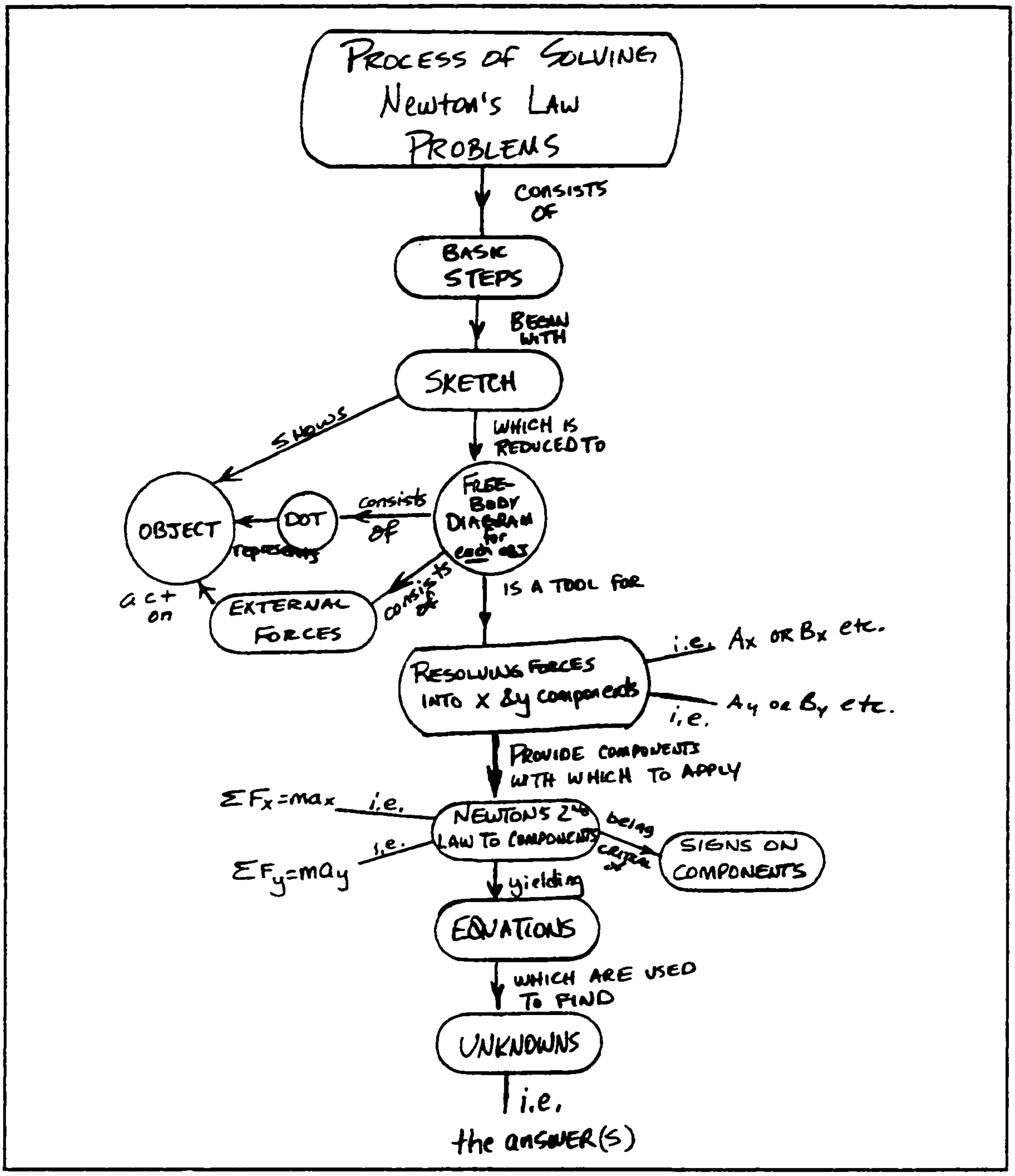


Figure 6. Concept map drawn during class discussion about solving Newton's Law problems (drawn here by researcher). After heat and energy topics, motion was introduced in the MVRL treatment as motion was considered to be a more specific item than heat/energy.

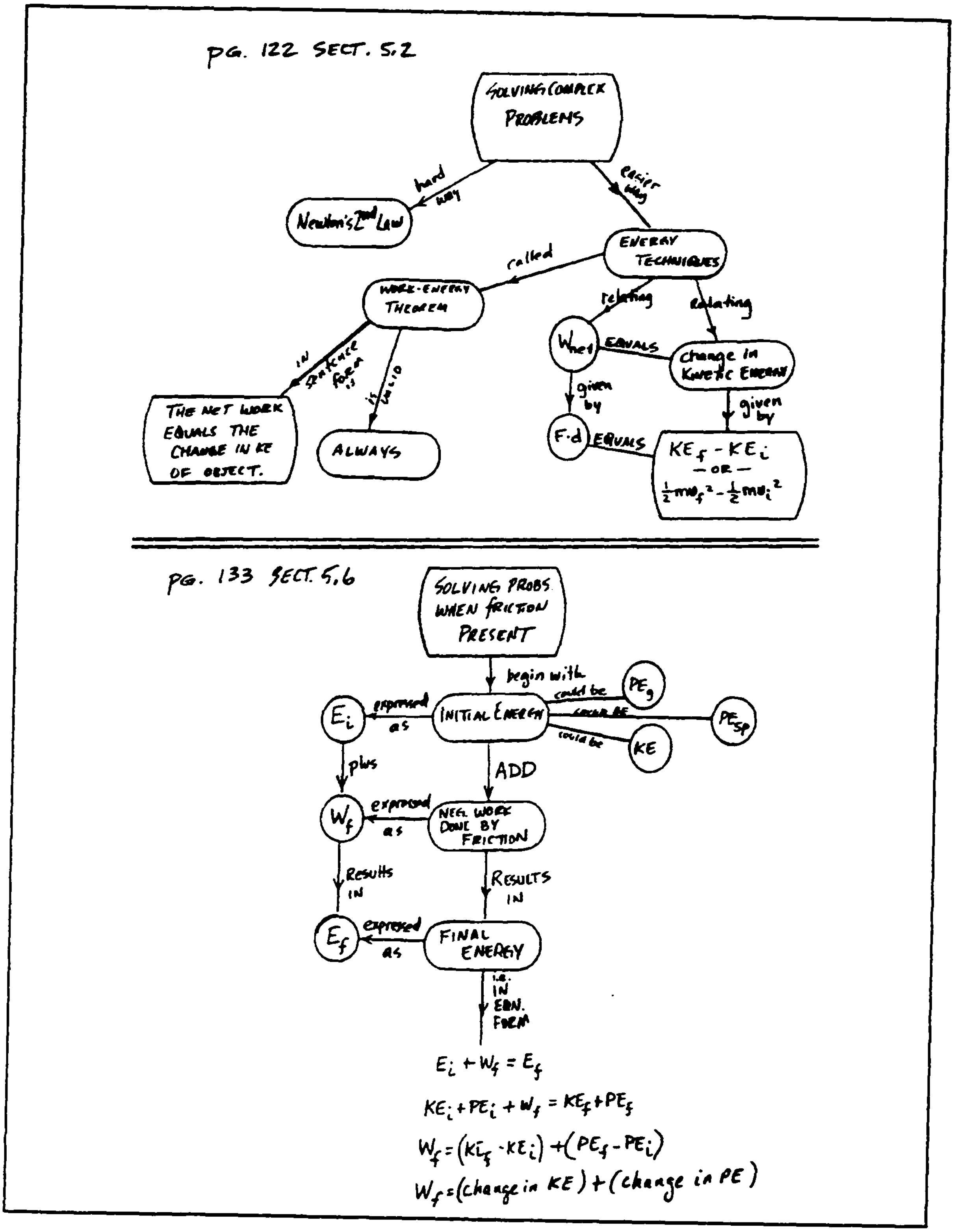
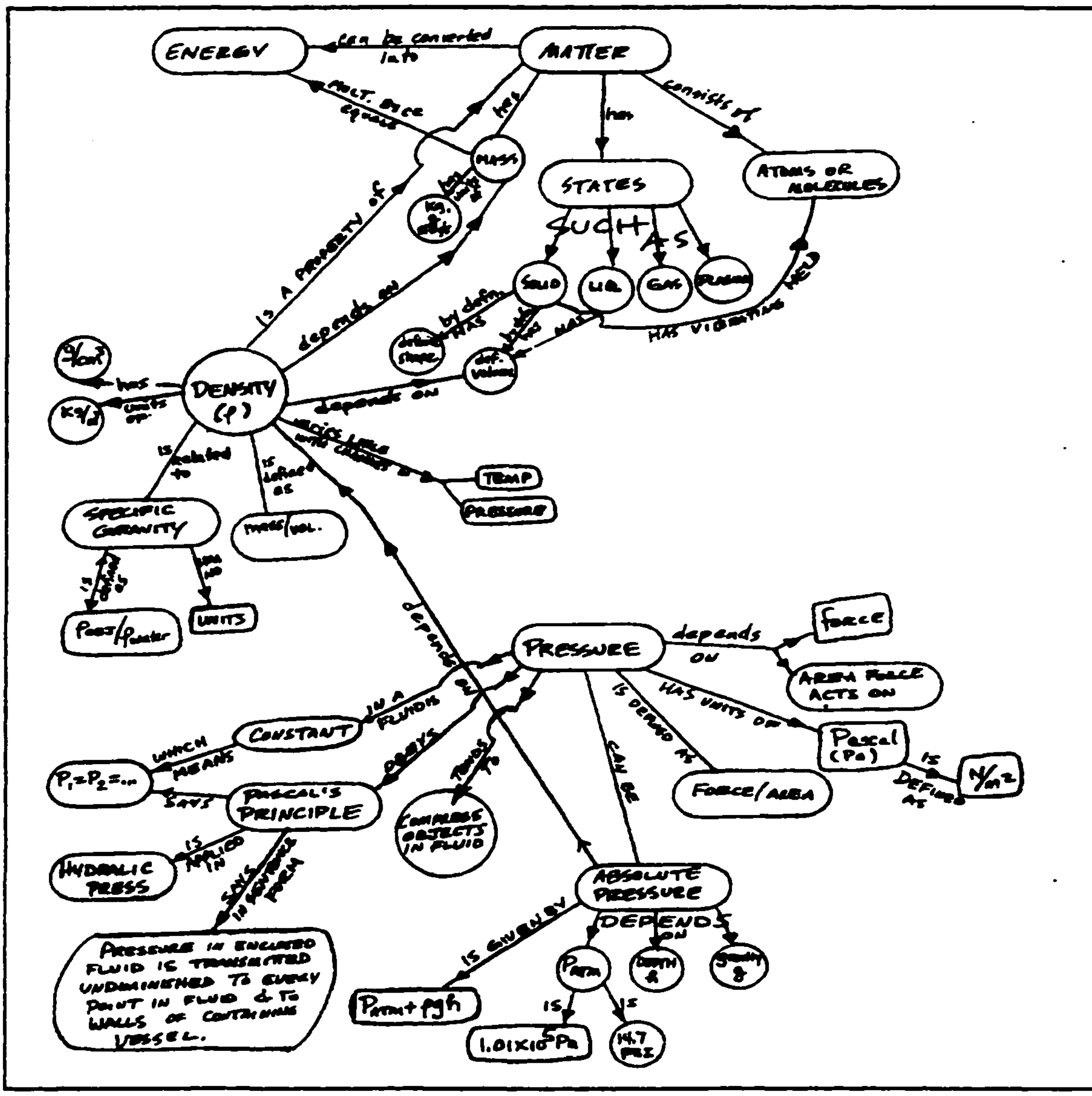


Figure 7 and 8. This concept map drawn after students read about energy techniques for motion (with (8) and without (7) friction) problem solving and drew their own concept maps over the sections in the textbook. This map was drawn during class discussion of the material.



<u>Figure 9.</u> Students were to read a section on energy, matter, pressure, and density to draw a concept map relating these items. This was a concept map that resulted from class discussion afterward.

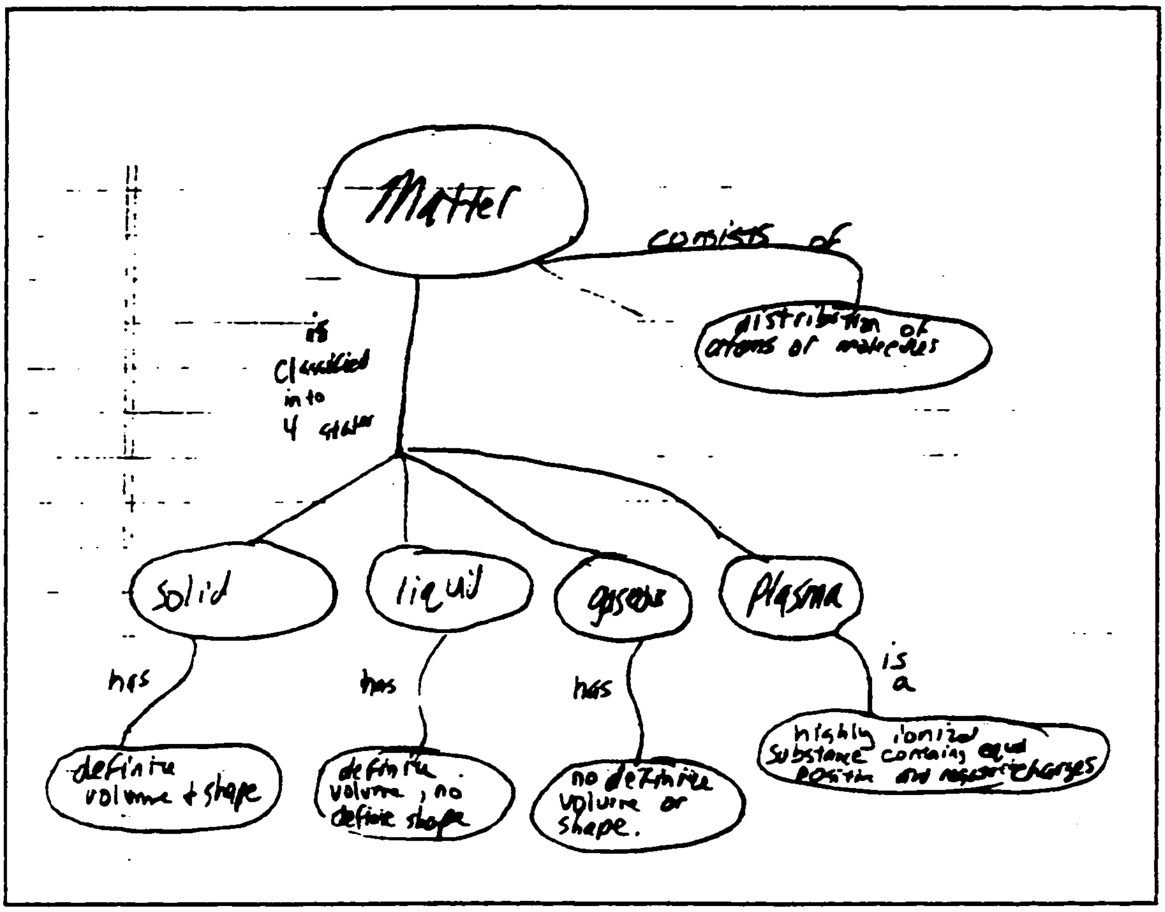


Figure 10. Student concept map with very few linkages to matter, no links to density or pressure.

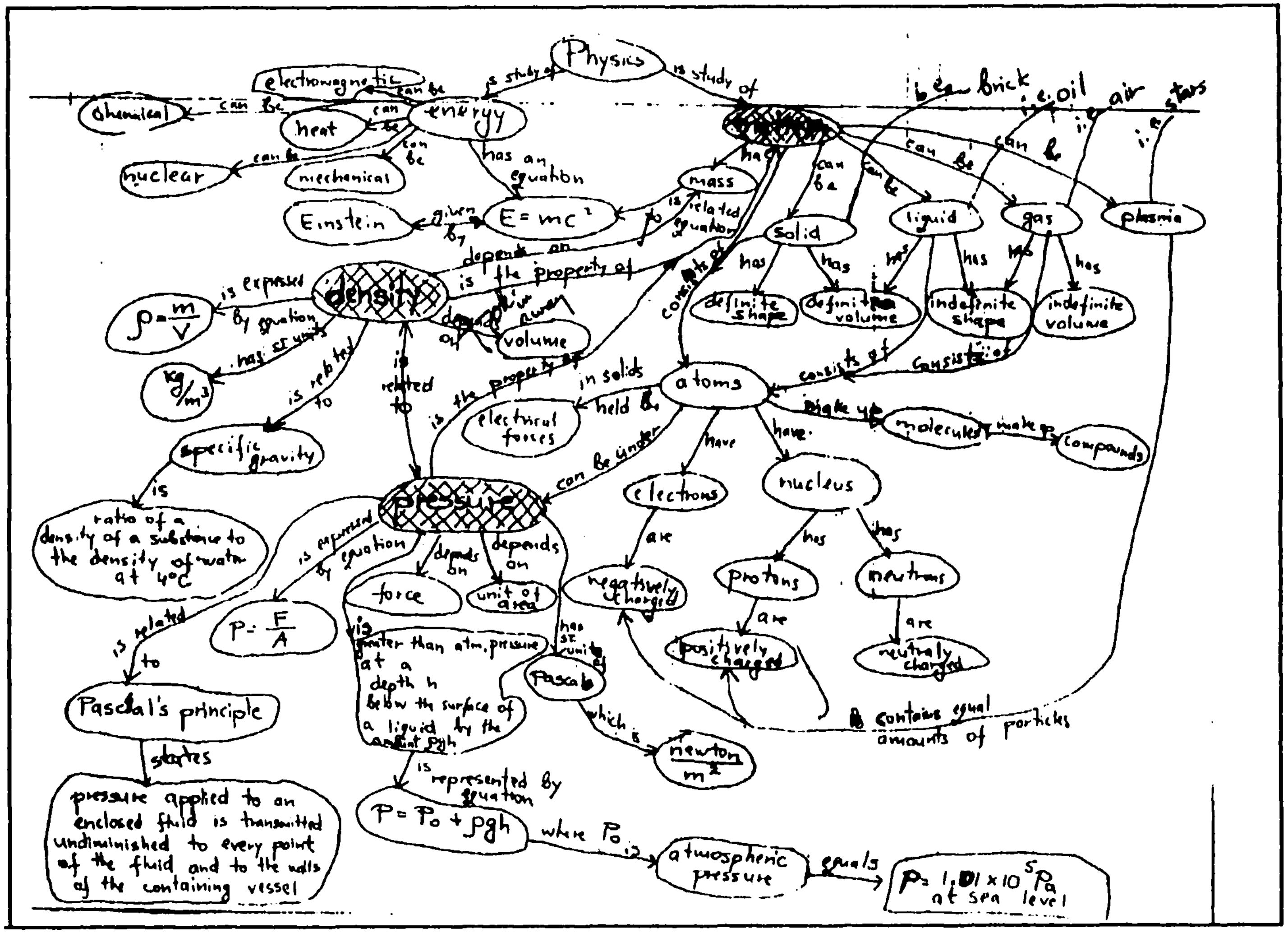


Figure 11. Students were to read a section on energy, matter, pressure, and density and to draw a concept map relating those items. This was one of the better student maps.

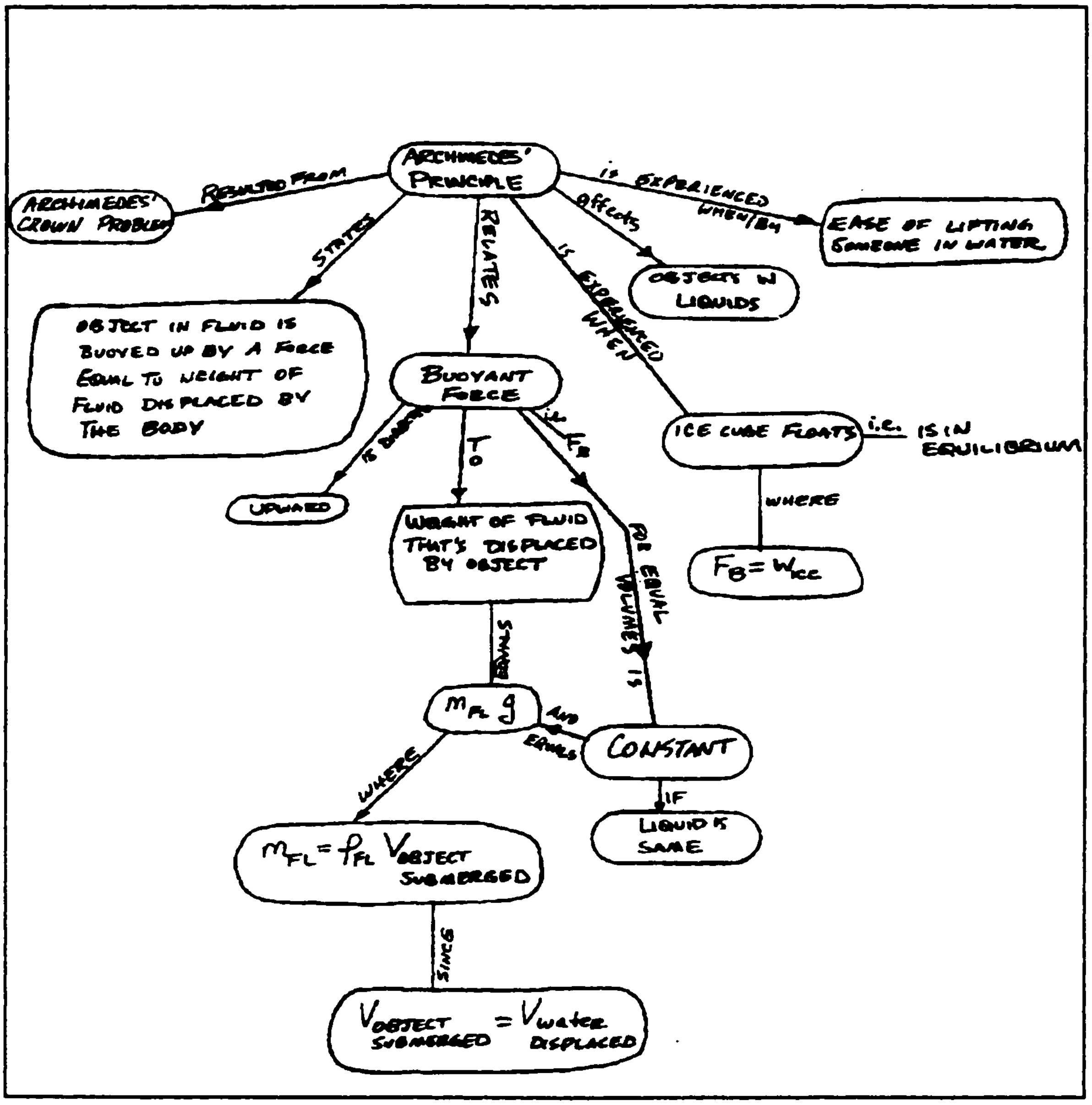


Figure 12. Concept map that resulted from discussion over text reading on Archimedes' Principle. Students read the sections assigned and constructed their own maps. This map was used in lab also.

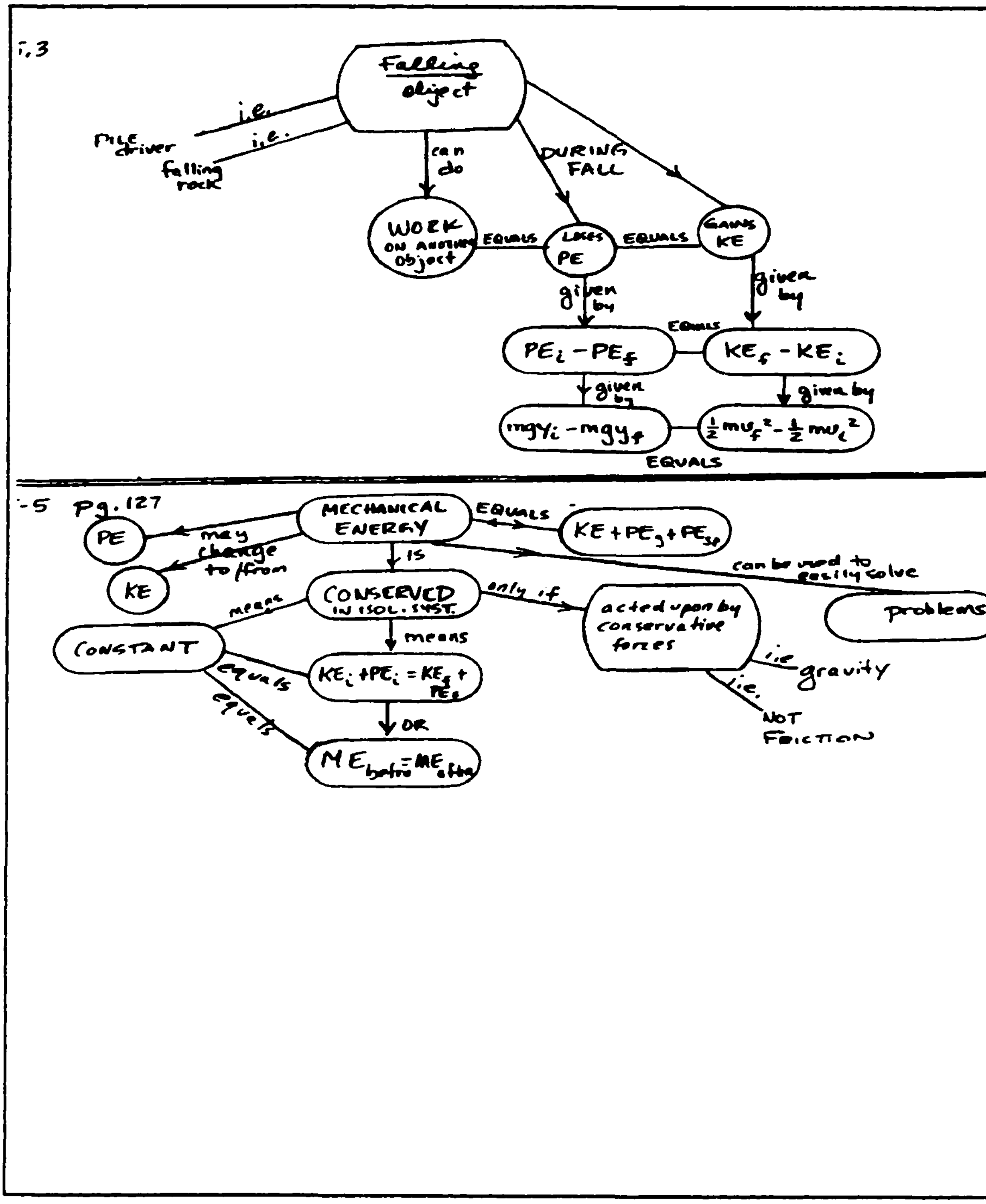


Figure 13. Concept map on the topic of the physics of falling objects. This was constructed by the class after reading the text on the topic and constructing their own concept maps.

APPENDIX E: Miscellaneous Statistics

ANCOVA Adjusted Means
Pearson Correlation Matrix for Force Data
Pearson Correlation Matrix for Density/Archimedes' Principle Data
Pearson Correlation Matrix for Heat Data
Descriptive Statistics Forces Data
Descriptive Statistics Density/Archimedes' Principle Data
Descriptive Statistics Heat Data

Table 10: ANCOVA Adjusted Means

Table	Posttest Mean Scores	LC	MVRL	LC Raw	MVRL Raw
1	Overall force understanding	*	*	58.511	47.649
2	Overall density understanding	34.450	27.425	33.667	28.208
3	Overall heat understanding	39.960	44.207	39.917	44.250
4	Learning approach (force)	65.773	66.707	65.280	67.200
5	Learning approach (density)	65.346	65.737	64.875	66.208
6	Learning approach (heat)	68.098	65.402	68.333	65.167
7	Force Concept Understanding	13.358	12.522	12.840	13.040
7	Force Problem Understanding	3.344	2.456	3.280	2.520
7	Force Mental Model Understanding	42.251	32.229	42.360	32.120
8	Density/ Archimedes' Concept Understanding	10.273	9.061	10.167	9.167
8	Density/Archimedes' Problem Understanding	4.079	2.587	3.833	2.833
8	Density/Archimedes' Mental Model Understanding	19.913	15.962	19.667	16.208
9	Heat Concept Understanding	8.442	8.558	8.375	8.625
9	Heat Problem Understanding	1.764	2.736	1.750	2.750
9	Heat Mental Model Understanding	29.417	33.249	29.792	32.875

Note: LC = means for learning cycle treatment (adjusted)
LC Raw = raw means for learning cycle treatment
MVRL = means for meaningful verbal reception learning treatment (adjusted)
MVRL Raw = raw means for meaningful verbal reception learning treatment
* = mean adjustment not necessary (ANOVA = ANCOVA)

Table 11. Pearson Correlation Matrix for Force Data

	FC1	FP1	FM1	RA1	LA1	FMU1
FC1	1.000					
FP1	.133	1.000				
FM1	.104	.322	1.000			
RA1	.211	.357	-.075	1.000		
LA1	.195	.154	.249	.310	1.000	
FMU1	.529	.372	.898	.045	.300	1.000
TX	.239	.288	.073	.085	.139	.178
FC2	.587	.131	.002	.451	.191	.263
FP2	-.020	.087	.157	.391	.073	.127
FM2	-.376	-.053	.088	-.106	-.090	-.093
FMU2	-.278	-.024	.100	.002	-.052	-.038

	TX	FC2	FP2	FM2	FMU2
TX	1.000				
FC2	.031	1.000			
FP2	-.213	.354	1.000		
FM2	-.254	-.132	.208	1.000	
FMU2	-.263	.060	.347	.979	1.000

Number of observations: 50

Definition of Variables:
FC1 = force concept understanding pretest
FP1 = force problem solving pretest
FM1 =force mental model pretest
RA1 =reasoning ability pretest
LA1 = learning orientation pretest
FMU1= overall meaningful understanding pretest
TX = treatment (1 = LC, 2 = MVRL)
FC2 = force concept posttest
FP2 = force problem solving posttest
FM2 = force mental model posttest
FMU2 = force meaningful understanding overall posttest

Table 12. Pearson Correlation Matrix for Density/Archimedes' Principle Data

	DC1	DP1	DM1	RA1	LA1	DMU1
DC1	1.000					
DP1	.230	1.000				
DM1	-.053	.300	1.000			
RA1	.226	.242	.109	1.000		
LA1	.280	.445	.143	.324	1.000	
DMU1	.564	.509	.784	.248	.335	1.000
TX	.016	.410	.268	.071	.061	.276
DC2	.406	-.033	.032	.387	.284	.252
DP2	.157	.233	-.117	.199	.344	.034
DM2	.193	-.254	.024	.034	.052	.091
DMU2	.287	-.203	.014	.147	.158	.145

	TX	DC2	DP2	DM2	DMU2
TX	1.000				
DC2	-.155	1.000			
DP2	-.277	.441	1.000		
DM2	-.141	.201	.090	1.000	
DMU2	-.198	.471	.315	.951	1.000

Number of observations: 48

Definition of Variables:
DC1 = density concept understanding pretest
DP1 = density problem solving pretest
DM1 = density mental model pretest
RA1 = reasoning ability pretest
LA1 = learning orientation pretest
DMU1 = density meaningful understanding overall pretest
TX = treatment (1 = LC, 2 = MVRL)
DC2 = density concept posttest
DP2 = density problem solving posttest
DM2 = density mental model posttest
DMU2 = density meaningful understanding overall posttest

Table 13: Pearson Correlation Matrix for Heat Data

	HC1	HP1	HM1	RA1	LA1
HC1	1.000				
HP1	.300	1.000			
HM1	.341	.202	1.000		
RA1	.451	.280	.149	1.000	
LA1	.148	.207	.012	.365	1.000
HMU1	.577	.305	.963	.263	.060
TX	.053	-.112	.359	.064	.029
HC2	.243	.393	.211	.348	.308
HP2	.153	.151	.136	.356	.190
HM2	.055	-.213	-.030	-.135	.092
HMU2	.107	-.117	.021	-.032	.157

	HMU1	TX	HC2	HP2	HM2	HMU2
HMU1	1.000					
TX	.318	1.000				
HC2	.266	.049	1.000			
HP2	.166	.338	.584	1.000		
HM2	-.022	.109	.116	.206	1.000	
HMU2	.040	.143	.334	.389	.972	1.000

Number of observations: 48

Definition of Variables:
HC1 = heat concept understanding pretest
HP1 = heat problem solving pretest
HM1 = heat mental model pretest
HMU1 = heat meaningful understanding overall pretest
RA1 = reasoning ability pretest
LA1 = learning orientation pretest
TX = treatment (1 = LC, 2 = MVRL)
HC2 = heat concept posttest
HP2 = heat problem solving posttest
HM2 = heat mental model posttest
HMU2 = heat meaningful understanding overall posttest

Table 14: Descriptive Statistics for Forces Data

For LC (TX = 1) with total observations: 25

	FC1	FP1	FM1	RA1	LA1
MINIMUM	3.000	.000	.000	2.000	55.000
MAXIMUM	16.000	1.000	22.000	10.000	85.000
MEAN	7.760	.040	5.120	6.800	65.240
VARIANCE	11.857	.040	30.443	4.833	60.690
STANDARD DEV	3.443	.200	5.518	2.198	7.790

	FMU1	FC2	FP2	FM2	FMU2
MINIMUM	4.000	7.000	1.000	11.000	29.000
MAXIMUM	31.000	20.000	6.000	85.000	102.000
MEAN	12.920	12.840	3.280	42.360	58.480
VARIANCE	45.743	12.807	2.210	403.657	389.093
STANDARD DEV	6.763	3.579	1.487	20.091	19.725

For MVRL (TX = 2) with total observations: 25

	FC1	FP1	FM1	RA1	LA1
MINIMUM	5.000	.000	.000	3.000	51.000
MAXIMUM	17.000	1.000	32.000	10.000	80.000
MEAN	9.400	.240	6.080	7.160	67.320
VARIANCE	11.250	.190	59.660	4.473	53.977
STANDARD DEV	3.354	.436	7.724	2.115	7.347

	FMU1	FC2	FP2	FM2	FMU2
MINIMUM	6.000	8.000	.000	6.000	21.000
MAXIMUM	44.000	19.000	6.000	75.000	92.000
MEAN	15.720	13.040	2.520	32.120	47.680
VARIANCE	79.043	9.290	4.093	388.943	429.727
STANDARD DEV	8.891	3.048	2.023	19.722	20.730

Note: Refer to Table 11 for variable definitions.

Table 15. Descriptive Statistics for Density/Archimedes' Principle Data

For LC (TX = 1) with total observations: 24

	DC1	DP1	DM1	RA1	LA1
MINIMUM	2.000	.000	.000	1.000	58.000
MAXIMUM	11.000	1.000	7.000	10.000	77.000
MEAN	6.375	.083	1.458	6.917	65.625
VARIANCE	8.853	.080	4.346	7.993	30.245
STANDARD DEV	2.975	.282	2.085	2.827	5.500

	DMU1	DC2	DP2	DM2	DMU2
MINIMUM	2.000	5.000	1.000	2.000	13.000
MAXIMUM	14.000	15.000	6.000	48.000	60.000
MEAN	7.917	10.167	3.833	19.667	33.667
VARIANCE	13.297	9.362	2.580	140.406	146.406
STANDARD DEV	3.647	3.060	1.606	11.849	12.100

For MVRL (TX = 2) with total observations: 24

	DC1	DP1	DM1	RA1	LA1
MINIMUM	3.000	.000	.000	1.000	53.000
MAXIMUM	11.000	2.000	20.000	10.000	83.000
MEAN	6.458	.625	3.333	7.292	66.458
VARIANCE	5.129	.679	19.275	6.389	66.259
STANDARD DEV	2.265	.824	4.390	2.528	8.140

	DMU1	DC2	DP2	DM2	DMU2
MINIMUM	4.000	2.000	.000	2.000	13.000
MAXIMUM	27.000	15.000	6.000	59.000	80.000
MEAN	10.417	9.167	2.833	16.208	28.208
VARIANCE	26.341	11.797	3.710	168.781	234.346
STANDARD DEV	5.132	3.435	1.926	12.992	15.308

Note: Refer to Table 12 for variable definitions.

Table 16. Descriptive Statistics for Heat Data

For LC (TX = 1) with total observations: 24

	HC1	HP1	HM1	RA1	LA1
MINIMUM	2.000	.000	.000	1.000	52.000
MAXIMUM	11.000	1.000	27.000	10.000	75.000
MEAN	6.208	.208	7.125	6.958	64.750
VARIANCE	4.868	.172	44.462	7.607	29.587
STANDARD DEV	2.206	.415	6.668	2.758	5.439

	HMU1	HC2	HP2	HM2	HMU2
MINIMUM	2.000	4.000	.000	14.000	20.000
MAXIMUM	38.000	13.000	4.000	55.000	66.000
MEAN	13.542	8.375	1.750	29.792	39.917
VARIANCE	67.389	6.418	1.587	142.085	152.341
STANDARD DEV	8.209	2.533	1.260	11.920	12.343

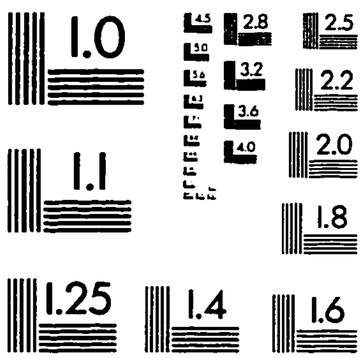
For MVRL (TX = 2) with total observations: 24

	HC1	HP1	HM1	RA1	LA1
MINIMUM	3.000	.000	.000	1.000	38.000
MAXIMUM	10.000	1.000	21.000	10.000	83.000
MEAN	6.417	.125	11.667	7.292	65.208
VARIANCE	3.123	.114	28.232	6.389	99.737
STANDARD DEV	1.767	.338	5.313	2.528	9.987

	HMU1	HC2	HP2	HM2	HMU2
MINIMUM	8.000	4.000	.000	8.000	20.000
MAXIMUM	29.000	14.000	5.000	61.000	77.000
MEAN	18.208	8.625	2.750	32.875	44.250
VARIANCE	33.563	7.201	2.457	266.810	314.457
STANDARD DEV	5.793	2.683	1.567	16.334	17.733

Note: Refer to Table 13 for variable definitions.

IMAGE EVALUATION TEST TARGET (QA-3)



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