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THE EFFECTS OF LEARNER-GENERATED REPRESENTATIONS VERSUS COMPUTER-GENERATED REPRESENTATIONS ON PHYSICS PROBLEM SOLVING

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by

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Abstract

In this study, multiple external representations and Generative Learning Theory were used to design instruction that would facilitate physics learning. Specifically, the study looks at the learning differences that may occur when students are engaged in generating a graphical representation as compared to being presented with a computer-generated graph. It is hypothesized that by generating the graphical representation students will be able to overcome obstacles to integration and determine the relationships involved within a representation. In doing so, students will build a more complete mental model of the situation and be able to more readily use this information in transfer situations, thus improving their problem solving ability.

Though the results of this study do not lend strong support for the hypothesis, the results are still informative and encouraging. Though several of the obstacles associated with learning from multiple representations such as cognitive load were cause for concern, those students with appropriate prior knowledge and familiarity with graphical representations were able to benefit from the generative activity. This finding indicates that if the issues are directly addressed within instruction, it may be that all students may be able to benefit from being actively engaged in generating representations.

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Acknowledgments

I started this journey as a 24 year-old newlywed who wanted options for her future career and had a desire to study more about how people learn. I end this journey 12 years later as a wife, mother of 2, and experienced teacher who wants nothing less than to become a professor of Educational Psychology so that I can still study more about how people learn. I have only to remember that even though the scenic route sometimes takes longer, the experience can be so much richer. So since my path was long and winding, I have many people to thank for helping me make it to my destination.

I would like to thank my committee for their time and effort, especially Peggy Van Meter without whose expertise this study would not have been completed. I look forward to collaborating with all of you in the future.

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On to the next journey. . .

Chapter 1

Introduction

One role of our nation's schools is to produce students who are successful problem solvers. No matter the circumstances or domain of interest, learners must be able to recall information learned over years of schooling and apply it appropriately in novel situations to solve problems. Though there have been major efforts to improve the accountability of schools as a way to ensure that students will learn the requisite knowledge, students' problem solving abilities are still lacking. For this reason, there is a continued need to understand student learning as well as the instructional methods that support the acquisition of problem solving abilities. Though one could investigate in any domain or subject area and find similar dilemmas, one specific area of interest within the over-arching study of problem-solving focuses on improving physics instruction to produce better problem solving in physics.

Historically, students in the U.S. have not been successful in learning physics or pursuing physics as a course of study or career. There are several reasons offered for this including lack of interest, lack of perceived need, and lack of self-efficacy in the subject area (Vazquez-Abad, Winer, & Derome, 1997; Pajeras, 1996). On the whole, students who enroll in physics classes struggle to learn and apply the concepts presented (Yeager, 1996).

The science education reform movements of the 1950's and 60's attempted to address the need to improve problem solving abilities by introducing the laboratory procedure into the curriculum (Rudolph, 2002). Since that time, laboratory procedures have been professed to be an essential part of a student's science education in that these

activities allow students to “do” science - experiencing science as “real scientists” would. The laboratory is seen as a venue in which students can apply their knowledge and skills in a variety of situations and conditions.

Unfortunately, laboratory procedures as an instructional tool have often failed to produce the results expected of them (Lunetta, 1997). This has been attributed to the fact that many laboratory procedures are “cookbook” in nature - engaging students in the manipulation of the equipment and focusing attention on getting the right answer rather than the manipulation of the data and focusing on the relationships involved (Champagne, Gustone, & Klopfer, 1985; Lunetta, 1997). If students are to gain knowledge and flexibility, students need to be involved in higher-level cognitive skills such as hypothesis generation, hypothesis testing, and data analysis while completing a procedure (Lunetta,1997; Hofstein & Lunetta, 1982).

In a move to decrease the focus on equipment manipulation and remove the tedium of data collection, most physics classrooms are now employing microcomputer based laboratory (MBL) procedures. MBL employs computer-interfaced probes to take multiple data points in very small time intervals producing “real-time” tables, graphs, and other analyses of this data. Although these procedures take the “boring” aspects of data collection out of the physics lab (Brasell, 1987), the opportunities for student participation are also removed. There are many advantages to using MBL including the ease of repetition and dynamic visualization (Mokros & Tinker, 1987). Because the computer completes most of the analysis, however, students may not engage in some of the higher-level cognitive skills necessary to benefit from the laboratory experience. For example, graphs typically constructed by the learner are now available in “real-time” and

can be simply printed instead of plotted by the students. At this time, it is unclear how this “short-cut” is effecting the learning of the relationships involved in the physics phenomena being studied and what alternatives to this should be explored. One question is whether students provided with graphs are able to uncover the relationships displayed in the graphs. Instead, it may be that the relationships would be more easily determined if the students were actually engaged in the generation of the graph.

In most instances, physics instructors are engaging students in laboratory procedures with the expectation that the knowledge gained can be used later in novel situations. Students, however, do not typically gain the deeper understanding necessary for problem solving, and physics educators are often disappointed in student performance on transfer tasks. In order to improve performance, students must engage in instructional activities, including well-designed laboratory procedures, which lead to the requisite cognitive processes for gaining this deeper understanding. To do this we must consider what the requisite processes are, what aspects of the design will accommodate these processes, and how instructors should present or represent physics concepts such that they will be able to use this information more flexibly and appropriately.

Research suggests that those people considered successful problems solvers have a knowledge organization that differs from those who are less successful (deJong & Ferguson-Hessler, 1986). They seem to have a highly organized knowledge structure based on principled knowledge that can be used flexibly in new situations. This knowledge structure, known as a mental model, is essential to the ability of a student to transfer knowledge and solve problems in new situations. For this reason, it is necessary for instruction to be designed so that students are engaged in cognitive activities requisite

for building such a knowledge structure. These cognitive processes should engage students in assimilating information into their knowledge structure, connecting it with prior knowledge, and, abstract the principle(s) that support problem solving.

There have been two distinct lines of research that have tried to answer the question of how to instruct students such that they are engaged in these cognitive activities. These lines include those studying the use of Multiple External Representations (MERs) and those pursuing Generative Learning Theory.

Multiple external representations have been shown to aid in the integration process by constraining the interpretations of more complex or unfamiliar representations and through their ability to provide complimentary information (Ainsworth, 1999). The goal of using MERs is for students to acquire a deeper understanding of the material by evaluating, selecting, and integrating information from each representation (Mayer, 1997). It is the hope that through this cyclic process, a complete mental model will be built. The use of MERs does cause some troubles for learners including those related to cognitive load and prior knowledge deficits, however there are ways that can facilitate their use to overcome these pitfalls.

Generative Learning Theory is a functional theory of learning from teaching (Wittrock, 1994). The model predicts that comprehension and understanding in science can be facilitated by teaching that leads learners to generate analogies, metaphors, problems, and related devices. The theory purports that engaging students in the four cognitive processes of conceptions, motivation, attention, and generation, will allow students to gain a deeper understanding of the material and become better problem solvers.

One way that both MERs and GLT may be incorporated into the physics classroom is through the use of microcomputer-based laboratory procedures (MBL). Though MBL has been used in the past to remove the tedium of data collection, if used appropriately MBL could also be used to improve student understanding. The physical observations, data tables, and graphs of the MBL along with corresponding text may be able to serve the complimentary and constraining functions of MERs. In addition, engaging students in the manipulation of the data and generation of the graphical representation may draw upon the strengths of GLT to improve student understanding and problem solving abilities.

It is from this perspective that a research study can be developed to answer the general research question:

> Will students who generate their own graphs during MBL procedures outperform those students who are provided with computer-generated graphs or students who have no laboratory experience at all on measures of problem solving.

Chapter 2

Review of the Literature

Introduction

"Education is what is left over when what was learned has been forgotten"

- B.F. Skinner

Though it is possibly ironic to begin a discussion of knowledge structure and mental models with a quote from Skinner, the sentiment is no less significant. If one were to ask a physics teacher what the main goal of the instruction is, surely the answer would not be the recall of facts. Instead, the most likely reply would be that the main goal is to produce good problem solvers. However, much of the instruction in which students are engaged is not successful at producing proficient problem solvers. Even the use of laboratory procedures has not met with great success. Though the main aim of laboratory procedures is to allow students to apply their knowledge and engage students in higher order cognitive activities such as hypothesis generation, students focus instead on getting the right answer and manipulating the equipment (Hofstein & Lunetta, 1982). So it seems necessary for us to look at the research surrounding this area in order to gain insight into what might possibly improve the current situation.

The quality of students' knowledge structures has been shown to be a strong predictor of problem solving abilities (deJong & Ferguson-Hessler, 1996; Chi & Ceci, 1987; Schoenfeld & Herrmann, 1982). Consequently, if the goal is to improve problem solving, then one must consider how to improve the quality of the students' knowledge structures. The use of multiple representations and generative learning theory are two approaches that have shown promise as means to reach this goal. When one looks at these

two lines of research together, it becomes apparent that they are both engaging students in cognitive processes necessary to gain a deeper understanding of material. In both cases, this deeper understanding comes from the construction of a complete mental model after experiencing theoretically sound instruction. The idea suggested here in this discussion is that combining both of these perspectives, MERs and GLT, will further enhance a student's opportunity for successfully building this knowledge structure.

Designing instruction that employs MERs appropriately may aid in building a mental model by making relationships more easily uncovered. This is possible because MERs activate proper prior knowledge and fulfill complimentary and constraining roles that may ease interpretation. Incorporating a generative learning activity will capitalize on the generation and attention aspects of GLT, increasing the ability to recognize relationships. Together, the two should increase the opportunity for students to integrate information and abstract the principles involved on their way to completing a mental model.

The following sections, then, will first address the characteristics of knowledge believed important for problem solving and then further explore MERs and GLT as means to promote quality knowledge acquisition and improving problem solving.

Knowledge structure and acquisition

When learning new material, it is important for students to assimilate the information into their existing knowledge structure. Knowledge is stored in a network of interconnected nodes with each node representing a concept (Schank & Abelson, 1977; Miller & Johnson-Laird, 1976). For example, the concept "velocity" is only understood when it is placed appropriately within a pattern of connections to the concepts of

distance, time, speed, and direction. This network of connections is the basis for the organization of knowledge or cognitive structure of that student. The ideal cognitive structure is a network, or system, that connects together all relevant knowledge and organizes it around the central principles encompassing the concepts. This representation is called a mental model and the arrangement and process of building such a structure is important to the students' ability to use the information for problem solving.

The pattern of connections is important because of the probabilistic nature of activation that is a common assumption in most theories of knowledge representation (e.g. Anderson, 1982; Kintsch, 1994). According to Paivio's Dual Coding Theory (Paivio,1991), internal representations differ with respect to the modal form of their representation. The two possible forms these internal representations can take are verbal and non-verbal including both visual and acoustic information. The verbal system is an interconnected system of "logogens" or verbal nodes. Likewise, the non-verbal system is an interconnected system of "imagens" or nodes of non-verbal information (images). Connections within each system form an associative network whereby nodes are "activated" by other connected nodes. Similarly, but more significantly, connections across the systems form a referential network where one node may activate many others due to multiple connections and associations. This process of taking in new information, assimilation, and connecting with prior knowledge, integration, is cyclic in nature and is essential to forming an understanding of the presented material.

Overall, the structure of the network determines how probable it is that one concept will be activated by exposure to a second, related concept. In other words, when one concept is activated there is a "spread of activation" throughout the network bringing

other related concepts to the forefront. This spread of activation is dependent on the number and structure of the associative links. So, if two concepts are not linked together at the time of learning, it is unlikely that they will be thought of together in the future. For example, if there is no link made between velocity and direction during learning, a student may only take into consideration the speed of a vehicle and not the direction it is traveling when solving a later task.

Having the necessary associative and referential connections will allow for appropriate spread of activation and as time and knowledge increases this network will become more organized and refined to encompass all necessary nodes. In fact, given additional experiences, new information and prior knowledge can become increasingly integrated, and what were once disjointed "trees of information nodes" now become more like integrated webs of knowledge. Integration allows a student's knowledge organization to become more flexible since now all the interconnected information will be available or more readily activated from a variety of cues.

As this happens, one will begin to lose details but retain the overall principles and relationships involved in the situation (Kintsch, 1994). When one can look past the details to determine what knowledge to activate based upon the principles or laws governing a situation, this learner has reached the level of abstraction. This type of knowledge organization allows for more flexible application because related concepts are subsumed within the structure called a mental model. This flexibility means that when confronted with a new situation, the learner is able to connect this new situation with a well-developed mental model and thus all related information will be activated and available for problem solving. In sum, qualitative, organizational aspects of knowledge

structure support transfer.

The formation of a mental model is the goal of instruction. However, the construction of such a knowledge structure is not always the end result of instruction. In fact, it is only through instruction encouraging students to engage in the requisite cognitive activities that this knowledge organization will be realized. There are many tools that could be employed to encourage mental model construction including cooperative learning (Brown & Palincsar, 1989), and problem based learning (Capon & Kuhn, 2004; Gick & Holyoak, 1983). Two that are of particular interest here are the use of MERs and GLT. As mentioned earlier, these two approaches have the potential to increase the opportunity for students to integrate information and abstract the principles involved. To understand how these two tools might work together, however, each must be understood individually. So this discussion will continue by exploring the key functions and characteristics of MERs as well as the obstacles they present and what can be done to facilitate the integration process.

Multiple External Representations:

In fields such as physics, instruction almost invariably employs multiple external representations (MERs). Instructional materials include a variety of formats including text, equations, tables, graphs, and even physical observations. For instance, the same relationship found in the equation for velocity (v=d/t) can be represented in a d vs. t graph that is plotted from data obtained from physically observing a cart traveling on a track. The goal of using these representations is to enhance understanding but this is not always the outcome. Students need to integrate within and between each representation while internally connecting the information within their knowledge structure. Each of

these external representations has its own characteristics and will function differently for each student when they use it to aid in the formation of their mental model of the situation. In order to exploit the instructional benefits of MERs, it is necessary to take a closer look at these characteristics and functions necessary for success in the integration process.

The use of multiple external representations can be effective in several key roles due to variations in their characteristics. Ainsworth (1999) has developed a useful taxonomy for describing the functions of MERs. This framework, as described in more detail below, suggests that MERs can be used to complement and/or constrain the interpretation of one another in such a way that their use leads to a deeper understanding of the material.

*Functions of MERs***.** There are two main ways that a representation can be complimentary. One way is due to the processing invoked by the representation for the learner. It has been shown that different sources can be equivalent in information but quite diverse in form such that varying inferences will be made. For instance, Larkin and Simon (1987) showed that diagrammatic information effects perceptual processes differently than sentential forms leading to differing inferences being made by the learner. In addition, different forms have varying "inferential power", meaning that certain forms may lead to a clearer or easier inference. For example, a graph of the relationship between two variables may lead to an easier interpretation than the algebraic expression that leads to the graph (Ainsworth, 1999). This difference is what is known as computational efficiency. The more computationally efficient a representation is the easier it will be for a learner to make an inference or gain meaning from the

representation (Seufert, 2003; Ainsworth,1999; deJong et.al.,1998; Larkin and Simon,1987).

Another way an external representation can be complimentary is through providing diverse information. Different sources can contain different but related information. In this way, complex material can be broken down so that each piece can be internally represented, understood, and then connected or integrated later. Or, two representations may provide pieces of the same information embedded in additional details. For instance, a graph of the movement of an object may be displayed at the same time as the actual object is seen moving. Both of these show the same movement, but the graph has additional information available while the physical observations may be more computationally efficient.

Due to the prior knowledge and experiences of the learner, one representational format may be more familiar to that learner than another. This is usually due to the level of complexity of that format (Ainsworth, 1999). As complexity increases, the external representation tends to be less familiar to the learner. By varying their use from less complex to more complex (more familiar to less familiar), it is possible for the previous to constrain or support the interpretation of the latter (Ainsworth,1999; deJong et. al., 1998).

Multiple external representations may also be used to constrain interpretation by varying in precision. Precision has been described as the level of abstractness or the degree to which it is quantitative or qualitative, the latter being more abstract (Ainsworth, 1999). Verbal descriptions, for instance, can be more ambiguous or abstract than a picture. For example, one may present the statement “A car is by a tree.” Though not

difficult to read, the statement leaves many questions about where the car really is in relation to the tree. However, if the statement is accompanied by a picture showing the location of the car, the statement is now much more constrained and thus more precise in its interpretation.

It is through proper variation in the characteristics that use of multiple external representations will have "synergistic effects", complimenting and constraining each other in such a way that learners interconnect external representations while actively generating a coherent mental model (Seufert, 2003). In doing so, these MERs will fulfill their third major role as promoting deeper understanding of the material.

By varying the modality, or form of expression, of the presented material, we give students a choice as to what to attend to and what inferences can be made. Written text, verbal text, diagrams, tables, illustrations, and graphs all provide valuable information that students can evaluate, select, and integrate (Mayer, 1993). Knowledge of one type of representation may aid in the interpretation of another and may lead to new inferences made from another. Through this process of integration, meaning is constructed. In the end, the hope is that students process and integrate the MERs so that the principles are abstracted and an appropriate mental model is constructed.

Abstraction can refer to several processes that all have the possibility of leading to an acceptable mental model. First, abstraction as subtraction refers to the ability of the learner to "throw away the details" and maintain the main idea of a situation. This is similar to the idea of Kintsch (1994) where the student engages in forming a "situation model." Second, abstraction as re-ontologization refers to the ability of the learner to resolve misconceptions within their already existing knowledge structure. Ontological

incompatibilities or pre-scientific misconceptions can impede integration of information (deJong et. al.,1998; Wittrock, 1991). In using multiple representations, one can point out these misconceptions in a variety of ways, allowing the student to resolve these irregularities or further develop their previously "naïve theories" (deJong et. al.,1998). Finally, abstraction as reification is the development of a higher-level organizational structure. The developed structure, in this case, will be considered to be the resulting mental model. Experiencing information in various modalities can lead to referential processing across the verbal and non-verbal systems leading to a mental model that can be accessed through a variety of avenues later allowing for more flexible problem solving.

It is this cognitive flexibility that is the key to being a successful problem solver in physics or in any other domain. Abstraction supports the generalization necessary to extend knowledge between different expressions or representations within a domain or the use of that knowledge in numerous domains (Ainsworth,1999). Being able to use one's knowledge in such a flexible manner is the hallmark of an expert problem solver (deJong & Ferguson-Hessler, 1986; Boshuizen & van der Wiel,1998) and is what educators hope to develop in the students they teach.

Integration of information from the various sources of material is necessary for abstraction and the generation of a mental model of the situation. However, just presenting information in several forms, varying the appropriate characteristics, does not ensure that this integration will occur. There are several obstacles to integration that can impede the generation of a mental model. It is important to realize what these barriers are and how it is that they can be ameliorated.

Obstacles to Integration. There are several obstacles involved in learning from MERs that need to be recognized. Cognitive load, attention, and prior knowledge issues are all valid concerns when using MERs as an instructional tool.

Cognitive load theory has been used to suggest that many commonly used instructional procedures are inadequate because they require learners to engage in unnecessary cognitive activities that impose a heavy load on working memory (Sweller, 1988). Cognitive load theory is based on several assumptions about cognitive architecture that are relevant here. These assumptions are (1) People have a limited working memory that is able to hold only a few items of information at a time; (2) People have a long-term memory which is effectively unlimited in size; (3) Storing information in higher-order organizational structures, such as mental models, in long-term memory reduces working memory load by permitting people to treat multiple elements as one; and (4) Automation of cognitive processes reduces working memory load by essentially by-passing working memory (Sweller, 1988). It is the working memory capacity, its limited size, and short time-span of availability that should concern those using multiple external representations. Mentally integrating multiple sources of information may result in the less effective acquisition of information than if learners are presented the same material in a physically integrated form (Mousavi, Low, & Sweller, 1995).

The split-attention effect occurs when learners are required to divide their attention among and integrate multiple sources of information (Mousavi, Low, & Sweller, 1995). For instance, if a student is required to hold diagrammatic information in working memory while searching for relations, working memory is over-loaded and information is eventually lost. Introducing multiple representations into a learning

environment may jeopardize the learning of information by introducing too many tasks for the learner to handle cognitively (deJong et al., 1998). To cope with this cognitive load, learners force decisions about what to attend to and what to process. Coordination of the representations is one of the main obstacles to the learner in the situation (deJong et. at., 1998).

A second, related obstacle to integration is selective-attention. Information is processed at a minimal level based on the importance assigned to the information. Extra attention is given to that information which is deemed important and due to that attention learning occurs. If information is not seen as important, there will be no (or little) attention given, and therefore, little (if any) learning of that material (Reynolds & Baker, 1987). The challenge in designing instruction with MERs is guiding learners to attend to each representation and the important elements contained within the representations.

One criterion that students may use for selecting what to pay attention to is familiarity. Holliday(1976) states that learners will put forth as little effort as necessary to complete a task. Therefore, if one can attend to a more familiar medium (like text) and still complete a task, then the chance that the less familiar medium (like a graph) will be inspected is reduced (Reynolds & Baker, 1987). This is similar to the earlier discussion of computational efficiency. The ease with which one can interpret a representation or make inferences from that representation will determine which representation a student will choose to attend to.

A third obstacle to integration is lack of appropriate prior knowledge. If a learner does not posses sufficient prior knowledge with which to approach and interpret a representation, that representation may not garner any attention at all. Worse yet, this lack

of knowledge may lead to misinterpretation of the representation resulting in the acquisition of incomplete or faulty knowledge. There are two main types of prior knowledge at play in this situation – domain knowledge and knowledge of the representation itself. With respect to knowledge of the representation, learners must know how to interpret the representation in order to learn from it. Again, a learner is more likely to effectively use a representation that is familiar. For example, one may have sufficient knowledge to interpret a list of math scores to determine the average, but may have difficulty in doing so when those scores are presented in a stem-and-leaf plot. On the other hand, one may have many experiences in interpreting pie graphs but may have difficulty gaining the appropriate meaning because it is labeled with the names of chemical compounds, a domain with which one may not be familiar. Additionally, if the prior knowledge or experiences of the student have led to misconceptions or erroneous knowledge structures, it will be even more difficult for the representations to convey the appropriate meaning to the person.

There are, of course, a number of related factors that have been shown to influence understanding of a single representation that may also be important for learning and coordinating MERs. For example, if learners are already familiar with the domain or the representations, then learning to integrate across the representations should occur more rapidly (Ainsworth, Bibby & Wood, 2002). Cognitive style and aptitude have often been related to performance with particular types of representations in addition to verbal and spatial abilities, but there are questions as to the degree of their influence.

Keig and Rubba (1993) considered not only spatial ability but also reasoning ability, gender, and specific knowledge influences on the ability of students to use

multiple representations in chemistry. All of these characteristics have been consistently associated with chemistry achievement and were chosen for this reason. Results from this study demonstrated that in general, students were poor in their performance when translating from one external representation to another. Regression analysis uncovered that gender and spatial ability were non-factors in the process, however. Instead, reasoning ability and, of course, prior knowledge of the representation were significant predictors of learning. In fact, the overwhelming majority of errors included those errors based in incomplete or erroneous knowledge of the representation itself. So, again, this study demonstrates that prior knowledge of the representation, or familiarity, is a strong influence on a student's ability to integrate.

When looking at the use of MERs by novices, one can see how prior knowledge, attention, and cognitive load all work together to inhibit integration. Novices tend to focus on the surface features and categorize based on the literal features of a representation (Kozma, Russell, Jones, Marx, & Davis, 1996; Kozma, 2003; Seufert, 2003). Learners with low prior knowledge have difficulty identifying conceptually relevant entities within a representation (Lowe, 1996) impeding students' abilities to integrate the relationships within a particular external representation. Because they have limited "chunks" of complex information, novices tend to experience cognitive overload when using MERs. In order to avoid this stress on working memory, novices tend to focus on one representation often choosing the more familiar or concrete representation to attend to (Tabachnek & Simon, 1998). Further, novices tend to focus on one particular representation until it no longer is useful before moving onto another representation, limiting the opportunity for determining the relationships between the representations

(Seufert, 2003). All of these phenomena combine to make integration difficult.

Facilitating Integration. Though there seem to be some inherent weaknesses in using multiple external representations including cognitive load, selective attention difficulties, and lack of prior knowledge, there are also many ways in which we can use MERs that will facilitate integration.

As in the discussion earlier of computational efficiency it is true that specific representations should be used for specific information (deJong et. al., 1998). The modality, such as propositional or graphical, can influence the ease of interpretation (Ainsworth, Bibby & Wood, 2002). Additionally, the inferential power differs depending on what type of information is to be presented. For instance, percentages are better presented in a pie graph than on a line graph whereas the latter graph type is better for showing trends over time (Shah, Mayer, & Hegarty, 1999). Choosing the wrong form can lead a learner astray or even cause the learner to completely ignore the representation. Choosing the appropriate form may allow a learner to gain information that would have been missed otherwise.

Appropriately varying the representational characteristics in a sequence can also aid in the learning process (deJong et. al.,1998). In presenting several forms of information, they should vary on complexity (less to more detailed), perspective (behavioral to functional), and precision (qualitative to quantitative). By doing this, a learner will have “intermediate” steps in the process with which to build a more coherent mental model. The more familiar representations will constrain the interpretation of the less familiar and the relationships between these will be more readily discovered by the learner.

One study that showed the advantage of intermediate representations was conducted by White (1993). In the study by White, sixth graders were asked to study Newtonian motion using an instructional device known as Thinker Tools. Thinker Tools used a variety of representations classified along two lines: dynamic → static, and concrete → abstract. Intermediate representations fall within the continuum sharing features of the real world and higher order abstractions. The Thinker Tools group outperformed the control groups in both post tests on translating from one representation to another as well as transferring knowledge to real world problems. In fact, the sixth grade students in the experimental group outperformed a group of high school physics students who had been taught in the traditional way. The intermediate representations provided the necessary help for students to abstract the principles necessary to describe the concrete phenomena.

Similarly, SkaterWorld (Pheasey, O'Malley, & Ding, 1997) is a computer environment designed for learners to explore the relationships of force, acceleration, velocity, and time. Many representations are available at one time including simulation skater, ticker tape, force arrows, net force indicator, and tables of velocity, in addition to a graph selected by the student. The more concrete representations are meant as constraints to the interpretation of the more abstract ones, but, at the same time, students must spend considerable time relating them all (Ainsworth, 1999). In fact, it would seem that there is a considerable amount of information for students to attend to at any one time, undermining the success of these MERs.

Typically, students do not use multiple sources of information but instead concentrate on one, usually the most familiar. It is not until the student encounters a

problem that he may switch to an alternate representation (Tabachnek & Simon, 1998). This is especially true for students with low prior knowledge. As shown in studies by Seufert (2003), if students have low prior knowledge, no new representations should be used until further instruction can be implemented. However, for students with moderate amounts of prior knowledge, simply directing them to the correct aspects of the representation will significantly increase their success in the use of that representation.

The use of intermediate representations, or representations that are presented sequentially such that interpretation is made easier, may direct students' attention to the new representation. For instance, having students read a text employing multiple representations and then having them answer questions that draw their attention to the particular representations may "force" them to shift their attention to that particular representation. Similarly, having them complete a laboratory procedure where the students physically observe the phenomena and then observe a graph of the phenomena may help ease the interpretation of the graph. Even further, having the students generate their own graph may focus their attention on that representation and allow them to integrate not only within the graph but between the graph and the physical observations and possibly the related text.

Beyond focusing the attention of students toward the various representations and the relevant features within each, it is important to remember that students have difficulty processing all of this information once they attend to it. Reducing the amount of cognitive load is a critical aspect in the proper use of MERs.

Suggestions for reducing cognitive load while using multiple external representations include (1) spatial integration of textual and pictorial information (Mayer,

1997; Chandler & Sweller 1991; Tarmizi & Sweller, 1988); (2) use of corresponding colors to accentuate relations (Kozma, 2003; Chandler & Sweller, 1991; Kozma, Russell, Jones, Marx, & Davis, 1996); (3) provision of visual and temporal cues (Lowe, 1999); and (4) presenting static information before dynamic information. (Bodemer, Ploetzner, Feuerlein, & Spada, 2004; Mayer & Chandler, 2001). Additionally, as has been mentioned previously, the more prior knowledge one has in a domain and about a representation, the less cognitive load issues will be a concern. This indicates that there is another advantage to using intermediate representations, as well as demonstrates the need for the appropriate amount of instructional support and practice (Reiber, 1990). In both cases, there is the opportunity to expand the necessary knowledge base as well as activate the appropriate prior knowledge necessary for successful integration.

In sum, when considering the use of MERs, facilitation of integration may be accomplished by providing the appropriate external representation with the appropriate characteristics, by providing practice, and by using familiar and intermediate representations. However, there is yet another way to alleviate the obstacles presented by prior knowledge deficits, selective attention issues, and cognitive load. This may also be accomplished through the use of generative learning activities.

Generation vs. Provision

An old Chinese proverb is at the center of the discussion of generation versus provision:

Tell me, I'll forget

Show me, I may remember

Involve me, I'll understand.

It has been known for many years, obviously, that a very effective way to teach students is by having them actively involved in the instructional activities. The old idea that "the mind is an empty vessel" led many to the belief that lecture and text would lead to desired learning outcomes and given the assessments employed were fairly successful. However, educators now look for students to use their knowledge to solve problems in specific domains and across domains and these instructional techniques do not produce students with such problem solving abilities. Instead, alternative methods of instruction need to be developed to engender the type of learning that has been described throughout this review. One basic difference in these alternative methods is the use of generative activities to present information as opposed to providing the information didactically.

The Generative Learning Theory (GLT) developed by Wittrock and his colleagues over many years of research is a functional model of learning from teaching. It focuses on what a teacher can do to facilitate comprehension and retention of material (Wittrock & Alesandrini, 1990). It has been described as "transforming unfamiliar to familiar by generating connections" (Kourilsky & Wittrock, 1992) and as "the creation and refinement of individual mental construction about the world" (Ritchie & Volkl, 2000). Building mental models and transforming the unfamiliar are the processes of comprehension and, according to Wittrock, depend directly on what students generate and do during instruction (Wittrock, 1991). Students must build relations (1) among the concepts presented in class, and (2) between the subject matter presented in class and the students' own perception and preconceptions (Wittrock, 1991).

Wittrock outlines several major factors that influence generative learning, and therefore generative teaching strategies as well, and those will be described briefly here.

The first factor is knowledge, experience, and conceptions. It has been clear throughout this discussion that a student's prior knowledge will be a significant factor in learning material. This could be prior knowledge in the domain, such as physics, or of the representation, such as prior knowledge and experience with a graph. It also includes students' perceptions of their roles as learners and misconceptions about the subject matter. Generation allows for students to change their view of themselves as learners from that of recording and memorizing information to one of generating understanding. It involves leading students to test and develop their models and thought processes in familiar contexts (Wittrock, 1991). This is done through participating in activities that relate concepts presented in class to real-world experiences. Students feel that they have more control over their learning in this environment and thus exhibit more effort attributions (Weiner, 1979), meaning that they believe it was through their own work or effort that the learning occurred.

Students' misconceptions are difficult to overcome by traditional teaching methods. Students have meanings for words and views about the world from a very young age which are often uninfluenced by science teaching. When these views do change they often do so in unanticipated ways (Osborne & Wittrock, 1983). Students learn to give teachers the answers they are looking for without changing their own model or preconception (Wittrock, 1991). In this way, students do well on lower level cognitive tasks on assessments but are not able to solve problems or complete transfer tasks correctly or efficiently. Allowing students to participate in activities that directly deal with these preconceptions leads them to a re-examination of their beliefs or a re-ontologisation (deJong et. al., 1998). Generative teaching deals with this by focusing on

teachers' responsibility for getting students to generate new meanings and understandings by revising misconceptions. This is done when the teacher (1) learns the students' conceptions and beliefs about science and their abilities, (2) learns the students' conceptions about what they must do to learn science, and (3) teaches the students that learning with understanding is a generative process (Wittrock, 1994).

A second factor influencing student learning is motivation. GLT emphasizes that the student take control and responsibility for being active in learning; for generating meaning from teaching; and for attributing success to this active, effortful learning (Wittrock, 1994). The effect of success, and subsequent motivation, depends upon the students' interpretation of the cause and meaning of the success (Osborne & Wittrock, 1983). One way to encourage students to have this viewpoint about their learning is by designing instruction that allows students to experience frequent success understanding the concepts.

The third component of GLT is attention. A common obstacle to learning is the inability of students to attend either to the relevant portions of the material or to the instruction as a whole. As with the issues surrounding selective-attention illuminated earlier, voluntary sustained attention is difficult for some students, yet is necessary to help students attend to specific aspects of the learning experience (Osborne & Wittrock, 1983). As with MERS, interest, meaningfulness, and familiarity will all play a role in focusing attention, as well as the use of more specific strategies such as headings, subheadings, objectives, and explicit instructions. One tactic that is successful for maintaining attention is the use of higher-order questions. These questions can be asked by the teacher but may also be generated by the learners themselves (Osborne &

Wittrock, 1983). They have been shown to direct students' attention to the meaning and implications of instruction, and are useful in getting students to generate connections and understanding (Wittrock, 1991).

The final factor influencing learning is generation itself. This is the process of relating individual events and ideas presented in class and relating instruction to knowledge and experience. The student's knowledge, inference, and learning strategies are critically important because answers given to the student must still be generated or discovered by the student before they are comprehended (Osborne & Wittrock, 1983). Generation includes more than effort, practice, or over-activity and has been shown to be an important factor in successful reading comprehension (Doctorow, Wittrock,& Marks, 1978; Linden & Wittrock, 1981) and science learning (Osborne & Wittrock, 1983).

Generation requires student effort and thought beyond learning from teacher reward or punishment, beyond telling the teacher the "right" answer. To get students to this point, teachers must initially generate for the students. Teachers should employ familiar materials taken from everyday experiences, devices such as analogies, metaphors, images, diagrams, demonstrations, etc., and provide structure such as titles, headings, questions, tables, summaries and problems (Wittrock, 1994). Teaching should begin by the use and demonstration of generation of such devices and move toward students' generation. Depending on a student's background knowledge, students can first be provided with the representation and asked to do something with it mentally. Then after familiarity has been established, they should be asked to generate their own representation.

Generation of a representation can be seen as directly influencing the

development of a mental model by looking at the two types of generative learning that have been identified. One approach is to uncover the organizational relationships between different components of the environment. This step helps a learner understand how items are connected to one another (Ritchie & Volkl, 2000). Some ways to stimulate generation among concepts given in instruction in this manner are to have students compose titles or headings, write questions or summaries, or draw graphs or tables (Wittrock, 1991). Manipulation of objects is thought to be on the "outskirts" of this category due to the fact that a "relationship is being drawn and extended between parts of the environment" (Grabowski, 1996). So one might look at manipulation of equipment within a laboratory procedure and the physical observations of those objects to develop organizational relationships. This type of generation can be useful in finding the connections between relationships within a domain, beginning the interconnected knowledge structure necessary for problem solving within the domain.

A second approach would be to integrate relationships between external stimuli and memory through the use of student generated demonstrations, metaphors, analogies, pictures, paraphrases, and inferences (Wittrock, 1991; Ritchie & Volkl, 2000). This latter approach is thought to require deeper processing of the material and a higher level of understanding. One might look at these two approaches as being the steps necessary for building a complete mental model. First the connections between relationships within a domain are developed and then the principles connecting those concepts and prior knowledge are extracted. The prior allows for problem solving within a domain, the latter for successful transfer.

There are many examples in the literature of generative activities improving

performance in the classroom both in reading comprehension and in science learning. Wittrock and Alesandrini (1990) demonstrated that students who generate summaries or analogies for high imagery text "learn more" from the text than students who are given no particular instructions on how to process the text beyond just reading it twice. Wittrock and Alesandrini randomly assigned fifty-nine (59) undergraduate students taking a course in psychology to one of three experimental treatments – Read Text, Generate Summary, or Generate Analogy. Each student was asked to read a 5,200 word selection of high imagery text and then asked to reread the paragraph, generate a summary of the paragraph, or generate an analogy for the paragraph read. The results of this study showed that students who participated in either generative learning activity outperformed those in the Read Text group. By asking students to generate summaries using their own words or by asking them to generate novel analogies for the information, the students were stimulated to construct relations between the text and their own knowledge and experience.

A study by Kourilsky and Wittrock (1992) combined GLT with cooperative groups as an enhancement strategy for teaching economics. One hundred and forty two high school seniors were randomly assigned to two groups, experimental and control. All students received training in cooperative learning and were engaged in this type of learning environment throughout the year. Additionally, the experimental group received training in generative teaching techniques to be used within their cooperative groups. When given the Market Equilibrium Test, made up of 7 verbal and 13 graphical items dealing with the functions of the market system, those in the generative condition out gained those in the control. In general, Kourilsky & Wittrock (1992) found that using

generative procedures in established cooperative learning groups increased student comprehension of economics, and decreased the level of misinformation learned.

An earlier study by Linden & Wittrock (1981) found significant improvement in reading comprehension for students given instructions to generate associations for the text. These associations were in the form of images, illustrations, analogies, metaphors, or summary sentences generated as the texts were read during classroom instruction. The results of this study were similar to those of several others (e.g. Doctorow, Wittrock, & Marks, 1978) researching generation and reading comprehension with the difference being that "real classrooms" and "real teachers" were used to employ the technique as opposed to the contrived laboratory setting.

GLT has also been shown to be effective in the field of science through the generation of hypotheses . In a study by Osborne (1981) elementary school children were presented with the concepts of DC electric current flow. Providing the students with a battery, light bulb, and 2 wires, the researchers asked the students to "make the bulb light." After participating in the activity, the students were then asked to describe the flow of the current. Generally, four separate models of current flow were described by the students, only one of which was the scientifically correct viewpoint. Even when shown that the model they held was incorrect, many students continued to hold their perspective, explaining the failure of the bulb to light with a range of rationalizations.

This study, as well as others using various science concepts, demonstrated to the researchers that students generally hold misconceptions related to science concepts and these misconceptions are resistant to change even with science instruction. Even when shown evidence to the contrary of their conception, students did not give up their naïve

theories but instead found some way to discredit the procedure or data to avoid dissonance. Those activities that resulted in a new and better understanding, were those that allowed students to generate the hypotheses for what was happening but also to generate the procedures necessary to test those hypotheses.

Ritchie and Volkl (2000) extended the definition of generative activities to include laboratory procedures due to the generation involved through the object manipulation. The researchers compared the object manipulation approach to concept mapping (an accepted generative learning activity). The study was run with sixth grade, above average, private school students taking Earth Science. The students were randomly assigned to two groups. The Concept group first completed the concept mapping activity and the Lab group first completed the laboratory procedure. The students were then given a multiple-choice test for knowledge acquisition. The results of this posttest showed that both groups performed equally, demonstrating that both approaches maintained the benefits of the generative learning activity. The students then switched and completed the other activity, either concept mapping or laboratory procedure. Thirty-two days later the students were given a delayed post-test. Those students who had worked with the concept map first tended to have better long-term retention than those who had originally completed the laboratory procedure. Looking to elaboration theory as reasoning, Ritchie and Volkl suggest that the order of generative activities may be important to the success of students on future tasks. They also point out that the laboratory procedure in this case used tables and lists to determine the characteristics of given minerals. Though obviously helpful, as demonstrated by the posttest results, a procedure that made more linkages to prior knowledge might have improved the results on the delayed posttest.

In contemplating the research discussed above, one can see the use of MERs along with GLT, especially in the studies within the science classrooms. Similarly, though the researchers may not reference GLT specifically, it is possible to find support for using Wittrock's theory in conjunction with MERs elsewhere in the literature.

"Practicing Representation" is a term used to refer to the exercise of students using representations such as tables or graphs and participating in the complex practices of communication and reasoning with representations (Greeno & Hall, 1997). From a situative perspective, this means designing activities that will engage the participation of students in the construction and interpretation of representations. These activities will ultimately determine what is learned. Where Greeno and Hall connect with Wittrock's theory is in the discussion of how understanding is constructed. Problem solving involves an interactive process in which students construct representations based on partial understanding and then use the representations to improve understanding. The invention of novel forms by students shows that they can use representations constructively. Further, for a notation to constitute a representation, one must interpret it or give it meaning. To do this, students must connect it to their prior knowledge and experiences – generating the necessary relations for understanding.

Further support for generative activities comes from Kozma (2003) and his research on the differences between expert and novice chemists. Kozma observed and interviewed both professional chemists working in an Organic Chemistry laboratory as well as chemistry students involved in an Organic Chemistry class. He found that experts were able to construct, reference, and understand many different types of representations including structural formulas, models, and text. Students involved in a wet-lab

synthesizing a compound as well as a computer imaging activity based on the same compound were not able to translate between representations. Students focused on the physical aspects of the wet lab and, though they were more able to discuss the chemistry involved in the computer imaging activity, these students were not able to connect the computer image to the compound synthesized in the wet lab.

To further study the implications for instruction and what could be done to make the novices more like the experts, Kozma engaged in the students in 4MChem, a software environment intended to alleviate some of these problems. Though focusing on the use of MERs, he found several keys to the success of the instruction in making novices become more like experts in their use of MERs and their understanding of the material. The advantageous ways to use multiple external representations include (1) provide at least one representation that has features explicitly corresponding to the entities and processes that underlie the physical phenomena; (2) have students use MERs in the context of collaborative, authentic laboratory settings; and (3) engage students in collaborative activities which generate representations and coordinate features. In all three suggestions, one can see the overlap with Generative Learning Theory. Both reference the necessary linkages to students' knowledge and experiences and both express the importance of student generation.

The use of drawing as a generative activity has also been shown to be an effective strategy for students learning from text. In a research study by Van Meter (2001) students were divided into 4 groups: read only, draw, illustration comparison (IC), and prompted illustration comparison (PIC). In the latter two, students compared their generated drawings with those provided and in the PIC students were asked questions based on the

differences noticed. In this study, the PIC students outperformed all groups on free recall measures but not on recognition tasks. The study demonstrated that students, given the proper support as in the PIC condition, benefit from generating a drawing from a given text. This result suggests that students who engage in this type of generative activity will be more successful on tasks that require the generation of connections between concepts.

If generation is successful for those using analogies, metaphors, tables, pictures, and other types of representations, then it is quite possible that generation will do the same for graphical representations such as line graphs. Considering that the use of graphs would invoke both types of generation, organizational relationships within a representation and integrative relationships between representations, one would expect that a generative activity employing a graph would be beneficial to students in building a mental model. Graphs, however, are a distinct form of representation with particular processes invoked and with some obstacles to understanding. For this reason, it is necessary at this point to take a further look at graphical representations and how students go about learning from graphs.

Learning from Graphs

As has been previously discussed, graphical representations are often used in the field of physics, and the interpretation of these representations is necessary for physics problem solving(Brasell, 1987; Svec, 1995; Ainsworth, 1999). Though all types of representations are encouraged, graphical forms play a special role in math and science (Ozgun-Koca, 2001). In the case of physics, it is generally acknowledged that it is practically impossible to address many basic content areas without intense use of graphical representations (Testa, Monroy, & Sassi, 2002).

A graph, in and of itself, involves the use of multiple representations. A graph is textual, graphical, and locational with all information being presented simultaneously (deJong et. al., 1998). Modalities shift within the creation or interpretation of the graph (visual represents numerical extracted from a phenomena). It is not surprising, then, given the previous discussion on MERs, that there will be some difficulty in the integration of information within a graph. For this reason, many people have studied the way in which students interact with graphical representations in order to facilitate comprehension and mental model construction.

There are several ideas concerning how students go about constructing mental models from graphical representations. There seems to be agreement, however that three major processes exist including (1) encoding visual patterns or pattern recognition, (2) identifying quantitative facts / translation into quantitative relations, and (3) relating quantitative relations to variables / determining the referent concepts (Shah, Mayer & Hegarty, 1999 ; Carpenter & Shah, 1998).

Pattern recognition involves encoding the visual array into distinct “functions”. For instance, one must recognize that each line with a different slope indicates qualitatively different x-y relations. Translation, as would be the case with MERs, is where multiple graphic features must be integrated into a unified interpretation. The amount of effort involved is dependent on the graphic pattern’s familiarity and the number of distinct patterns – a point that will be expounded upon during the discussion of graphic representation characteristics. Finally, the third major phase is determining the referent concepts and associating those concepts to the functions involved. One might

see this as determining the overall principle or function relating the variables within the graphical representation.

It has been demonstrated in various studies that students struggle in the processes involved in using and understanding graphs. Students have difficulties making connections among graphs of different variables, physical concepts, and the real world (Svec, 1995; Huetinck, 1992). Students do not understand the fundamental properties and functions of graphs in representing relationships among variables (Ozgun-Koca, 2001). For these reasons, students tend to avoid using graphs provided for them and are unlikely to draw any of their own. Unfortunately, even when they do use the graphs, they tend to over-generalize and make inferences beyond what the graph implies (Scanlon,1998).

There are three broad factors that can be identified in the inabilities of students to use and comprehend graphs. The first factor is the physical characteristics of the graphs themselves (Kwon, 2002; Shah, Mayer, and Hegarty, 1999; Friedler & McFarlane, 1997; Carswell, Emery, and Lonon, 1992; McKenzie & Padilla, 1986). Research in this area has shown that difficulties in graph interpretation may be due to poor design or lack of attention to computational efficiency. Also, graphs displaying trend reversals or lack of symmetry caused students to focus on details rather than relationships incorporated in the graph.

The second factor is based in the misconceptions students hold concerning graphs and the instruction students receive specifically addressing this type of representation. There are two main misconceptions that students harbor in this respect. The first is the graph-as-picture interpretation in which students expect the graph to be a picture of the phenomenon described (Mokros & Tinker, 1987). For example, in problems dealing with

balls rolling down tracks or people riding bicycles over hills, students using graph-as-picture will often draw velocity-time graphs resembling the shapes of the tracks or hills, rather than showing the velocity of the ball or bicycle. This misconception has been demonstrated with individuals of various ages including middle school students (Mokros & Tinker, 1987) and college undergraduates (McDermott, Rosenquist, & van Zee, 1987), and with varying expertise including middle school teachers (Barclay, 1985).

The second common misinterpretation is known as slope/height confusion (Svec, 1995; Thorton & Sokoloff, 1990; Brasell,1987; McDermott, Rosenquist, and van Zee, 1987). Even in simple cases, students confuse their interpetation of the height of the y-axis with their interpretation of the slope or steepness of the line (McDermott, Rosenquist, and van Zee, 1987). This becomes even more common as graphs become more curvilinear (Thorton & Sokoloff, 1990). Students commonly draw or select graphs for velocity vs. time that resemble the correct graphs of distance vs. time (Svec, 1995). Some question whether this misconception is due to a true confusion in slope and height or is more related to confusion about the concepts of velocity and distance (Brasell,1987). Either way, in using graphing to relate physics concepts, this confusion is resistant to change even after instruction and is thus a problem in physics problem solving.

The third factor in students' inability to interpret graph may be the direct consequence of the instruction (or lack there of) given to students using graphs. It has been pointed out that much of the graphing instruction takes place in the math classroom. The concern is that graphs are taught as an end product with an emphasis on plotting and reading points (Ozgun-Koca, 2001). Global meanings of graphs and interpretation of graphs are often left out of the math curriculum. Padilla, McKenzie, & Shaw (1986)

while looking at the line graphing ability of students in grades seven through twelve noted that a reasonable amount of school time is spent teaching students to construct graphs, but it appears there is much less curricular emphasis on interpreting graphs. Though results of their study showed that older students outperformed the younger students overall, it was clear that for all students construction skills such as plotting points were good but interpreting skills were rather poor. Similar concerns are expressed by Ainely, Nardi, and Pratt (2000). They suggest that this is a result of the emphasis students and teachers place on the drawing of the graph itself, referring to neat presentation and adherence to convention. These authors, and many others, believe that the "tedium" of graphing – plotting, scaling, neatness, etc. – detract or distract the students from attaining the overview or relationships within the graph (Ainely, Nardi & Pratt, 2000; Huetinck,1992; Adams & Shrum, 1990). This brings about questions on the relation of graph generation and learning from graphs which will be explored further later in the discussion.

Facilitating Learning from Graphs. There are several clear steps that can be taken to facilitate comprehension of and learning from graphs. First, use the appropriate graph at the appropriate time. Based on the discussions of informational equivalency and computational efficiency, one would need to discover which type of representation is the most familiar to students and still conveys the necessary information. As an example, line graphs have been shown to elicit inferences about trends over time much more efficiently than bar graphs (Shah, Mayer, & Hegarty, 1999).

Second, when using graphs, in particular line graphs, be aware of the complexity of the graph. The more asymmetrical and the more departure from linearity involved –

the more difficulty students will have in interpreting the graph. In addition, the curvature and perspective of the graph as well as the number of lines that intersect will greatly influence the difficulty involved in comprehending the correct relationships (Carpenter & Shah, 1998). In these cases, it may be helpful to use intermediate representations, use several graphs to increase computational efficiency, or change the perspective (e.g. from z-y to x-y or vice-versa).

Third, there are several features of graphical representations that may improve the ability of the learner to construct meaning. Diagram properties that enhance comprehension include localization (Guthrie,Weber, & Kimmerly 1993; Lin, Liebscher, & Marchlonini, 1991), perceptual enhancement (Larkin & Simon, 1987), and labeling (Mayer, 1989; 2002).

Fourth, misconceptions may occur when studying certain subjects. For instance in the case of kinematics, graph-as-picture and slope/height confusion tend to mislead students into incorrect inferences. Allowing students the opportunity to experience multiple external representations beyond the graph may help to alleviate this as well as allowing students the opportunity to generate graphs of motion. If students are able to connect the graph to the “real-world” motion in some way, such as through a laboratory experiment, these misconceptions may be alleviated (Svec, 1995; Brasell, 1987; Mokros & Tinker, 1987).

Fifth, instruction needs to be designed to focus students on the relationships involved in a situation as opposed to the surface features of the graph. Allowing students plenty of opportunity to practice construction skills should reduce the cognitive load experienced in this situation. Focusing evaluation of the graphing activity not on the

neatness and presentation of the product, but on the interpretations made from the product should also shift students' attention away from these surface features. Additionally students need practice in reading and interpreting graphs (Reynolds & Baker, 1987), in strategies for appropriately searching documents (Guthrie, Weber & Kimmerly,1993), and using graphs more intensely and appropriately (Schnotz, Picard, & Hron, 1993).

Finally, it is possible that using the graphs as part of a generative learning activity will improve learning from these types of representations. One study that has shown results to this effect was completed by Stern, Aprea, and Ebner (2003). The focus of the study was the use of active versus passive graphing , and its effect on transfer. In the domain of economics, the researchers developed 3 conditions under which students could learn the material. The first group received text that included an appropriate graph relevant to the to-be-learned material. They then received text on a different topic that involved similar relationships such that a similar graph would be appropriate for learning the material and solving problems on the new topic. This group was labeled "different topic / passive graph." The second group, "different topic/ active graph" was similar but instead of receiving a graph in the first passage, they were asked to generate one of their own. Third, as a control, a "same topic / no graph" condition was formed to determine the effects of both the active and passive graph overall.

The conditions were given to samples of students with varying degrees of prior knowledge of both the subject and graphs including college-level students majoring in Business (knowledge of topic but not graphs), college-level math and computer science students (knowledge of graphs not topic), vocational business "apprentices" (practical experience in the topic but little math background), and University humanities students

(low knowledge in both areas).

The results suggested the following:

(1) The presence of a graph (active or passive) improved performance for all levels of prior knowledge.

(2) Students in the active graph condition outperformed students in the passive graph condition on transfer tasks for both the college-level business and college-level math & computer science students.

(3) When vocational business students were given the proper supports (e.g. labeled axes), active graphing improved performance on transfer tasks (Stern, Aprea, & Ebner, 2003).

Though this study revealed issues with prior knowledge, it also shows clearly that active generation of graphs can lead to improved learning and transfer.

In the physics classroom, where the use of graphs is quite prevalent, a teacher needs to take into account all of these suggestions for the facilitation of learning from graphs within their instruction including laboratory instruction. Laboratory procedures are integral to physics instruction as are graphical representations. Similarly laboratory procedures employing graphs are quite common. In recent years, physics laboratory activities have become more reliant on the use of computer interfacing and computer generated graphical representations. These types of laboratory procedures are viewed as opportunities to efficiently expose students to physics phenomena as well as familiarize them to graphical representations. However, since these procedures remove the necessity for students to engage in producing the graphs, it is possible that the advantages of generation, so vividly show in the Stern, et. al. (2003) study, are removed.

Microcomputer Based Laboratory Procedures

One way to improve learning from graphs is to employ computers as an instructional tool in conjunction with laboratory procedures. To that end, the microcomputer- based laboratory (MBL) has been incorporated into many math and science classrooms. However, MBL has been especially popular in the field of physics education where graphing and the use of multiple external representations is not only natural but necessary for many topics, in particular in the teaching of kinematics (motion).

One reason researchers support MBL use is the inclusion of different ways of experiencing the material (Barclay, 1985). The use of multiple modalities is an advantage because it emphasizes the complimentary and constraining roles of the MERs involved (Mokros & Tinker, 1987). Many researchers assert that the most important pairing of these representations, however, is the connection between the "real world motion" and the graph itself.

Linn, Layman, & Nachimias (1987) suggest that the one major advantage of MBL is that graphs are formed as the experiment is carried out and immediately related to experience. This agrees with Barclay's (1985) view that the grounding of the graphical representation in concrete actions combined with the fast feedback allows for immediate relation of the graph to the event. In fact, most of the research in this field supports the view that MBL brings about a connection between the "concrete movement" with the "abstract" graph (Admas & Shrum, 1990; Brasell, 1987; Mokros & Tinker, 1987).

Many of the researchers in this field also assert that MBL is useful due to its efficiency in data collection and display (Huetinck, 1992; Adams & Shrum, 1990;

Brasell, 1987; Mokros & Tinker, 1987). Thorton & Sokoloff (1990) summarize these thoughts by offering three major advantages to MBL including (1) it allows for exploration but frees students from time-consuming collection and display; (2) the speed of collection allows for varying experimental conditions and more time for interpreting, discussing, and analyzing ; and (3) it takes the focus off of complicated tools.

Though most of the research in the field of MBL touts its successes and usefulness, a closer look at the results of the studies referenced in these discussions raises questions as to the true achievements of these procedures. For example, Mokros & Tinker (1987) identified the most common graphing misconceptions as graph-as-picture and slope/height confusion that were described earlier in this discussion. After doing so, they embarked on a three-month study looking at MBL effects on alleviating these misconceptions. No other instructional method was used as a control so a pre- post-test comparison was used to demonstrate differences. Students were engaged in a variety of MBL activities involving motion over this period of time. In all activities, a motion sensor was employed and students were asked to move in certain ways in front of the sensor and the computer then produced a graph of this motion. In the end, MBL was shown to reduce graph-as-picture misconceptions but not slope/height confusion. In fact, a task was developed to determine if students gained graph interpretation skills or gained knowledge of salient features by asking students to determine trends if events happened in reverse. Results of this task demonstrated that MBL students were not significantly better as this “backwards in time” task.

One conclusion that can be made from the results of this study is that the real-time graphing improved the graph-interpretation ability of the students (Mokros & Tinker,

1987). An alternative, however, is that the students have abundant opportunity to view graphs while controlling the motion to be graphed. This control of the motion brings about the alleviation of graph-as-picture. The real time graphing does not lead to any better understanding of what the relationships involved are, it does not help with integration of information as evident with the slope/height persistence, and students are still not able to attend to salient feature and interpret correctly as evident with the "backwards in time" task.

The alternative is further supported by the research of Adams and Shrum (1990). The students in their study completed many MBL activities on heating and cooling curves. As opposed to controlling motion using motion sensors, thermosensors were used to measure the temperature of materials during the heating / cooling process. The students were compared to students in traditional laboratory groups. Results showed that traditional laboratory procedures actually led to better graph construction skills. In addition, there were no significant differences in interpretation skills between MBL and traditional lab groups though an effect size of 0.48 was reported and used as evidence of MBL superiority. This brings in the question of whether the real-time graphing in effective if students are not in control of the motion.

Beichner (1990) stated that if the real-time graphing and immediacy of the graph production was really the key to success, then these results should be found when students viewed videotaped motion and the corresponding graphs. His results showed no improvement for students using the videos of motion lending credence to the interpretation that it is the control of the motion that is an important factor not the immediacy of the graph.

Other researchers have reported the success of MBL in improving students' graph interpretation ability and ability to extract meaning (Brasell, 1987; Linn, Layman, & Nachimias, 1987). And though in these cases they were able to show gains in performance, those gains were seen mainly in the alleviation of graph-as-picture misconceptions and common graphing errors. Students still demonstrated difficulties in the domain and continued to ignore salient features of the graphs. For this reason, one would conclude that students are not integrating information and would have difficulty on transfer tasks. Questions of transfer were only addressed in one study where again evidence was shown that graph-as-picture was reduced but not much additional learning had taken place (Linn, Layman, & Nachimias, 1987).

So then, the use of MBL seems to have only one main advantage over traditional laboratories that could lead to improved learning. Given that in both cases students control the motion and in both cases there is an appropriate use of MERs, the advantage to MBL is the opportunity for learners to experience various experimental conditions numerous times (practice).

With this in mind, therefore, there must be something beyond the use of MBL to bring about goal of increased transfer of learning. One possible addition to the use of MBL that would lead to such a result would be the addition of a generative activity such as having the students build their own graph as opposed to providing a computer-generated graph. Though this may seem to negate the "immediacy" effects of the real-time graphing, the control over the motion would still be present and the effects of learner generation would be an added benefit.

Conclusion. A goal of instruction is to improve the problem solving skills of

students. To this end, research has shown that people with knowledge structures organized into complete mental models demonstrate better problem solving skills than those with less organized structures. For this reason, one would believe that engaging students in instruction that promotes the building of mental models would in turn improve problem solving skills. The two lenses through which the discussion on how to encourage mental models are the use of Multiple External Representations and Generative Learning Theory.

Using MERs appropriately can encourage integration through complimentary and constraining characteristics, however they can also cause problems such as cognitive load issues. GLT is a functional model of how to improve students' understanding and has not been directly tied to MERs in the past but has shown that the use of generative learning activities improves students' abilities to integrate relationships and therefore improves problem solving. Using MERs together with GLT should aid in overcoming many of the obstacles to integration that hinder mental model construction.

Specifically, using MERs and GLT in physics can be seen in the use of laboratory procedures that include graphical representations. MBL saves time and removes boring data collection as well as provides for multiple practice opportunities, however integration is still not afforded as evidenced by the perseverance of misconceptions. Using text, equations, physical observations, and graphical representations together may be the appropriate use of MERs necessary to overcome some of these difficulties. Additionally, using a generative learning activity, such as having students generate their own graph during the laboratory procedure, may increase the possibility that integration will occur.

And so, it is with all this in mind that one can develop a research study to begin determining the credibility of this argument. Much of the study of physics can be classified as the study of motion or kinematics. Early on, students encounter the concept of velocity. The relationships of speed, distance, time, and direction are essential to the study of kinematics and represent one of the fundamental areas of physics. The relationships learned from this topic are similar to those to be learned in other topics such as force and work, and so transferring such information will be important to students later in their studies.

As was mentioned earlier, many physics classes are employing MBL procedures as a way to aid students in learning the material. Within these labs, students have control over the motion of objects and can repeat the procedures easily, however, they have minimal interaction with the data including being provided with the graphs that correspond to the movement.

In this study, MBL procedures will be used in conjunction with text and practice problems to instruct students on the topic of velocity. Some students will experience only the text and problems, others will experience text, problems, and MBL where the graphs are provided for them. The third group will experience text, problems, and MBL but will engage in the generative activity of producing their own graph from the data collected.

As has been discussed previously, the construction of a mental model is completely dependent on the prior knowledge base of the student. The success of MERs depends on the student's familiarity with both the topic and representation while the success of GLT depends on the preconceptions of the student. Further, students' ability to construct graphs is usually high whereas their ability to interpret graphs may be quite

low. How familiar students are with graphs, their ability to construct them, and the instruction they have received previously on graphs will all influence how much cognitive load such tasks will incur and how successfully they will be able to interpret and integrate the information.

Based upon this background, this study will address the following questions:

(1) Do students who generate their own graphs during a laboratory procedure outperform those who receive computer-generated graphs or those students who have no laboratory procedure at all on tests on physics knowledge and problem solving?

(2) Do students who generate their own graphs during a laboratory procedure outperform those who receive computer-generated graphs or those students who have no laboratory procedure at all on tests of graph construction?

(3) Do students who generate their own graphs during a laboratory procedure outperform those who receive computer-generated graphs on follow-up questions dealing with the graph produced within the procedure?

(4) Does the increased time in instruction for the learner-generated students affect performance on outcome measures?

(5) Do students who generate their own graphs during a laboratory procedure outperform those who receive computer-generated graphs or those students who have no laboratory procedure at all on delayed posttests of physics knowledge and problem solving as well as graph construction?

(6) Does difference in grade effect performance on outcome measures?

Chapter 3

Methods

This research investigated the impact of learner- generated graphs during laboratory activities as compared to students given computer-generated graphs and students who receive no graph at all. The study employed a three group experimental design where students within each class were randomly assigned to a treatment.

Subjects

The study began with approximately 120 students, 65 male and 55 female, from a rural school district participating. All participants were in the 8th and 9th grade science classes and varied in ability level. The experiment ran as part of the instruction and thus all students in these classes participated in the instruction. All students were familiar with the equipment involved and knowledgeable of the computer manipulations necessary through prior use and exposure to similar equipment. Use of human subjects protections were fulfilled as monitored by the Pennsylvania State University institutional review board.

The data from participants unable to complete all measures due to absenteeism was excluded from analyses. Some participants were unable to complete all measures due to issues surrounding their Individualized Education Plans or learning disabilities such as reading level. These were students were full participants in the study. however, their data was excluded from analysis. At the time of analysis, data from ninety-nine (99) participants was included.

Design

In order to answer the research question as stated earlier, a 2 (grade) x 3 (treatment) pretest-posttest design was used. There were three treatment groups including, (1) Control,(2) Computer-generated (CG), and (3) Learner-generated (LG) as described below. Students who submitted informed consent forms were randomly assigned to one of three treatment conditions. Random assignment was completed within class to control for potential class effects and ability-level effects.

Pretests. The experimenter administered pretests to measure students' physics knowledge and students' graph construction and interpretation skills. The pretests were used to test equivalence of the treatment groups and were thought to be a possible covariate to increase the power of posttest analyses. Since each measure was developed specifically for this study, reliabilities for each test were determined after administration.

Posttest. The experimenter administered a posttest to measure students' graph construction and interpretation skills and students' physics knowledge. This test was similar in form to the pretests but included questions based more specifically on the covered in the instruction and laboratory activity. Further, the posttest included questions requiring the students to transfer knowledge of the material covered to novel situations. For instance, questions surrounding the topic of Work as a product of force and distance could be used since the relationships are similar to distance, time, and velocity.

Delayed Posttest of physics and graphing knowledge: Two weeks after the completion of instruction, delayed posttest were given to all students. The questions appearing on these tests were a subset of the original posttest with the questions chosen to represent both higher- and lower-order questions as well as both physics knowledge and

graphing knowledge. This was done to determine the stability of any differences between the CG and LG treatments.

Materials

Text. Each student read an excerpt of text taken from the Physical Science textbook from Prentice Hall (Appendix A). This complete text was five pages in length and the main concepts were presented in approximately 850 words. These concepts included motion, speed, velocity, average speed and constant speed. The text also incorporated six figures with captions, one sample problem, and two practice problems, as well as a career-related portion of text that was not required to be read by students.

Laboratory Procedure. Students in the LG and CG treatment conditions were asked to complete a laboratory procedure. The step-by-step procedure (Appendix B) indicated to each student how to manipulate the equipment as well as whether they were to generate a graph or simply print the graph presented to them.

Measures

Physics Knowledge Pretest. Students' initial physics knowledge was measured by a multiple-choice pretest developed by the experimenter (Appendix C). The pretest was developed using questions from the standardized tests corresponding to the textbook from which the text used in the experiment came. To further validate the pretest, two science teachers were asked to evaluate each question for grade level and topic appropriateness. Any discrepancies were mediated and alleviated before the pretest was administered. Before computing the scores, a test for reliability was done. The 35 question test as a whole obtained a Cronbach's alpha of 0.63. However, the pretest was reduced to the 28 most appropriate questions resulting in an alpha of 0.68. Those items removed for

analysis are marked on the test seen in Appendix C and represented a variety of physics topics.

Graph Interpretation Pretest. Students' ability to construct and interpret graphs was measured using a multiple-choice pretest (Appendix D). This 15 question test was developed by the experimenter and was evaluated by two science teachers for grade level and topic appropriateness. Reliability tests for the original pretest produced a Cronbach alpha =0.54, however by removing one item the alpha increased to 0.64. The item removed dealt with transforming a distance versus time graph into a corresponding velocity versus time graph, a relatively difficult task for most students.

The questions on this test were developed based on two separate sources. One of these sources of questions was the Test of Graphing Skills (TOGS) (MacKenzie & Padllia, 1986), an instrument developed to measure the graph construction and interpretation skills of students in grades seven through twelve. The reliability of the TOGS (KR-20) was 0.83 ranging from 0.71 with 8th graders to 0.88 with 9th graders. Item difficulty on the TOGs ranged from 0.21 to 0.84 with an average of 0.51. Results of studies using the TOGS indicated that though students were able to construct graphs, typically students were not able to interpret graphs and held some misconceptions such as graph-as-picture and slope/height confusion.

In addition to those taken from the TOGS, questions for the pretest were also developed based on the results of an informal pilot study completed by the experimenter. A pretest of graph construction and interpretation skills was developed by the experimenter to be given to senior physics students based on knowledge of the TOGS. Though no reliability or validity data exist for these tests, results showed that though

graph construction skills were high, interpretation skills were low and reflected the work of MacKenzie and Padilla including the presence of common misconceptions such as graph-as-picture and slope/height confusion. These questions all focused in the area of graphing in physics whereas the TOGS utilized more general topics.

Graph Construction Pretest. All students completed a graph construction pretest (Appendix E). Through a series of questions, students were asked to appropriately label and plot a graph given a set of data. Cronbach's alpha for this pretest was found to be 0.80. This test was scored on an 8 point scale and included tasks such as choosing the correct axes and appropriate scale for those axes, labeling the axes, plotting the points, and drawing a best fit line.

Immediate Posttest. The immediate posttest was designed to measure both physics knowledge as well as graph interpretation and graph construction skills. All questions developed for this measure focused on the physics domain including the construction and interpretation of graphs for physics problem solving. The 25 question posttest (Appendix F) was divided into two distinct measures based on the two areas of interest, physics knowledge and graphing skills, encompassing both graph construction and interpretation skills. The 10 question physics knowledge test resulted in a Cronbach alpha of 0.58, and the 8 question graphing knowledge test had a Cronbach alpha of 0.45. If one looks at Appendix F, those questions categorized as physics knowledge are marked with a P whereas those on graphing knowledge are marked with a G. Unmarked questions are the items that were removed from the analysis. the items removed include both physics knowledge and graph-related questions as well as higher and lower order questions.

Delayed Posttest. Two weeks after the instruction, a delayed posttest (Appendix G) was given to all students to determine the stability of the results of the immediate posttest and to see if the treatment conditions would differ with time. As with the immediate posttest, the delayed test was divided into two smaller measures based on the type of knowledge being tested, physics or graphing. The results of this separation produced a physics knowledge delayed posttest of 4 questions (Spearman-Brown = 0.504) and a graph interpretation delayed posttest of 4 questions (Spearman-Brown = 0.202). As before, when looking at Appendix G, those questions categorized as physics knowledge are marked with a P and those classified as graph interpretation are marked with a G.

Delayed posttest of graph construction: A delayed posttest of graph construction skills (Appendix H) was given to determine if the treatments had any effect on the students' ability to construct graphs. This test was scored on a 7 poinnt scale including tasks such as choosing the correct axes and appropriate scale for those axes, labeling the axes, plotting points, and drawing a best fit line. Reliability tests for this posttest produced a Cronbach alpha of 0.80.

Short answer questions. For both the CG and LG treatments, four short-answer questions appeared at the end of the laboratory procedure (Appendix B). These questions dealt with interpretation of the data and the relationships involved in the graph resulting from the procedure.

Time in Instruction: The time for each student to complete the laboratory procedure was documented by having the students record start and stop times on the procedure page (Appendix B). This was done with the expectation that there would be

differences in time to complete the task due to the difference in the treatment, specifically those students who generate their own graphs would take more time than the students who print the graph provided by the computer.

Treatments

In all three conditions, students were asked to take three pretests, read a text based on the appropriate topic, and take a posttest.

Control. The control group's instruction consisted solely of the text and practice problems within the text (Appendix A). First, students were asked to complete the reading and solve the problems at their own pace. Next, the students were given a second chance to read the material, but were not asked to answer the problems again. Finally, students were asked to take the posttest as described in the Measures section above. Given that this study was being run as part of the classroom instruction, these students were given the opportunity to complete the same laboratory procedure as the LG group (described below) after completing the posttest for the study.

Computer-generated. The CG group was asked to read and study the text and complete the practice problems within the text, the same as the control group. After completing this at their own pace, the students were then asked to complete a laboratory procedure (Appendix B). During this procedure, students were able to print out computer-generated graphs of the data collected by the computer. There were four short-answer questions at the end of the procedure for which students could refer to the generated graphs. Finally, these students were asked to complete the posttest as described above.

Learner-Generated. The LG group read and studied the text and completed the practice problems within the text, just as was done in the other treatments. After completing this at their own pace, the students were asked to complete a laboratory procedure (Appendix B). During this procedure, students were asked to generate their own graphs using the data collected by the computer. The graphs were then available for use when answering the four short follow up questions at the end of the procedure. Finally, the students were asked to complete the posttest as described above.

Procedure

Before beginning instruction, students who have returned informed consent forms were randomly assigned to treatment groups. Also, all students were asked to complete the pretests as described in the Measures section above.

To begin instruction, all students were asked to read an excerpt of text on the relationships of distance, time, and velocity taken from Prentice Hall Physical Science, a textbook used in many 8th and 9th grade physical science classrooms (Appendix A).

After reading the text and completing the practice problems, students in the CG and LG treatment conditions were asked to work individually to complete a laboratory procedure (as described above) demonstrating the relationships discussed in the text. Step-by-step instructions for completing the procedure were provided for each student depending on group (Appendix B).

Due to the lack of computer equipment as well as differences in the procedure for each treatment group, there were times when students were done with their tasks for the day but still had class time remaining. A schedule for task completion was developed, as

seen in Table 1 below. During the times where no task related to the experimental procedure was being completed, students did one of the following tasks:

(1) Write a short essay, approximately two paragraphs long, to describe why physical science is important to every day life.

(2) Read through the articles in the InDemand magazine provided. Choose one career dealing with Energy that interests you and answer the following questions:

a. What are the main duties/responsibilities of this job/career?

b. What type of education/training is required for the job/career?

c. Why did you choose this career? What do you like/dislike about it?

Table 1

Task Completion Schedule

	Day				
	Monday	Tuesday	Wednesday	Thursday	Friday
Group					
C	Pretests	Read/Problems	Read/Filler	Posttest	Lab
CG	Pretests	Read/Problems	Lab/Filler	Lab/Filler	Posttest
LG	Pretests	Read/Problems	Lab/Filler	Lab/Filler	Posttest

It is the purpose of the investigation as described above to explore the impact of learner-generated graphs during laboratory activities and answer, at least in part, the following research questions:

(1) Do students who generate their own graphs during a laboratory procedure outperform those who receive computer-generated graphs or those students who have no laboratory procedure at all on tests on physics knowledge and problem solving?

(2) Do students who generate their own graphs during a laboratory procedure outperform those who receive computer-generated graphs or those students who have no laboratory procedure at all on tests of graphing knowledge?

(3) Do students who generate their own graphs during a laboratory procedure outperform those who receive computer-generated graphs on follow-up questions dealing with the graph produced within the procedure?

(4) Does the increased time in instruction for the learner-generated students affect performance on outcome measures?

(5) Do students who generate their own graphs during a laboratory procedure outperform those who receive computer-generated graphs or those students who have no laboratory procedure at all on delayed posttests of physics knowledge and problem solving as well as graphing knowledge?

(6) Does difference in grade effect performance on outcome measures?

Chapter 4
Results

Pretest Analyses

A 2(grade) x 3(group) ANOVA was used to test for pretest differences between experimental conditions and grades. There were no significant differences found for the physics knowledge pretest among the treatments, F (2, 93) = 0.80 or between the grade levels, F (1,93) = 1.2. Similarly, no significant differences were found for graph construction pretest among the treatments, F (2,93) = 0.21 or between the grades F (1,93) = 1.1. No treatment by grade-level interaction was found for either test. A summary of these analyses can be seen in Table 1. Means and standard deviations for these tests by grade can be seen in Table 2.

Table 1

Summary of the Analysis of Variance for Pretests of Physics Knowledge and Graph Construction

	Physics Knowledge			Graph Construction		
Source	df	MS	F	df	MS	F
Treatment	2	14.4	0.80	2	0.96	0.21
Grade	1	21.9	1.2	1	5.2	1.1
Treatment x Grade	2	4.4	0.25	2	0.13	0.28
Error	93	18.1		93	4.6	

Table 2

Means and Standard Deviations for Pretest Measures

Measure (total number of questions)	Treatment C			CG			LG			Total	
	Mean	(SD)	n	Mean	(SD)	n	Mean	(SD)	n	Mean	(SD)
Physics Knowledge (28)											
8	10.1	4.4	14	10.7	4.1	14	11.1	4.9	14	10.7	4.4
9	10.6	3.9	18	12.5	3.5	21	11.8	4.9	16	11.7	4.1
Combined	10.4	4.1	32	11.8	3.8	35	11.5	4.8	30	11.2	4.2
Graph Interpretation (14)											
8	6.4	2.6	14	6.6	2.3	14	5.5	2.7	14	6.2	2.5
9	5.7	2.9	18	7.5	2.6	22	8.1	2.2	16	7.1	2.7
Combined	6.0	2.7	32	7.2	2.5	36	6.9	2.7	30	6.9	2.7
Graph Construction (8)											
8	6.3	2.5	14	6.5	2.3	14	6.7	1.6	14	6.5	2.1
9	5.9	2.3	18	6.0	1.8	22	6.2	2.3	16	6.0	2.1
Combined	6.1	2.4	32	6.2	2.0	36	6.4	2.0	30	6.2	2.1

For the graph interpretation pretest, the results indicated no difference between the grades, $F(1,93)=1.30$, or a difference between the treatment groups, $F(2,93)= 1.43$. However, there was a significant treatment by grade interaction, $F(2,93) = 3.2$, as can be seen in Figure 1. Summaries of these analyses can be seen in Table 3. Means and Standard Deviations can be found in Table 2 above. As Figure 3 indicates, the ninth grade, LG students scored significantly higher than the ninth grade control group,

resulting in a Cohen's D effect size of 0.94. However, LG students scored lower than all other eighth graders, Cohen's D = 0.4.

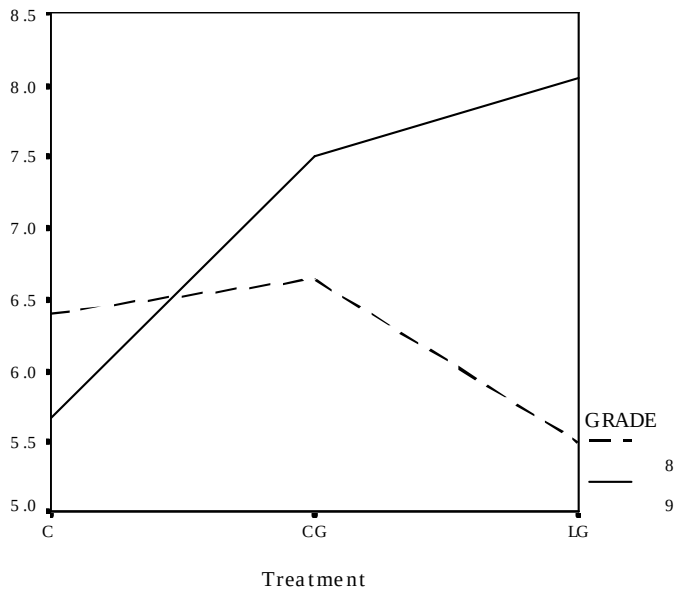

Figure 1. *Grade by Treatment Interaction for Graph Interpretation Pretest*

Table 3

Summary of the Analysis of Variance for Pretest of Graph Interpretation

Source	df	MS	F
Treatment	2	9.5	1.4
Grade	1	19.3	2.9
Treatment x Grade	2	21.2	3.2*
Error	93	6.6	

*p <0.05

Posttest Analyses

Knowledge Posttest. An analysis of variance was used to determine if the treatment had an effect on physics knowledge posttest scores. There were no significant differences among treatments, F (2,93) = 1.5 or between the grades F(1,93) = 0.26. The summary of this analysis can be found in Table 4. As can be seen in Table 5, the means for all groups on this posttest were quite low. Since no overall differences were found, no further analyses on this posttest were conducted including those originally planned to determine if treatment affected ability to solve transfer problems in particular.

Table 4

Summary of Analysis of Variance for Physics Knowledge Posttest

Source	df	MS	F
Treatment	2	6.7	1.5
Grade	1	1.2	0.26
Treatment x Grade	2	2.8	0.62
Error	107	4.7	

Table 5

*Means and Standard Deviations for Physics Knowledge Posttest**

	Treatment								
	C			CG			LG		
Grade	Mean	SD	n	Mean	SD	n	Mean	SD	n
8	5.3	1.7	15	6.2	2.2	14	4.7	2.5	14
9	5.6	2.3	18	5.8	1.7	22	5.5	2.5	16
Combined	5.5	2.0	33	6.0	1.9	36	5.1	2.5	30

*Total Number of Questions = 10

Graphing Knowledge Posttest. Due to the differences on the graph interpretation pretest, an ANCOVA with this pretest as the covariate was used to analyze the effects of condition and grade on the graphing knowledge posttest. This analysis resulted in no differences among treatments, $F(2,92) = 2.4$, or between grades, $F(1,92) = 3.7$, as can be seen in Table 6. The Adjusted means and standard deviations for this posttest can be seen in Table 7.

Table 6

Summary of the Analysis of Covariance for Graphing Knowledge Posttest

Source	df	MS	F
Covariate	1	12.9	7.1*
Treatment	2	4.3	2.4
Grade	1	6.6	3.7
Treatment x Grade	2	1.2	0.68
Error	92	1.8	

*$p < 0.05$

Table 7

*Adjusted Means and Standard Deviations for Graphing Knowledge Posttest**

	Treatment								
	C			CG			LG		
Grade	Mean	SD	n	Mean	SD	n	Mean	SD	n
8	2.1	1.0	16	1.2	0.9	17	1.6	1.7	12
9	2.4	1.8	16	2.0	1.0	23	2.5	1.7	20
Combined	2.3	1.4	32	1.7	1.1	40	2.2	1.8	32

*Total number of questions = 8

Delayed Posttest Analyses

Two delayed posttests were given approximately two weeks after the instruction. The first delayed test was divided into two tests, physics knowledge and graph interpretation. As can be seen in Table 8, an ANOVA, with scores on the physics knowledge test serving as the dependent variable, revealed no differences by treatment, $F(2,93)= 0.14$. There was, however, a difference between grades $F(1,93) = 4.2$. The means and standard deviations in Table 9 indicate that the eighth grade students scored significantly higher than the ninth grade students on this measure.

Table 8

Summary of Analysis of Variance for Delayed Posttest of Physics Knowledge

Source	df	MS	F
Treatment	2	0.16	0.14
Grade	1	4.6	4.2*
Treatment x Grade	2	0.56	0.51
Error	93	1.12	

*p<0.05

Table 9

*Means and Standard Deviations for Delayed Posttest of Physics Knowledge**

	Treatment								
	C			CG			LG		
Grade	Mean	SD	n	Mean	SD	n	Mean	SD	n
8	2.1	1.1	15	2.4	0.8	14	2.1	1.3	14
9	1.7	0.9	18	1.6	1.0	22	1.9	1.2	16
Combined	1.9	1.0	33	1.9	1.0	36	2.0	1.2	30

*Total number of questions = 4

The ANCOVA of graph interpretation delayed posttest scores, again using the graph interpretation pretest scores as a covariate, indicated no significant main effects for the treatment, $F(2,92)= 0.10$. There were however significant grade level differences, $F(1,92)=4.8$, as indicated in Table 10. The means and standard deviations for this test shown in Table 11 indicate that the ninth grade students scored higher than the eighth grade students.

Table 10

Summary of Analysis of Covariance for Delayed Posttest of Graph Interpretation

Source	df	MS	F
Covariate	1	1.7	2.5
Treatment	2	0.07	0.1
Grade	1	3.3	4.8*
Treatment x Grade	2	2.1	3.1
Error	92	0.7	

*p<0.05

Table 11

*Means and Standard Deviations for Delayed Posttest of Graph Interpretation**

	Treatment								
	C			CG			LG		
Grade	Mean	SD	n	Mean	SD	n	Mean	SD	n
8	0.7	0.8	15	1.2	0.8	14	1.2	0.8	14
9	1.7	0.8	18	1.3	0.9	22	1.4	0.7	16
Combined	1.2	0.9	33	1.3	0.8	36	1.3	0.8	30

*Total number of questions = 4

The results of the ANOVA of the graph construction posttest produced no significant differences between treatment groups, F(2,93)=1.1, or between grades F(1,93) = 1.6, as shown in Table 12.

Table 12

Summary of Analysis of Variance for Delayed Posttest Graph Construction

Source	df	MS	F
Treatment	2	4.9	1.1
Grade	1	7.5	1.6
Treatment x Grade	2	10.7	2.3
Error	93	4.6	

*p<0.05

Table 13

*Means and Standard Deviations for Delayed Posttest of Graph Construction**

	Treatment										
	C			CG			LG			Total	
Grade	Mean	(SD)	n	Mean	(SD)	n	Mean	(SD)	n	Mean	(SD)
8	4.9	1.6	15	3.7	2.0	14	4.1	2.4	14	4.2	2.0
9	3.1	2.5	18	3.4	2.2	22	4.6	1.9	16	3.6	2.3
Combined	3.9	2.3	33	3.5	2.1	36	4.3	2.1	30	3.9	2.2

*Total possible score = 7

Laboratory Question Analyses

After completing the laboratory procedure, students in the LG and CG treatments were asked four short answer questions pertaining to the information and graphs involved in the procedure. As shown in Table 14, a significant difference was found between treatments for this measure, $F(1,60) = 18.0$, with the CG treatment scoring higher than the

LG treatment as shown in Table 15. This difference resulted in a Cohen's D effect size of 1.1.

Table 14

Summary of Analysis of Variance for Laboratory Questions

Source	df	MS	F
Treatment	1	18.5	18.0**
Grade	1	0.72	0.70
Treatment x Grade	1	1.2	1.2
Error	60	1.0	

**p<0.01

Table 15

*Means and Standard Deviations for Laboratory Questions**

Group	Mean	SD	n
CG	2.1	1.0	36
LG	1.0	1.0	28
Overall	1.6	1.2	64

*Total number of questions = 4

When looking at the raw data for this measure in conjunction with this large difference between the treatments on this measure, it was though that this difference may stem not solely from how many questions were answered correctly, but how many questions were answered at all. As can be seen in Table 16, students in the LG treatment were less likely to answer the laboratory questions as compared to the students in the CG treatment, $c^2(3,64) = 29.7$, $p<0.01$.

Table 16

Frequencies of the Number of Laboratory Questions Answered by Treatment

	Treatment	
	CG	LG
No. Questions Answered		
0	1	15
1	0	1
2	1	3
3	7	4
4	27	5

Time in Instruction. Differences in time to complete instruction were expected due to the differences in the treatments for the CG and LG groups. Since the LG group was asked to produce graphs using paper-pencil, it was expected that the time to complete the procedure would be higher for that treatment group than the CG students who had graphs provided for them by the computer. An ANOVA on the time in instruction data confirmed that there was a significant difference on treatment, $F(1, 61) = 33.3$, as seen in Table 17. The means and standard deviations for this measure in Table 18 show that the LG group took an average of 15 minutes longer to complete the procedure which results in an effect size of 1.5 (Cohen's D).

Table 17

Summary of Analysis of Variance for Time in Instruction

Source	df	MS	F
Treatment	1	3716	33.3**
Grade	1	144	1.3
Treatment x Grade	1	159	1.4
Error	61	111	

**p<0.01

Table 18

Means and Standard Deviations for Time in Instruction

Group	Mean	SD	n
CG	11.7	6.8	35
LG	26.8	13.8	30
Overall	18.6	13.0	65

Supplemental Analyses

When considering the difference in time between the treatment groups and the inability of the LG students to answer the laboratory questions as well as the low scores on posttests, one becomes concerned that the treatment is not effective in overcoming obstacles to learning such as cognitive load. The results of these measures directs attention back to the previous theoretical discussion on this very concern. When using

multiple external representations, cognitive load is one of the main obstacles to learning, and when asking students to generate their own graphical representations there is an even greater cognitive demand. This may be particularly true if these students have low prior knowledge of these types of representations. Students with less ability in interpreting and constructing graphs are more likely to be hindered in their performance from cognitive load due to the fact that they are more focused on the processes of building the graph instead of using those cognitive resources to understand the relationships evidenced in the graph. On the other hand, those who are considered high ability in graph interpretation and construction should benefit from the use of graphical representations. For those of high ability, the cognitive load issues should not be as much of a concern due to the familiarity these students have with such representations. Instead, the graphical representations should be able to fulfill their roles as MERs such that these higher ability students would be aided by their use.

To investigate the potential ability level effect, additional analyses were conducted on data from students based on their graphing ability. Using a combined score from the graph construction and graph interpretation pretests, students were grouped in thirds. The students who scored in the bottom third were considered low ability on graphing, those in the top third were considered high ability, and those with scores in the middle grouping were identified as average ability.

To test the hypothesis that the treatments may differentially affect students of differing ability, a 2 (grade) x 3 (treatment) x 3 (ability) ANOVA analyzed the immediate and delayed posttest scores of all students. No significant differences were found for the immediate posttests for treatment or grade, as seen in Table 19, however, there was a

significant difference due to ability, $F(2,80) = 5.7$. Tukey post hoc analyses of the means and standard deviations in Table 20 indicate that the high ability students scored significantly higher than the low ability students on the physics knowledge posttest. For the graphing knowledge posttest, post hoc analyses indicate that the high ability students scored significantly higher than the low ability students as well as average ability students.

Table 19

Summary of 2 x 3 x 3 Analysis of Variance for Immediate Posttest Measures

	Physics Knowledge			Graphing Knowledge		
Source	df	MS	F	df	MS	F
Treatment	2	6.9	1.7	2	4.8	2.8
Grade	1	0.88	0.22	1	3.9	2.2
Ability	2	22.9	5.7*	2	11.6	6.2*
Treatment x Grade	2	0.37	0.09	2	2.1	1.2
Treatment by Ability	4	6.0	1.5	4	1.3	0.75
Grade by Ability	2	5.7	1.4	2	2.6	1.5
Treatment by Grade by Ability	4	1.4	0.36	4	0.39	0.22
Error	80	4.0		80	1.8	

*$p<0.05$

Table 20

*Means and Standard Deviations for Posttest Measures by Ability**

	Physics Knowledge			Graphing Knowledge		
Ability	Mean	SD	n	Mean	SD	n
High	5.5	2.0	32	2.2	1.4	32
Average	6.0	1.9	36	1.7	1.0	36
Low	5.1	2.5	30	2.1	1.8	30
Overall	5.6	2.1	98	2.0	1.4	98

* Total number of questions for Physics Knowledge = 10; for Graphing Knowledge = 8.

The summary of the 2 (grade) x 3 (treatment) x 3 (ability) ANOVA for the delayed posttests can be seen in Table 21. The results of this analysis for the physics knowledge delayed posttest indicate a significant main effect for ability, $F(2,80) = 8.6$. The means and standard deviations cam be seen in Table 22. Post hoc analyses indicate that the high ability students scored significantly higher than the low ability students. This analysis also indicates a significant treatment by ability interaction, as seen in Figure 2, as well as a grade by ability interaction, as seen in Figure 3. By inspection of the means and standard deviations in Table 22, one can see that the low ability students in the LG treatment scored below the other two conditions. Post-hoc analyses indicate that the low ability students in the LG condition scored significantly lower than the students in the CG condition. This difference results in an effect size of 1.2. Though not a statistically significant difference, the LG, high ability students scored higher than the other high ability students (Cohen's D = 0.73). Also, inspection of Figure 3 reveals that the ninth grade high ability students scored lower than all other participants whereas the

eighth grade high ability students scored the highest. The effect size for this difference in the high ability students is 1.3 (Cohen's D).

Table 21

Summary of 2 x 3 x 3 Analysis of Variance for Delayed Posttest Measures

	Physics Knowledge			Graph Interpretation		
Source	df	MS	F	df	MS	F
Treatment	2	0.37	0.51	2	0.05	0.07
Grade	1	2.1	3.0	1	3.6	5.2*
Ability	2	6.2	8.6*	2	0.43	0.62
Treatment x Grade	2	0.21	0.29	2	1.4	2.1
Treatment by Ability	4	4.5	6.2*	4	0.37	0.53
Grade by Ability	2	4.2	5.8*	2	1.4	2.0
Treatment by Grade by Ability	4	1.4	1.7	4	1.15	1.7
Error	80	0.72		80	0.69	

*$p<0.05$

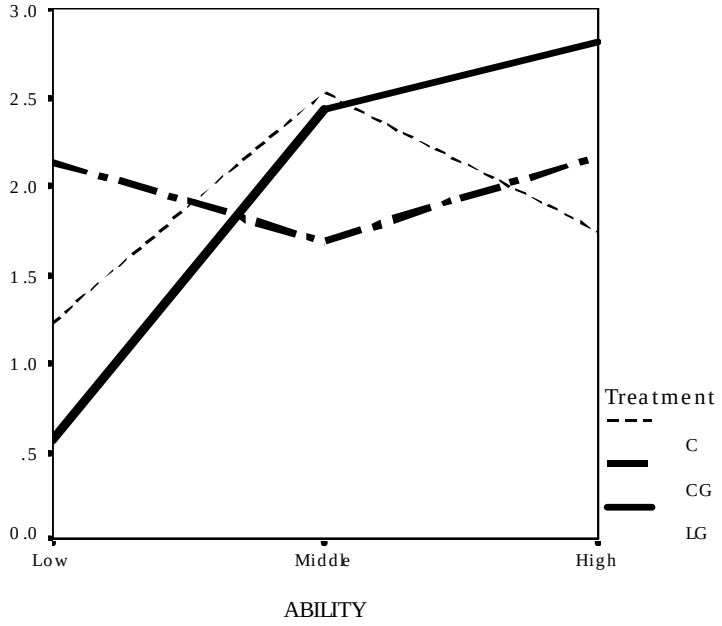

Figure 2. *Treatment by Ability Interaction for Delayed Posttest of Physics Knowledge*.

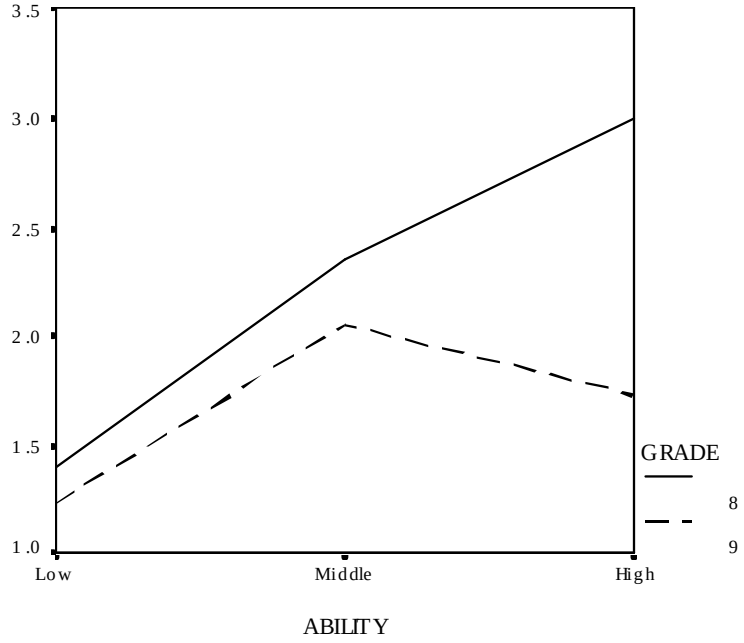

Figure 3. *Grade by Ability Interaction for Delayed Posttest of Physics Knowledge*.

Table 22

*Means and Standard Deviations for Delayed Posttest of Physics Knowledge**

	Treatment											
	C			CG			LG			Total		
Grade	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
8												
High	2.3	1.0	4	2.7	0.8	7	3.4	0.5	5	2.8	0.8	16
Average	2.4	1.2	8	2.3	1.0	4	1.3	1.2	3	2.1	1.2	15
Low	1.0	1.2	2	1.7	0.6	3	1.3	1.0	6	1.4	0.8	11
9												
High	1.3	0.5	4	1.4	0.9	9	2.2	1.0	9	1.7	0.9	22
Average	2.8	0.5	5	1.4	0.9	9	2.5	0.6	4	2.1	0.9	18
Low	1.2	0.7	9	2.5	1.0	4	0.0	0.0	3	1.3	1.1	16
Combined												
High	1.8	0.9	8	2.0	1.0	16	2.6	1.0	14	2.2	1.0	38
Average	2.5	1.0	13	1.7	1.0	13	2.0	1.0	7	2.1	1.0	33
Low	1.2	0.6	11	2.1	0.9	7	0.9	1.1	9	1.3	1.0	27

*Total number of questions = 4

Analyses of the graph interpretation delayed posttest indicated only a significant effect due to grade. The means and standard deviations seen in Table 23 indicate that the ninth grade students outperformed the eighth grade students on this measure.

Table 23

Means and Standard Deviations for Delayed Posttest of Graph Interpretation

Grade	Mean	SD	n
8	1.05	0.85	42
9	1.46	0.83	56
Overall	1.29	0.86	98

*Total number of questions = 4

Summary

The pretests demonstrated that prior knowledge and experience were not significantly different for the grade levels. Treatment groups were also found to be equal for both the physics knowledge and graph construction skills. The one difference found was in graph interpretation. A treatment by grade interaction was found for this test which was then used a covariate for posttests directly related to graphing knowledge.

Looking over the posttest results, it could be said that the treatment had no positive immediate effect. There is a significant difference in time and ability of students to answer the laboratory questions. Further analysis of the laboratory questions demonstrated that many LG students did not answer the short answer questions indicating a difficulty with the task presented to them. This difficulty can also be seen in the overall low scores on the knowledge posttest and the significant changes indicated by the posttest of graphing knowledge.

The delayed posttest of physics knowledge results reflected that the eighth grade students scored higher than the ninth grade students. Graph interpretation, however, was

not effected. This delayed posttest reflected the same pattern as the original posttest with the ninth grade students outperforming the eighth grade students. The delayed posttest of graph construction showed a marked decline in scores as compared to pretest results. This decline was most substantial for the ninth grade students to the point where the eighth grade students now scored significantly higher on this task.

Finally, supplemental analyses based on students' graphing ability suggest that low-ability students score lower in the LG condition than the other conditions. In addition, high-ability students in the LG condition score higher than high-ability students in the other two conditions.

Chapter 5
Discussion

In order to improve students' problem solving abilities, it is first necessary to improve the knowledge structures they possess. It was hypothesized that engaging students in cognitive processes that lead to a deeper understanding of the material would improve the students' knowledge organizations into complete mental models. Two tools thought to be effective in encouraging such processes are multiple external representations and generative learning activities. The results of this particular study did not lend strong support for the hypothesis that these two approaches together would facilitate integration and abstraction of information into a complete mental model. In fact, when looking at the analyses, there is evidence that there may have been several obstacles to integration when using MERs during this task. For this reason, the remainder of this chapter will be a discussion of the issues related to learning in this setting including prior knowledge concerns, the use of MERs in this study, and cognitive load.

Prior Knowledge

Prior knowledge in two different areas was relevant to performance in the experimental setting and participants in this study seemed to be lacking both. These two areas are domain knowledge and knowledge of the representation. As indicated by the low scores on the pretest of physics knowledge, students were not comfortable with the physics domain in general. Participants with low prior knowledge within this domain may have difficulty because these students may not be able to activate the appropriate knowledge with which the new information is to be integrated. This lack of prior knowledge may also cause a problem when trying to interpret the graphical

representations. Even if the students had experience with graphing, gaining the appropriate meaning and relationships would be difficult within an unfamiliar domain.

Graph interpretation scores indicate that students were not familiar with using graphical representations to interpret information and find relationships between variables. Scores on this test indicate that many of the participants held the common misconceptions such as graph-as-picture. Though they were mainly able to construct a graph, they made basic mistakes such as placing the variables on incorrect axes. The combination of the graph interpretation and graph construction results may reflect that they had little experience in the actual use of graphs. Without this experience, the prior knowledge of graphical representations necessary to be successful in this task might be lacking. This may affect the graph construction and interpretation scores for the immediate posttest as well as the delayed graphing posttest scores. Most importantly, if students found graph construction and graph interpretation a problem, then it may be very difficult for the treatment to improve physics problem solving. Students in this case might be focused on the graph construction task at hand and lose the relationship to the physics concepts. Further, difficulty in graph interpretation would hinder students' abilities to discern the relationships necessary to understand the physics concept and would encumber their chances of activating the proper prior knowledge with which to integrate any new information.

Use of MERs and Study Design

In this study, it was expected that the text, physical observations, and graphical representations would work together as multiple external representations. As MERs, it should have been possible for these representations to fulfill their complimentary and

constraining roles (Ainsworth, 1999), aiding students in the process of integration. If this had occurred, students in both the CG and LG conditions would have outperformed the control group on posttest measures. This was not the case, however. Overall, scores did not reflect that students were aided by their use.

Pretest scores of physics knowledge, graph interpretation, and graph construction, all show a lack of familiarity with the subject matter as well as graphical representations. This lack of familiarity may have made it difficult for the MERs to fulfill their complimentary role. In her framework for MERs, Ainsworth (1999) indicates that students can use the representations they are familiar with to aid in the interpretation of the representations they do not understand. In this case, the graphical representations were meant to aid in the understanding of the physics concepts. Unfortunately, the students' struggles with the graphical representations themselves did not allow this to occur. Additionally, though the physical observations were meant to constrain the interpretation of the more abstract graphical representations, this seemingly did not occur. One possible reason for this is that the physical observations were quite short-lived. For example, a student may have only been looking at the cart on the track for less than 3 seconds before data collection was complete. The procedure was *not* repeated and so there was little opportunity for observation to occur.

One intention for using MERs, especially in conjunction with GLT, was the opportunity for the students to experience reontologisation (deJong et. al., 1998; Wittrock, 1994), or resolution of misconceptions, with respect to the concepts at hand. In the case of this study, the notable graph-as-picture and slope/height misconceptions were found for most students at pretest. Considering the low means on the graph interpretation

posttest, it would seem that these misconceptions had gone unresolved. One reason for this may be that misconceptions are very tightly held by the learner (deJong et. al., 1998). Giving students only one short opportunity to resolve any misconception, as was the case with this study, has been show to be insufficient (Osborne & Wittrock, 1983).

Cognitive Load

When using MERs that include graphical representations with which students are unfamiliar, one of the biggest concerns or obstacles to integration is cognitive load. Overloading the working memory of students by asking them to integrate information from multiple sources may be increasingly problematic if the students are not familiar with the representations (Sweller, 1988). For example, the students in the LG condition of this study may have been mired in the details of constructing the graph and therefore could not cognitively cope with trying to find the relationships held within the graphs. The poor scores on the immediate posttests reflect this possibility, but even more evidence can be seen in the results of the laboratory questions and time in instruction. The students in the LG condition took much longer to complete the laboratory procedure than those in the CG condition. This was expected because of the tasks required of them. However, it was expected that part of this time would be spent in answering the laboratory questions including calculating the slope of the graph. For most of the LG students, however, it seems that most if not all of the time difference was spent in building the graph considering that many of the LG students did not even attempt to complete the laboratory questions. This may indicate that the coping costs of the task were so high that these students were not able to place any resources toward answering the laboratory questions.

Further evidence of cognitive load may be seen in the ability level analyses of the immediate and delayed posttests. It is likely that the students most affected by cognitive load on the experimental tasks were those with the least knowledge of graph interpretation and construction. The results of the immediate and delayed posttests all show a trend in this direction with the students in the LG condition scoring lower than the other low ability students. In fact, this difference was shown to be statistically significant for the physics knowledge delayed posttest. This same trend was not seen for the students in the CG treatment, however, and thus suggests that it was the generative activity that may have caused the overload as opposed to the use of the MERs.

Though the generative activity was designed to focus students' attention on the necessary aspects of the graph and to alleviate some of the cognitive load experienced when using MERs, the activity seemed to fail in these respects. If one looks at the generation component of GLT more closely, this result may actually not be that surprising. The generation component first requires teachers to initially generate for the students before asking students to do so (Wittrock, 1994). Given the low pretest scores on graph interpretation and graph construction, this would seem to be an important part of GLT that was not included in this study.

Limitations

There were several limitations to this study that were revealed through inspection of the results. Many of the limitations stem from the practical boundaries of doing natural classroom research impinging on the theoretical constructs to be studied.

First, since the entire study, excluding the delayed posttests, was competed in a one-week time period, it was not possible to modify instruction based on pretest results.

Once the pretests had been analyzed, GLT would indicate that the students should have received explicit instruction in graphical representations, both the construction and interpretation. Had this occurred, the issues dealing with prior knowledge and familiarity with the representation may have been alleviated.

Second, due to lack of computers and interfaces, students were required to rotate through the use of this equipment. Completing unrelated activities while waiting for their opportunity to complete the laboratory procedure may have hindered their ability to connect information learned from text to the information in the laboratory procedure.

Third, the low mean scores on the posttest measures indicate that many students found these tests to be very difficult. In fact, in may be argued that the scores reflect those approaching a floor effect. Together with the low reliabilities of some measures, it should be noted that the treatments may have been successful but the tests may not have been sensitive to the differences due to their level of difficulty.

Finally, given the unreliability of the delayed posttest scores and concerning results of the delayed graph construction posttest, the effort of the students may be in question. If students did not participate in the study with the intention of putting forth their best effort then the results of the measures may be suspect.

Educational Importance

The results of this study illustrate several important points when using multiple external representations in conjunction with generative learning activities.

Too often educators assume that students are familiar with a particular type of representation just because it is well used in the subject matter or field of study in question. This is a large assumption that should not be made. As has been seen

throughout this discussion and evidenced in the results, students have many misconceptions and difficulties with graphical representations, so common in the physical sciences. Students who are not familiar with a representation will not be able to learn effectively using that representation. In fact, they may not attend to that representation at all. Though generative activities have been shown to be effective in focusing the attention of students on the necessary aspects of the desired representation, the same lack of familiarity will again hinder the student from being successful in learning from the activity. If the student is only focusing on the construction of the representation and not the relationships depicted within the representation, then the desired connections will not be generated while completing the task.

Another point of concern stems from the common use of computers in today's science classrooms. It is important to note that just because computers are more efficient for data collection, this does not mean that they will fulfill a role in instruction. Previous studies using MBL reported attributed improved scores to two aspects of MBL: (1) real-time graphing (Mokros & Tinker, 1987) and (2) removal of the "boring data collection" (Brasell, 1987). If this were the case, the students within the CG condition of this study should have outperformed the students in the other conditions on posttest measures. Since this was not the case, it should be considered that it was not these aspects that improved performance but rather the opportunity for repetition and practice of the MBL procedures studied previously that may have accounted for more of the difference.

Also, it is important for educators to realize when students are cognitively overloaded. Students who experience cognitive overload may have a tendency to shut down. Even when time constraints are not placed on completing a task, students who

have to place a majority of their resources toward completing a task may not even attempt to continue once that task is complete. As was the case with the LG condition of this study, many students were unable to attempt the laboratory questions after completing the necessary line graph.

Finally, given the sound theoretical background for using MERs in conjunction with GLT, one should realize that, with the proper instructional supports, students may be successful in learning material this way. As seen in other studies (Van Meter, 2001), students are not necessarily able to use representations solely due to the fact that they are exposed to these representations repeatedly. On the contrary, there must be understanding of how to use these representations in order for the representations to be effective in aiding learning. The trends seen in the delayed posttest data give merit to this idea. Students of high graphing ability were able to benefit from the generation of the graphical representation. Thus, those who have an understanding of the graphical representation are able to use it as an aid to learning the material and building a more complete mental model.

Future Research

Future research in the effectiveness of using MERs and GLT should consider (1) the use of proper instructional supports and (2) the effect of the treatment on higher-level versus lower-level questions.

Specifically, researchers in this area need to look at the differences that occur if the students are already familiar with the graphical representation, or if the teacher directly addresses the need to familiarize the students with the graphical representation. In addition, researchers should determine if the treatment is effective when the procedure

is repeated. Ensuring that there is enough equipment available to allow for many students to complete the procedure simultaneously will allow the time necessary for the repetitions to take place. Also, researchers should ensure the appropriate level of difficulty on the measures so that students who put forth their best efforts will obtain scores that reflect what they have learned.

Appropriate use of multiple external representations and generative learning activities should aid in the building of a complete mental model. Based on this theoretical viewpoint, students who benefit from this instruction should show an ability to outperform the others on higher-order cognitive tasks including transfer tasks. So if overall differences are seen between treatment conditions, it would be interesting for future research to determine on what types of tasks the treatment was most effective.

Future research in this area may be helpful in determining how physics instruction and MBL can be designed more effectively to improve physics problem solving.

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Appendix A
Sample Text

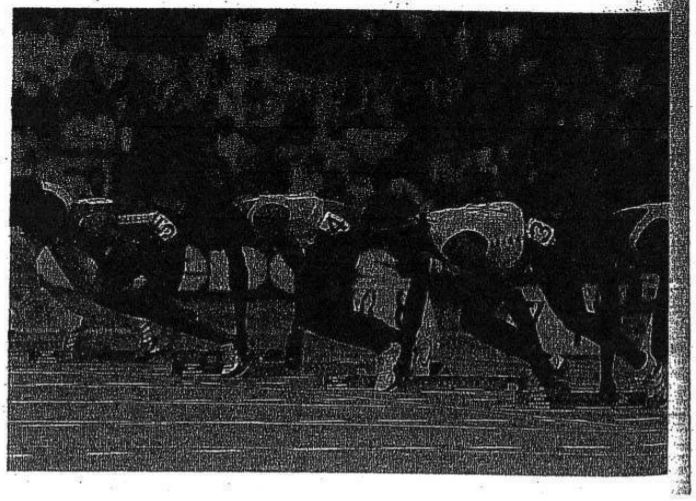
Section Objective

define and calculate speed and velocity

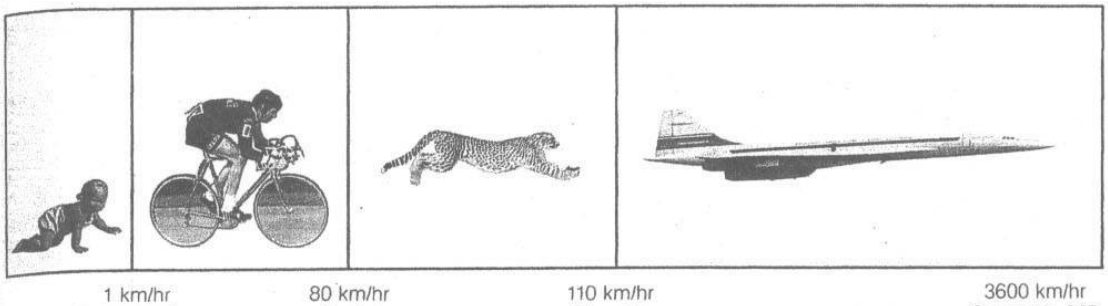
12–2 Speed and Velocity

The runners are poised at the starting blocks. One hundred meters down the track, the timers ready their stopwatches. The starting gun sounds. The timers start their watches as the runners leap from their blocks. Seconds later, the winner breaks the tape and the timers check their watches.

The runners got from the starting blocks to the finish line because they moved, or changed their position. **Motion** is a change in position relative to a frame of reference. The motion of the runners was measured relative to the starting blocks. Motion is measured by distance and time. Distance is the length between two places. In the metric system, distance is measured in meters or kilometers. Time is measured in seconds or hours. In the race, the fastest runner ran 100 meters in 12 seconds.



12–4 *Three seconds after ce began in Cologne, rmany, the lead runner had veled 20 meters. What was her ed at that point?*



1 km/hr
Baby crawling

80 km/hr
Cyclist

110 km/hr
Cheetah

3600 km/hr
Concorde SST

Figure 12–5 *You can compare the speeds of some common objects on this scale. Where do you think your walking speed would fit?*

Speed

Speed is the distance traveled by a moving object per unit of time. You can calculate the **speed** of a moving object by dividing the distance the object travels by the time it takes to travel that distance.

$$\textbf{speed} = \frac{\textbf{distance}}{\textbf{time}}$$

Since distance is measured in meters or kilometers and time is measured in seconds or hours, the units of speed are meters per second (m/sec) or kilometers per hour (km/hr). What was the speed of the winning runner?

Sample Problem

A car travels 300 kilometers in 6 hours. What is the speed of the car?

Solution

Step 1 Write the formula

$$\textbf{speed} = \frac{\textbf{distance}}{\textbf{time}}$$

Step 2 Substitute given numbers and units

$$\textbf{speed} = \frac{\textbf{300 kilometers}}{\textbf{6 hours}}$$

Step 3 Solve for unknown variable

$$\textbf{speed} = \frac{\textbf{50 kilometers}}{\textbf{hour}} \textbf{ or 50 kilometers/hour}$$

Practice Problems

1. What is the speed of a jet plane that flies 7200 km in 9 hours?
2. The speed of a cruise ship is 50 km/hr. How far will the ship travel in 14 hours?

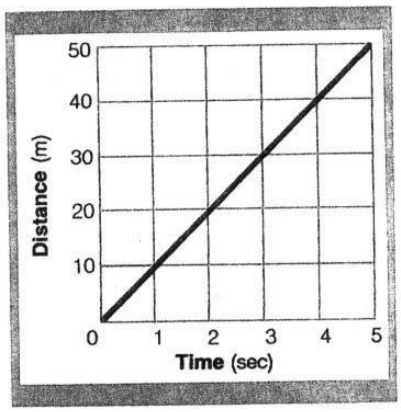


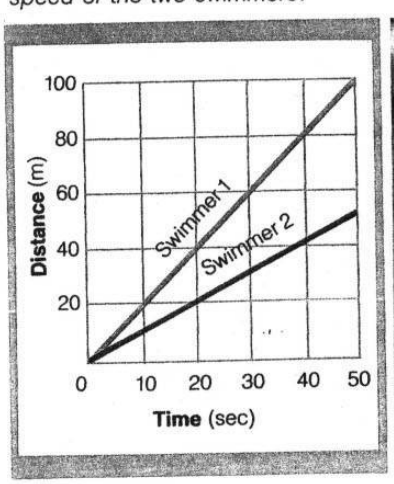
Figure 12–6 *In a distance–time graph, the distance an object travels is plotted as a function of the time it takes the object to go that distance. How do you know that the object whose motion is shown here traveled at a constant speed?*

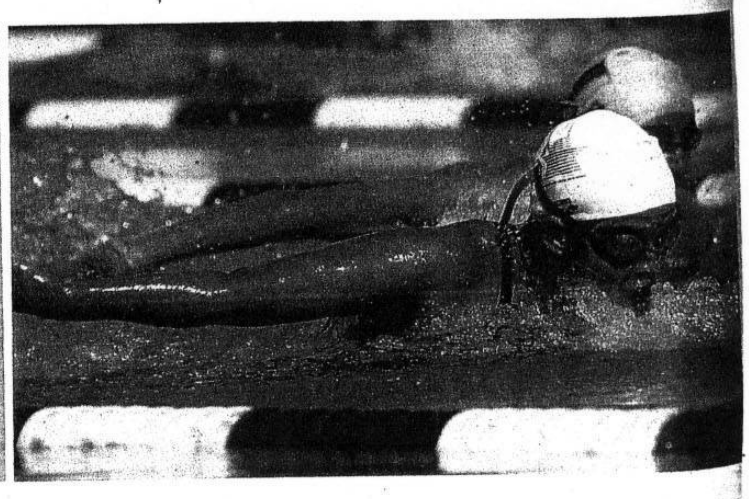
CONSTANT SPEED Figure 12–6 is a distance–time graph of a runner's motion. Distance is plotted on the vertical, or Y, axis. Time is plotted on the horizontal, or X, axis. According to the graph, how many meters did the runner travel after 1 second? You are right if you said 10 meters. The runner's speed was 10 m/sec. After 3 seconds, the runner had run 30 meters. So his speed was 30 m/3 sec = 10 m/sec. The runner's speed did not change. Speed that does not change is called **constant speed.** The speed at any particular instant can be found by dividing distance by time. Notice that a distance–time graph for constant speed is a straight line.

In Figure 12–7, the motions of two swimmers are plotted on a graph. Are the speeds of both swimmers constant? How can you tell? Now use the graph to determine if both swimmers are moving at the same speed. Swimmer 1 swims 100 meters in 50 seconds. So her speed is 100 m/50 sec = 2 m/sec. Swimmer 2 swims 50 meters in 50 seconds. Her speed is 50 m/50 sec = 1 m/sec. Swimmer 1 is the faster swimmer. If you compare the graphs of the two swimmers, you will see that the graph for swimmer 1 has a steeper, or greater, **slope.** The slope of a distance–time graph is directly related to the speed. The steeper the slope, the faster the speed.

AVERAGE SPEED The speed of a moving object is not always constant. Look at Figure 12–8. The distance–time graph describing this motion is not a straight line. According to the graph, after the first

Figure 12–7 *Study the distance–time graphs for the two lead swimmers in this race. Which graph has the steepest slope? What does that tell you about the speed of the two swimmers?*





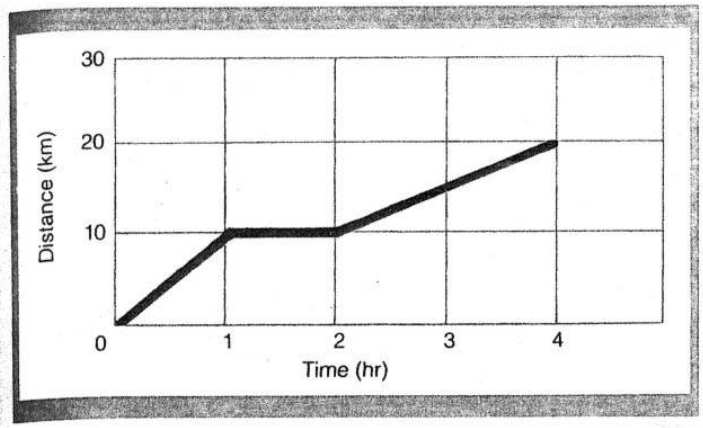


Figure 12–8 *According to this distance–time graph, how far did the object move between the first and second hour? What was the object's average speed after one hour? After two hours?*

hour the speed of the moving object was 10 km/hr. During the second hour, no additional distance was covered. There was no motion. What happened during the next two hours? How did the speed between hours three and four compare to the speed during the first hour? At the end of the fourth hour, the object had gone a distance of 20 km. But as you can see, the object did not move at a constant speed.

Speed that changes is not constant speed. Dividing the total distance by the total time gives the **average speed** and not the actual speed at that instant. What is the average speed of the object in Figure 12–8?

Velocity

"The National Weather Bureau reports that Hurricane Heather is moving east at a speed of twenty kilometers per hour." A weather forecast such as this causes people to worry. But those in the potential path of a hurricane are more concerned about its direction than its speed. They want to know the **velocity** of the hurricane. **Velocity is speed in a given direction.** The speed of the hurricane is 20 km/hr. The velocity is 20 km/hr east, or 20 km/hr E. If the storm suddenly moves north, is the speed the same? Is the velocity the same?

Navigation by land, sea, or air requires precise measurements of velocity. To reach the Hawaiian Islands, a pilot must determine both the direction and speed of the plane. If either measurement is wrong, the plane will not reach its destination.

Sharpen Your Skills

Marble Motion

1. On a level floor or a table top about 1.5 m long, place a 30-cm metric ruler at an incline of about 1.5 cm. Use a book at one end of the ruler to raise it.

2. Roll a marble down the incline.

3. Record the distance the marble rolls from the bottom of the incline along the table top or floor in two seconds. Repeat this procedure two more times.

4. Record the distance the marble rolls in three seconds, again making three trials.

5. On the basis of your observations, answer the following questions:

What is the average distance the marble rolls in two seconds? What is its average speed?

What is the average distance the marble rolls in the third second? What is its average speed during that second?

How does the speed during the third second compare with the speed during the first two seconds?

How can you explain the change in speed?

CAREER — Air Traffic Controller

HELP WANTED: Experienced **AIR TRAFFIC CONTROLLER** to begin work immediately at local airport. Must have controller's license. Person with pilot's license preferred but not necessary.

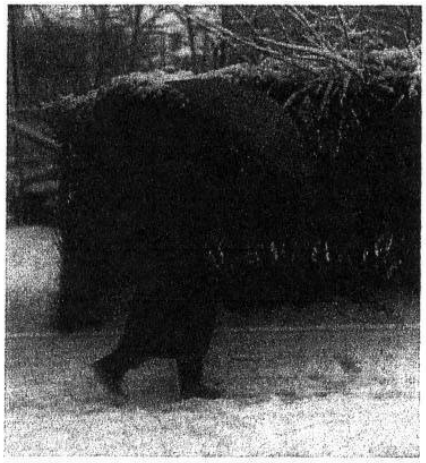
A blanket of fog covers the airport. Aboard a jumbo jet, the pilot studies the cockpit instruments and listens carefully to orders radioed by an **air traffic controller.** The pilot cannot see the runway. The air traffic controller sees the airplane only as a moving dot on a radar screen.

An air traffic controller has several responsibilities. These include directing arriving airplanes, departing airplanes, and airplanes that are in flight between airport destinations. A controller communicates with a pilot by radio, providing the information necessary to keep the airplane safely on its course.

An air traffic controller informs pilots of weather conditions, ground conditions, and suggested routes. The job of an air traffic controller requires a great deal of concentration, steady nerves, and efficient work habits. In order to become an air traffic controller, an applicant must pass a federal civil service exam as well as physical and psychological exams. A college degree is usually necessary.

If you would like to find out how to become an air traffic controller, write to the U.S. Government Printing Office, Library and Statutory Distribution Service, 5208 Eisenhower Avenue, Alexandria, VA 22304. Enclose a self-addressed mailing label and ask for a copy of the publication *Government Careers # GA-300-128.*

Figure 12–9 *When walking into a heavy wind, this person must increase the amount of energy she expends in order to travel at her normal walking speed. Explain why.*



Suppose you are rowing a boat downstream at 16 km/hr. Would it surprise you to learn that you are actually going faster than 16 km/hr? How is this possible? The river is also moving. Since you are rowing downstream, you are going in the same direction as the river. The two velocities combine.

Velocities that have the same direction combine by addition. If the velocity of the river is 10 km/hr, then you are actually moving at 16 km/hr + 10 km/hr, or 26 km/hr.

Velocities that have opposite directions combine by subtraction. If you are rowing 16 km/hr upstream, then you are actually moving at 16 km/hr − 10 km/hr, or 6 km/hr. What would happen if you were rowing at 8 km/hr upstream in the river?

This idea is very important in launching rockets. Rockets are launched in the same direction as the earth rotates. The speed of the earth's rotation is about 1800 km/hr. Thus, the rocket gets an added boost of 1800 km/hr to its speed. That boost is enough to allow the rocket to escape the earth's gravitational force.

Appendix B
Laboratory Procedures

Average Velocity of a Dynamics Cart on a Track. (CG)

Procedure:

Looking at the **Notes window** on the computer, make sure that the equipment at your laboratory station is set in the same way as the picture demonstrates. If there are any problems, please ask the teacher for help.

Start Time: _____

Part 1

1. Place the dynamics cart approximately 20 cm away from the right end of the dynamics track.
2. Click the **Record** button on the screen.
3. Directly after clicking Record, give the cart a slight push toward the photogate.
4. After the cart has traveled completely through the photogate, click **Stop** on the screen and also stop the cart.
5. The **Data table** should now show values for **position** and **time**.
6. The **graph window** should now have a graph **of position vs. time** and should also show the corresponding statistics.
7. Print this graph by choosing **Print Active Display**.
8. Circle **a2** in the statistics, this is the slope of the graph.

Part 2

9. Slightly raise the right end of the track by placing a textbook under that end.
10. Hold the dynamics cart in place about 20 cm from the right end of the track.
11. Click **Record** and then let go of the cart.
12. After the cart has traveled completely through the photogate, Click **Stop** on the screen and also stop the cart.
13. The **Data table** should now show values for **position** and **time**.
14. The **graph window** should now have a graph **of position vs. time** and should also show the corresponding statistics
15. Print this graph by choosing **Print Active Display**.
16. Circle **a2** in the statistics, this is the slope of the graph.

Questions:

1. What are the units on position? time?
2. What does the slope of your graph represent?
3. Which graph shows constant velocity? acceleration?
4. Looking at your graphs, describe the relationship between distance, time, and velocity?

Stop Time: _____

Average Velocity of a Dynamics Cart on a Track. (LG)

Procedure:

Looking at the **Notes window** on the computer, make sure that the equipment at your laboratory station is set in the same way as the picture demonstrates. If there are any problems, please ask the teacher for help.

Start Time: _____

Part 1

1. Place the dynamics cart approximately 20 cm away from the right end of the dynamics track.
2. Click the **Record** button on the screen.
3. Directly after clicking Record, give the cart a slight push toward the photogate.
4. After the cart has traveled completely through the photogate, click **Stop** on the screen and also stop the cart.
5. The **Data table** should now show values for **position** and **time**.
6. Print the data table by choosing **Print Active Display**.
7. Use this data to build a line graph of position vs. time on the graph paper provided. Make sure to label the axes clearly.
8. Find the slope of the graph (make sure to include units) and write it below.

Slope = _____

Part 2

9. Slightly raise the right end of the track by placing a textbook under that end.
10. Hold the dynamics cart in place about 20 cm from the right end of the track.
11. Click **Record** and then let go of the cart.
12. After the cart has traveled completely through the photogate, Click **Stop** on the screen and also stop the cart.
13. The **Data table** should now show values for **position** and **time**.
14. Print the data table by choosing **Print Active Display**
15. Use this data to build a line graph of position vs. time on the graph paper provided. Make sure to label the axes clearly.
16. Find the slope of the graph (make sure to include units) and write it below.

Slope = _____

Questions:

1. What are the units on position? time?
2. What does the slope of your graph represent?
3. Which graph shows constant velocity? acceleration?
4. Looking at your graphs, describe the relationship between distance, time, and velocity?

Stop Time: _____

Appendix C
Pretest of General Physics Knowledge

Individual Number _____ (R = Removed from Analysis)

R1. A graph of distance versus time for an accelerating object is a
a. straight line sloping upward.
b. horizontal line.
c. line curving upward.
d. line curving downward.

2. The basic SI unit of length is the
a. yard.
b. foot.
c. meter.
d. mile.

3 The product of mass and velocity is
a. momentum.
b. acceleration.
c. inertia.
d. weight.

4. The plates that make up Earth's surface move at speeds of
a. kilometers per year.
b. meters per year.
c. centimeters per year.
d. miles per year.

R5. The force holding two atoms together in a molecule is
a. magnetism.
b. gravity.
c. a chemical bond.
d. an electrode.

6. The opposite of evaporation is
a. sublimation.
b. freezing.
c. condensation.
d. melting.

7. To determine the velocity of a moving object, you need to know both its speed and its
a. distance traveled.
b. acceleration.
c. direction of motion.
d. time of travel.

8. When a ball being juggled reaches its highest point, it has
   a. maximum potential energy.
   b. maximum kinetic energy.
   c. 50% kinetic energy and 50% potential energy.
   d. maximum kinetic and maximum potential energy.

R9. Mechanical advantage can be increased by
   a. increasing input force.
   b. increasing output force.
   c. increasing both output and input force.
   d. decreasing both output and input force.

10. The force of gravity acting on an object is known as its
   a. mass.
   b. weight.
   c. density.
   d. inertia.

11. The amount of work done on an object can be increased by
   a. increasing the speed with which the object moves.
   b. decreasing the speed with which the object moves.
   c. increasing the distance the object moves.
   d. decreasing the distance the object moves.

12. The pivot point of a lever is called a
   a. wedge.
   b. gear.
   c. fulcrum.
   d. simple machine.

13. Matter is classified into the two general categories of
   a. solids and liquids.
   b. elements and compounds.
   c. solutions and mixtures.
   d. mixtures and pure substances.

14. The vertical or y-axis of a graph usually shows the
   a. independent variable.
   b. dependent variable.
   c. constant.
   d. timeframe.

R15. According to Boyle's law, when the pressure of a gas increases its volume

a. stays the same.
b. increases.
c. decreases.
d. always doubles.

16. Which of the following is the correct relationship between speed and distance?

a. Speed = Distance x Time
b. Speed = Time x Distance
c. Speed = Distance / Time
d. Speed = Time / Distance

17. A liquid has

a. a definite shape and volume.
b. no definite shape, but a definite volume.
c. a definite shape, but no definite volume.
d. no definite shape or volume.

18. Which energy conversion takes place when steam turns a turbine at a power plant?

a. mechanical to electrical energy
b. thermal to chemical energy
c. thermal to mechanical energy
d. mechanical to thermal energy

19. Which of the following has the highest viscosity?

a. water
b. orange juice
c. salad oil
d. molasses

20. The tendency of an object to resist change in its motion is called

a. inertia.
b. net force.
c. acceleration.
d. friction.

R21. A Ferris wheel moving at constant speed is accelerating because the

a. direction is always changing.
b. wheel moves relative to the ground.
c. wheel moves relative to the sun.
d. the average speed does not change.

22. According to Newton's second law of motion, if the force acting on an object stays the same but the mass of the object increases, then acceleration will

a. stay the same.
b. increase.
c. decrease.
d. become.

23. A wedge or screw is made up of a(n)

a. inclined plane.
b. lever.
c. pulley.
d. wheel and axle.

24. Which of these surfaces has the least amount of friction?

a. sand
b. metal
c. wood
d. ice

25. A group of atoms joined together that act as a unit is called a(n)

a. element.
b. mixture.
c. solution.
d. molecule.

26. Which of the following is an example of a chemical change?

a. mixing sugar into hot tea
b. chopping nuts
c. lighting a match
d. making a puree in a blender

27. In which of these situations is NO work done?

a. lifting a box off the floor
b. carrying a box across the room
c. pushing a box across the floor
d. carrying a box upstairs

R28. An object's mass

a. is the same as its weight.
b. would be different on the moon than it is on Earth.
c. is the amount of matter it contains.
d. is related to its volume.

29. The basic particles from which all matter is made are called
    a. atoms.
    b. molecules.
    c. compounds.
    d. mixtures.

30. An object is in motion when it changes position relative to
    a. the observer.
    b. the sun.
    c. Earth's surface.
    d. a reference point.

31. An object's density is equal to its
    a. weight times its volume.
    b. mass divided by its volume.
    c. volume times its mass.
    d. volume divided by its mass.

32. An example of a chemical change is
    a. cutting paper.
    b. boiling water.
    c. dissolving sugar in hot tea.
    d. burning wood.

R33. The rate at which work is done is called
    a. force.
    b. power.
    c. efficiency.
    d. velocity.

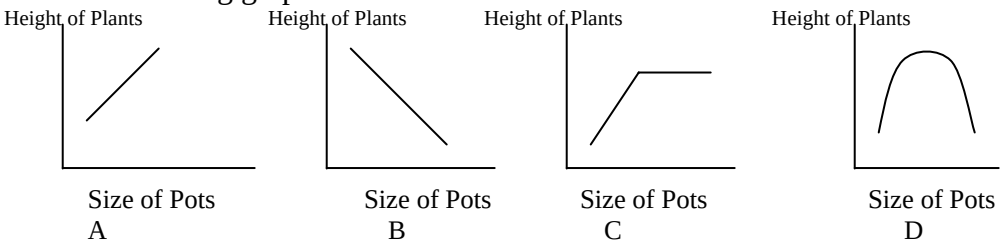
34. To calculate average speed, you need to know
    a. the total distance traveled.
    b. the total time to make the trip.
    c. the total time, speed of travel, and direction of travel.
    d. the total distance traveled and the total time.

35. If force is doubled and distance and time stay the same, then power
    a. stays the same.
    b. is halved.
    c. is doubled.
    d. is quadrupled.

Appendix D
Pretest of Graph Interpretation

Individual Number _____ (R = Removed from Analysis)

Use the following graphs to answer 1 – 2



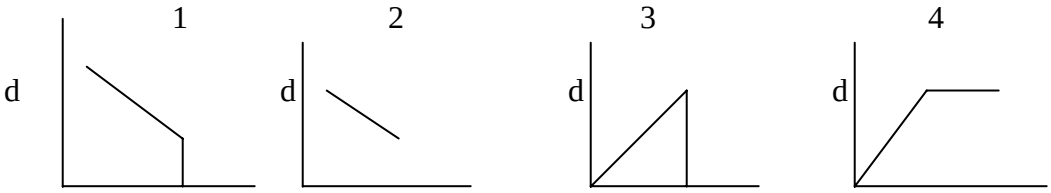
1. Which graph is best described by the statement "As the pot-size increases, the plant height decreases"?

a. A
b. B
c. C
d. D

2. Which of the graphs is best described by the statement "As the pot-size increases the plant height increases up to a certain pot-size. With larger pots, plant height remains the same"?

a. A
b. B
c. C
d. D

Use the following graphs to answer 3

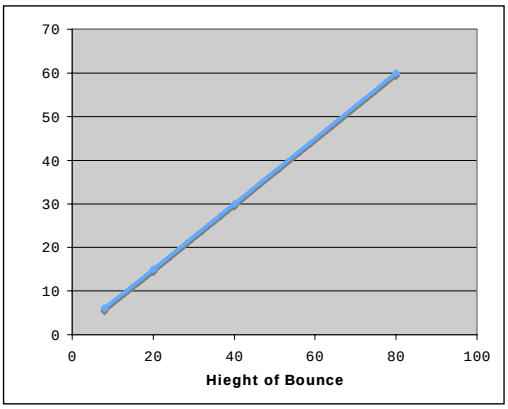


3. Which of the graphs best represents the distance vs. time graph of a person riding a sled downhill and stopping suddenly?

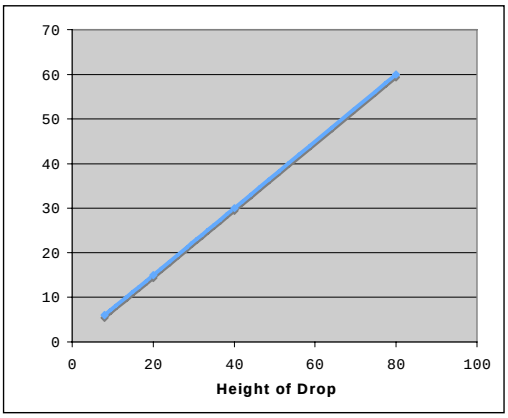
a. graph 1
b. graph 2
c. graph 3
d. graph 4

4. Lisa performs an experiment to determine how the height of a ball's bounce changes with the height from which that ball is dropped. An 8 cm drop produces a 6 cm bounce. When she drops the ball from 20 cm, it bounces 15 cm. A drop of 40 cm produces a 30 cm bounce and a drop a 80 cm produces 60 cm bounce. Which graph below would be produced from this data?

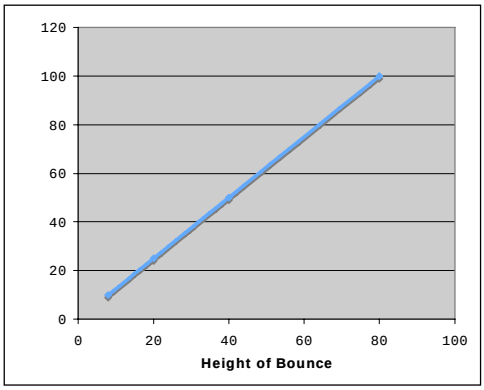
a.



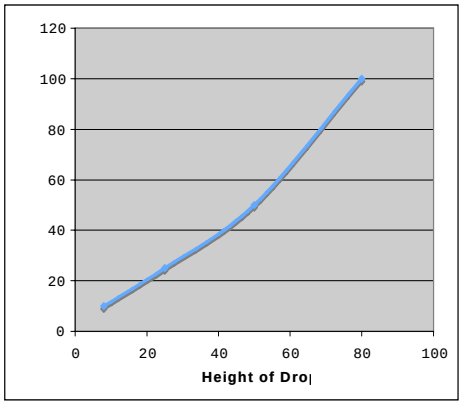
b.



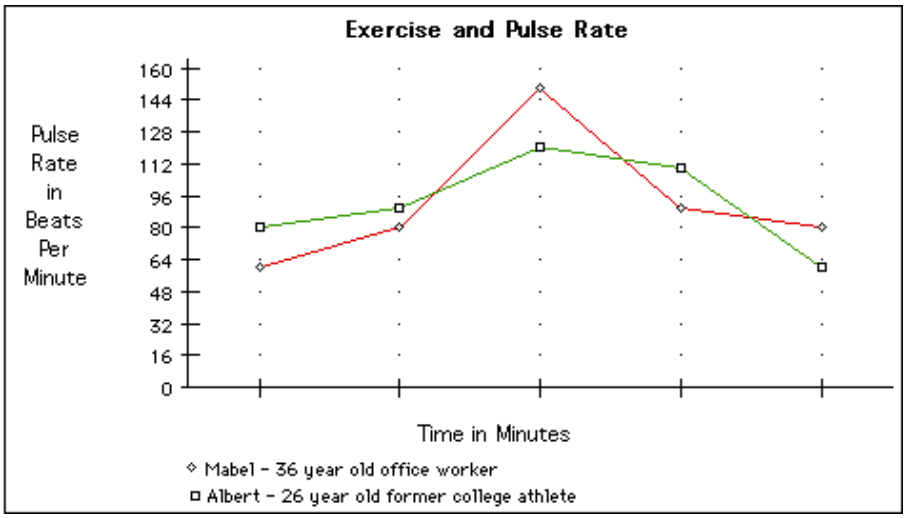
c.



d.



Use the following graph to answer 5-7



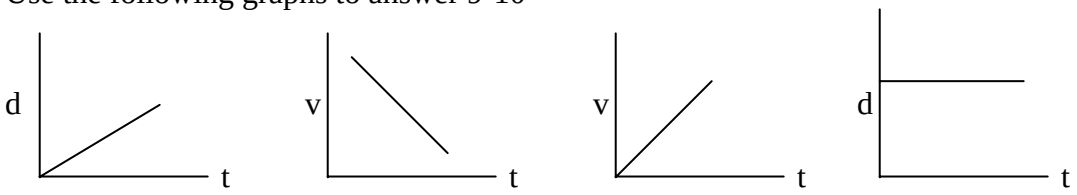
5. What is Alberts's heart rate after 1 minute?
   a.60
   b.80
   c.96
   d.78

6. How much time does it take for Mabel's heart rate to reach 160?
   a.1
   b.3
   c.2.5
   d.5

7. At what time are their two heart rates the same?
   a.1 minute
   b.2.25 minutes
   c.3 minutes
   d.1.5 minutes

8. What was Albert's heart rate at 1.5 minutes?
   a.70
   b.52
   c.48
   d.80

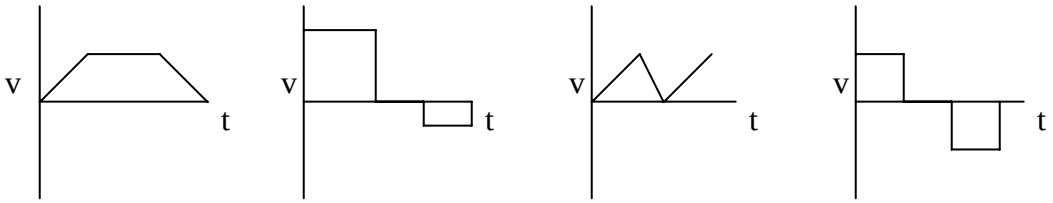
Use the following graphs to answer 9-10



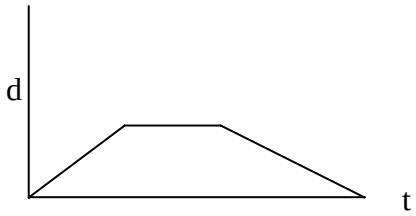
9. Which of the graphs shows an object with constant velocity?
   a. graph 1
   b. graph 2
   c. graph 3
   d. graph 4

10. Which graph shows an object with constant acceleration?
   a. graph 1
   b. graph 2
   c. graph 3
   d. graph 4

Use the following graphs to answer 11



R11. Which of the velocity vs. time graphs corresponds to the following distance vs. time graph?

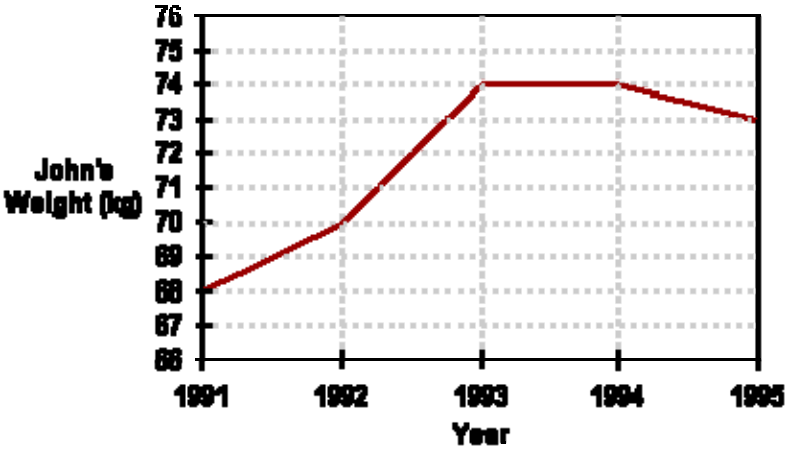


   a. graph 1
   b. graph 2
   c. graph 3
   d. graph 4

12. The x axis of a graph usually represents the
   a. independent variable
   b. constant
   c. dependent variable
   d. counted variable

13. The slope of a graph can be determined by
    a. rise/run
    b. run/rise
    c. change in x / the change in y
    d. change in x * the change in y

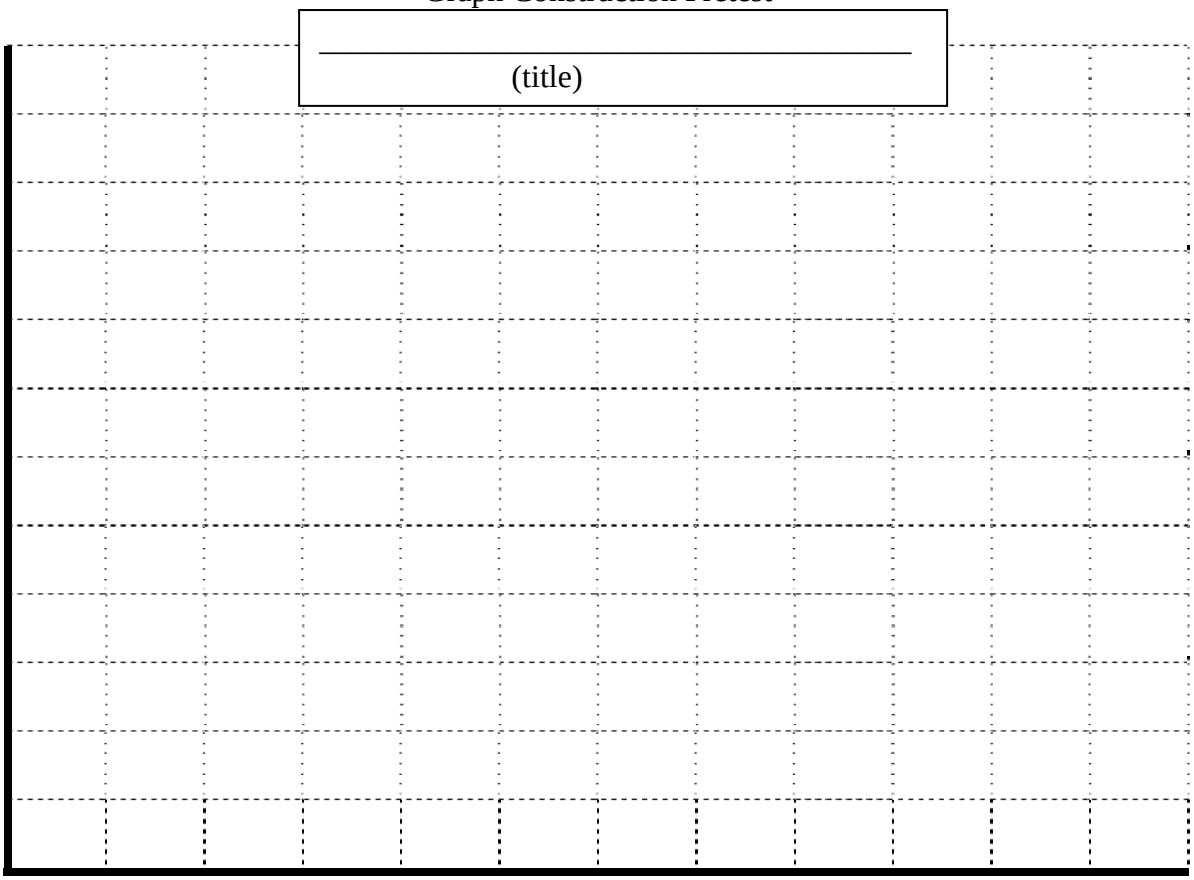
Use the following graph to answer 14 – 15



14. An appropriate title for the graph is
    a. John's weight gain over the past 20 years
    b. Changes in John's weight in the past 4 years
    c. Average male weight gain in the 1990's
    d. John's weight changes

15. In what year was John's weight change the greatest?
    a. 1991-1992
    b. 1992-1993
    c. 1993-1994
    d. 1994-1995

Appendix D
Graph Construction Pretest



Temperature(°C)	Time(sec)
0	5
12	10
24	15
36	20
48	25
60	30

1. Label the x-axis by placing the name of the independent variable on the correct line.
2. Label the y-axis by placing the name of the dependent variable on the correct line.
3. Place appropriate units in the parentheses () next to the labels.
4. Give the graph a title and write it on the “title” line on the graph.
5. Determine an appropriate scale for the x-axis and place the correct number under each tick mark.
6. Determine an appropriate scale fort he y-axis and place the correct number next to each tick mark.
7. Plot all the points on the graph using the data given in the table above.
8. Using a ruler, draw a “best-fit” line on your graph.

Appendix F

Posttest of Physics Knowledge and Graphing Knowledge

(P = Physics Knowledge; G = Graphing Knowledge; Unmarked = Removed from analysis)

Individual Number _____

P1. Which of the following are important in measuring motion?

a. distance, time, speed
b. velocity, acceleration, density
c. distance, volume, speed
d. acceleration, momentum, speed

2. The distance traveled by an object per unit time is called

a. velocity
b. force
c. momentum
d. acceleration

P3. Motion is

a. an increase in the speed of an object
b. a decrease in the speed of an object
c. the stopping of an object relative to a frame of reference
d. a change in position relative to a frame of reference

P4. Find the speed of an object that covers 400 km in 5 hr.

a. 40 km/hr
b. 80 km/hr
c. 2000 km/hr
d. 800 km/hr

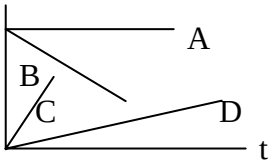
P5. An object with negative velocity

a. is slowing down
b. is traveling downhill
c. is moving back toward from the reference point
d. is moving forward away from the reference point

P6. Velocity is

a. the same as speed
b. the same as acceleration
c. speed in a specific direction
d. the same as momentum

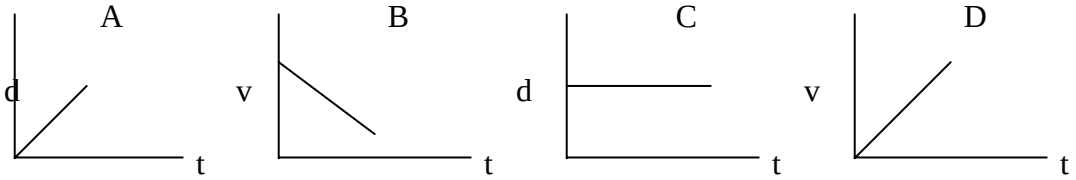
Use the following graph to answer 7



7. Which of the cars represented in the graph is the slowest?
   a. A
   b. B
   c. C
   d. D

8. Acceleration is
   a. the rate of change in momentum
   b. the rate of change in speed
   c. the rate of change in velocity
   d. amount of time needed for an object to reach a destination

Use the following graphs to answer 9 –11



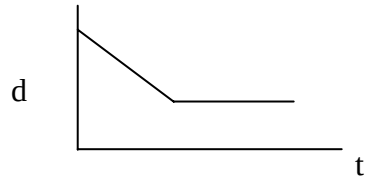
G9. Which of the graphs above shows a positive, constant velocity?
   a. A
   b. B
   c. C
   d. D

G10. Which of the graphs above shows an object accelerating?
   a. A
   b. B
   c. C
   d. D

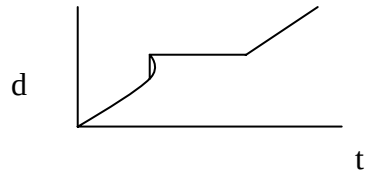
P11. Which of the graphs above shows an object at rest?
   a. A
   b. B
   c. C
   d. D

G12. Which of the following graphs corresponds to the following statement: The person rode her bike down the hill away from the start and then stopped before continuing away at a constant speed.

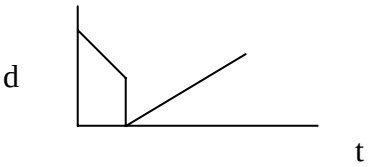
a.



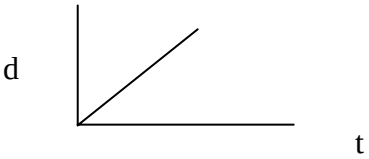
b.



c.



d.



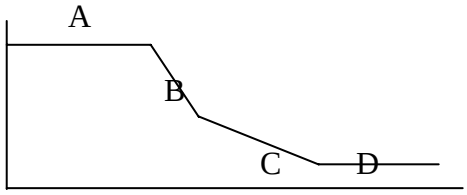
G13. Correct units for velocity would be

a. seconds
b. meters/second
c. hours/kilometer
d. meters

P14.The slope of a distance vs. time graph represents

a. velocity
b. acceleration
c. distance traveled
d. time to reach destination

Use the following graph of the motion of a dynamics cart on a track to answer 15 – 16

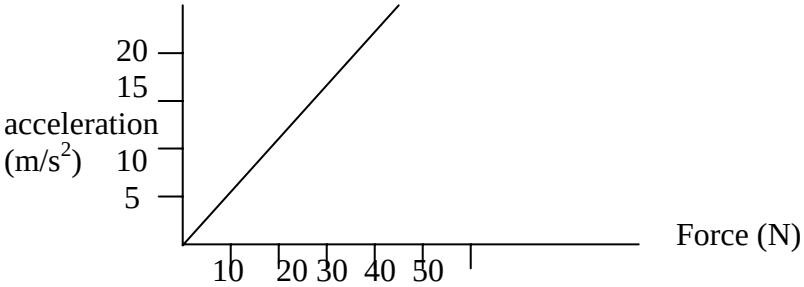


15. Where is the cart furthest from the sensor?
    a. A
    b. B
    c. C
    d. D

P16. Where is the cart traveling the fastest?
    a. A
    b. B
    c. C
    d. D

17. A push or pull on an object is
    a. a force
    b. an acceleration
    c. weight
    d. a change in mass

Use the following graph to answer 18-20



P18. What is the acceleration of the cart if the force is 50 N?
    a. 10 m/s^2
    b. 5 m/s^2
    c. 50 N
    d. 25 $N/m/s^2$

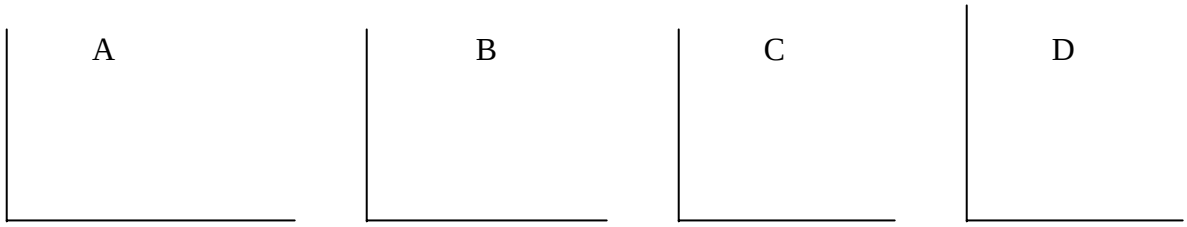
19. What force is needed to produce an acceleration of 20 m/s^2?

a.20
b.35
c.40
d.50

20. If F = ma, what does the slope of the graph represent?

b. Force
c. 1/Mass
d. Acceleration
e. 1/Velocity

Use the following graphs to answer 21-23



G21. A computer plotted a graph of Joe's work as he lifted a mass attached to a sensor. Which graph was plotted from this data?

Work	**Distance**
0.10	50
0.20	100
0.30	150
0.40	200

a. A
b. B
c. C
d. D

P22. What are the units of Work?

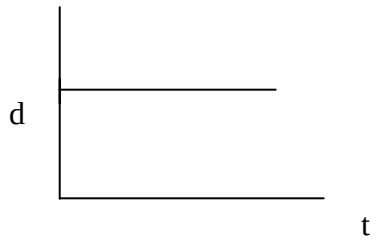
a. N
b. J
c. m
d. m/s

G23. If the slope of the above graph is force, which equation fits best?

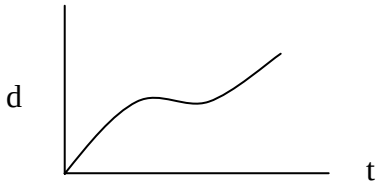
a. W = F/D
b. W / D = F
c. D/W = F
d. W * D = F

G24. Which of the following graphs best describes the motion of a ball rolling across a table?

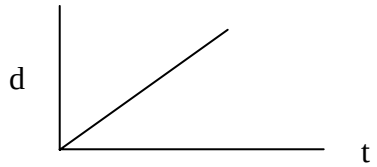
a.



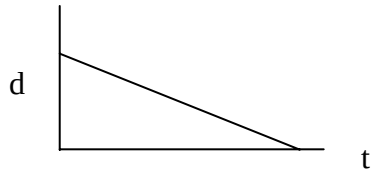
b.



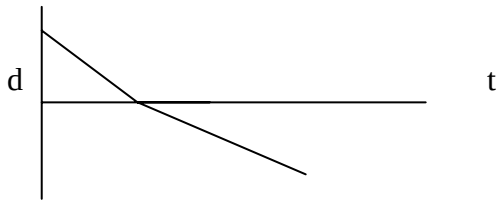
c.



d.

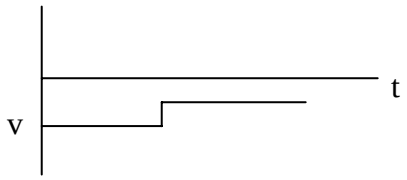


Use the following graph to answer 25.

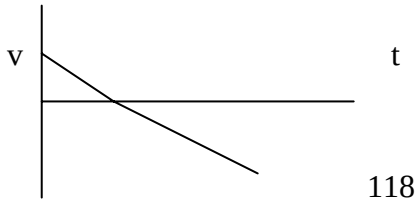


G25. Which of the following v. vs. t graphs corresponds to the above d vs. t graph?

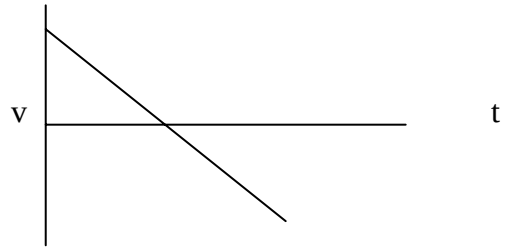
a.



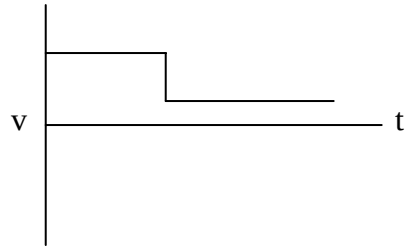
b.



c.



d.



Appendix G

Delayed Posttest of Physics Knowledge and Graph Interpretation

(P = Physics knowledge; G = Graph Interpretation; Unmarked = Removed from Analysis)

Individual Number _____

P

1. Motion is
    a. An increase in the speed of an object
    b. A decrease in the speed of an object
    c. The stopping of an object relative to a frame of reference
    d. A change in position relative to a frame of reference

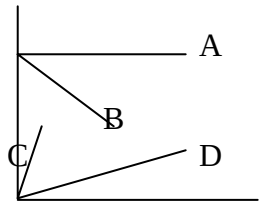
P

2. Find the speed of an object that covers 200 km in 5 hr.
    a. 40 km /hr
    b. 80 km/hr
    c. 1000 km/hr
    d. 800 km/hr

P

3. Velocity is
    a. The same as speed
    b. The same as acceleration
    c. Speed in a specific direction
    d. The same as momentum

Use the following to answer #4

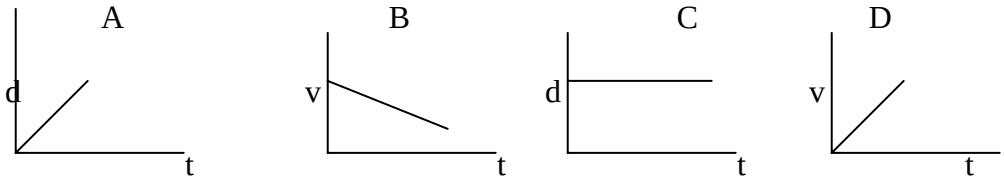


4. Which of the cars represented in the graph is the slowest?
    a. A
    b. B
    c. C
    d. D

P

5. The slope of a line is equal to
    a. The change in x over the change in y
    b. The change in y over the change in x
    c. The difference between x and y
    d. X times Y

Use the following graphs to answer 6 – 7



G

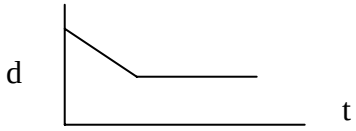
6. Which of the graphs above shows positive, constant velocity?
   a. A
   b. B
   c. C
   d. D

G

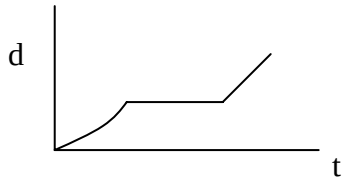
7. Which of the graphs above shows an object at rest?
   a. A
   b. B
   c. C
   d. D

8. Which of the following graphs corresponds to the following statement: The person rode her bike down a hill away from the start then stopped before continuing away a a constant speed.

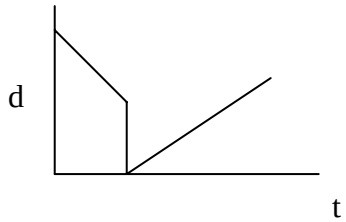
a.



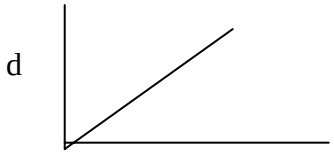
b.



c.



d.



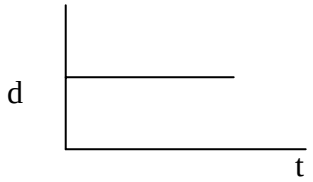
G

9. Correct units for velocity would be
    a. Seconds
    b. Meters/second
    c. Hours/kilometer
    d. Meters

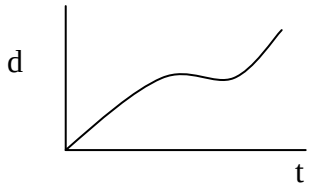
10. The slope of a distance vs. time graph represents
    a. Velocity
    b. Acceleration
    c. Distance traveled
    d. Time to reach destination

11. Which of the following graphs best describes the motion of a ball rolling uphill?

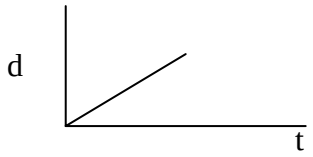
a.



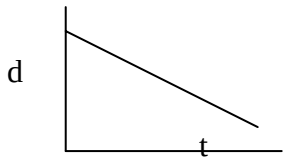
b.



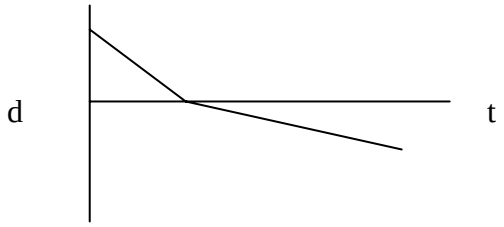
c.



d.



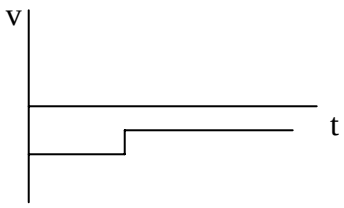
Use the following graph to answer 12.



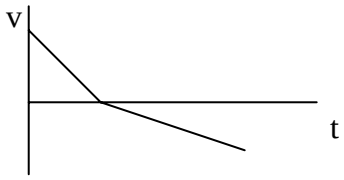
G

12. Which of the following v. vs. t graphs corresponds to the above d vs. t graph?

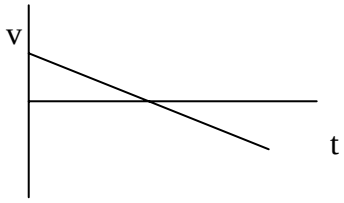
a.



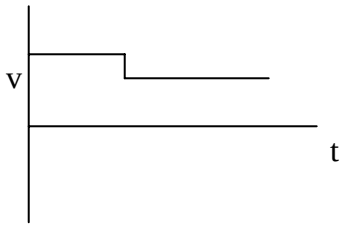
b.



c.



d.



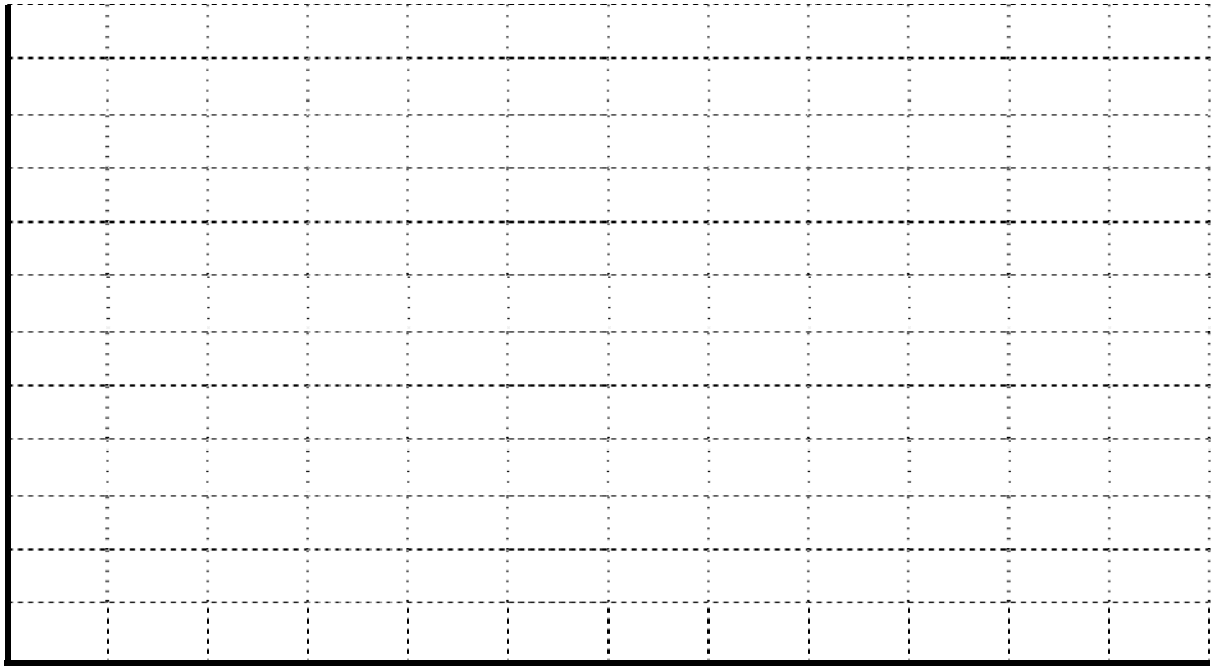
Appendix H
Delayed Posttest of Graph Construction

Joe decides to see how much the motion of an object will change when he places different amounts of force on that object. Using a force sensor and a motion sensor, a computer records the following data for Joe.

Force	Acceleration
5.0	3.45
5.5	3.79
6.0	4.02
6.5	4.36

Use the graphing grid below to make a line graph for Joe's data.

_____ (title)



_____ (x)

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Jan. 1999-Present	*Science Teacher at Juniata Valley High School* Physics, Chemistry, and Physical Science
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PUBLICATIONS

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In progress	The Effects of Varying Laboratory Instruction on Goal Orientation of First Year Anatomy Students