AN INVESTIGATION INTO THE EFFECTS OF COMPLETION PROBLEMS ON THE PERFORMANCE OF INTRODUCTORY PHYSICS STUDENTS

by

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INTRODUCTION

Motivation for the Study

Frequently, the goal of physics instruction is to teach students to independently solve difficult problems that involve multiple concepts. And, it is frequently the case that the students will not have encountered many of the required concepts before attending the class. Often these problems have several conceptual steps that must be connected by the students before they can arrive at an answer. To simplify a problem, or to help guide the student towards the correct answer, difficult problems can be broken up into multiple steps. Each step is presented as a unique question with an answer that is intended to help the student move forward to the next step and eventually reach the correct answer.

Frequently, these multi-step questions are used because the question that the teacher might want the students to answer is too difficult and thus the teacher is giving some scaffolding to assist the student. Students can easily slip into a plug and chug or means-ends problem solving strategy. In the process, students may learn the small individual steps, but without reflecting on the problem as a whole the students' learning is at risk. Most would agree that arriving at an answer is not the value of a homework problem. Rather, learning how concepts are connected and to connect concepts without assistance is the value of homework problems. Furthermore, when a complex problem has been broken into a multi-step problem there is frequently little left for the student to do but a few math steps; the physics has been done for the student by the teacher.

This can further reduce the students' abilities to reach the teacher's intended goal of independently solving difficult problems.

That is not to say there is no value in providing scaffolding for students during the learning process, but if the goal is for those students to solve difficult problems then the homework and the assessments of learning should reflect that goal. The homework needs to provide a platform for the learner to connect ideas and reflect on the process of problem solving. It must also give the learner a chance to practice solving difficult problems with no scaffolding.

How do we train our students to solve difficult problems? In my opinion, there is a need to reflect on both the "how" and "why" certain steps are performed. This allows students to alter their understanding by adding to previous knowledge or correcting previous misconceptions. Frequently, there is a focus on the "how" but little focus on the "why." Some students will take advantage of a multi-step problem and reflect on the process, but many will read through the problem and not make the intended connections. Without some element of reflection there can be a tendency for students to focus on the "how." This is frequently seen in students who simply want to finish an assignment and move on to something else.

In the following chapters I will describe an investigation into one method of encouraging students to reflect on the process of problem solving, which is suggested by a particular model of learning called cognitive load theory. Chapter 2 presents a definition of learning and attempts to distinguish between learning and problem solving. Chapter two also includes a literature review of cognitive load theory. Chapter 3

describes the experiment and the methods used to conduct the investigation. Chapter 4 contains a description of the statistics used to analyze the results of the investigation followed by the results. Chapter 5 finishes with conclusions from the investigation, suggested improvements, and recommendations of how the techniques of our study could be implemented in an introductory physics course.

LITERATURE REVIEW

Definition of Learning

The process of learning is often described as the creation and the modification of schemata (Sweller, 1988). Schemata are an organization of related facts and concepts that can be stored in long term memory and be recalled when needed. Schemata also contain information regarding the interconnectivity of concepts and facts contained within the schemata. For example, a schema could be the information related to the concept of a number, for example the number "four." The schema contains information that the symbol "4" and the symbol "four" are associated with the same quantity. Thus, there is an interconnection between the two symbols the information regarding the interconnection is contained within the schema. Further, the concept of "four" is not associated with a particular object; that is four spoons, four rocks, or four cars are all associated with the schemata of "four." The schema is general and can be recalled to analyze or recognize multiple situations. In the context of problems solving, an analogy can be made between schema and a set of tools. A schema does not only represent a set of tools to solve a problem but also the instruction manual of how to use those tools. Thus as students create and modify schemata they have more tools available to solve increasingly difficult and sophisticated problems.

Creation of new schemata can be accomplished by simply learning new facts, by making new connections between previous knowledge, or making associations between new facts and previous knowledge. The most significant and efficient learning occurs

when the learner is making modifications and or simply adding to existing schemata. The creation of new schemata requires significant effort from students and can result in less efficient learning due to the effort and time required. As learners mature in a particular domain their domain-specific schemata increase in size as well as the number of elements that are interconnected in each schema (Sweller, van Merrienboer, & Paas, 1998). Most importantly, connections between schemata are made. For example, experts understand the concepts such as momentum and energy to be connected but separate. Novices may have no connection between the schemata of momentum and energy and would struggle to solve a problem that required both concepts. Or novices may have only one schema for the two concepts, thus blurring the two concepts into one and thus be unable to use both concepts appropriately to solve a problem.

Central to my definition of learning are the concepts of long term memory and short term memory, frequently referred to as working memory. Long term memory is essentially a storage device. Long term memory is used to store schemata for future recall. There is no construction or modification of schemata in long term memory. Working memory is where schemata are constructed and modified. To quote Sweller, van Merrienboer and Pass (1998), “Working memory can be associated with consciousness.” Working memory is where an individual processes sensory information. It is also where problems are solved and where learning occurs (Baddeley, 1992). The capacity of working memory is significantly limited. Studies have shown that a person can store about 7 elements in working memory (Miller, 1956). Each of those elements can be individual facts or entire schemata. Each schema can be dealt with as an

individual element in working memory and thus several schemata can be in working memory at any one time. Thus, the larger an individual schema is the more information that is available for learning or the problem solving process.

The terms short term memory and working memory are not fully interchangeable. Baddeley (1992) makes an argument that the definition of short term memory is not sufficient to describe the role and responsibilities attributed to short to memory and chooses to use the term “working memory.” The majority of authors cited in this study also use the term working memory rather than short term memory, to be more in-line with the current definition and research I will use the term working memory rather than short term memory.

In addition, working memory is further limited in that it can only work with between 2 and 4 elements at any one time (van Merrienboer & Sweller, 2005). An analogy can be made to having several tools on a work bench. The space on the work bench is limited, but the worker's hands are even more limited. The worker must first put down one tool before he or she can use another. Likewise, a problem solver can only reason with 2-4 schemata or facts at any one time despite having more schemata in short term memory. Elements in working memory from sensory sources need to be refreshed as frequently as every 20 seconds. Elements in working memory that are recalled from long term memory do not have this restriction (van Merrienboer & Sweller, 2005).

Well-developed schemata in long term memory can vastly improve problem solvers’ abilities and learning efficiencies. Using the example above, energy and

momentum can be separate and disconnected schemata for a novice learner and take up multiple positions in working memory. However, for the expert learner both would be contained in one interconnected schema thus using the limited working memory capacity more efficiently than the novice.

Facts transmitted via lecture or from the pages of textbook to a learner can be stored in long term memory. The result is a modification of or addition to long term memory, which is defined as learning. For learning to be meaningful, or for learners to make use of knowledge, the individual facts must be integrated into schemata such that the facts are also interconnected with each other. Otherwise, the learning is largely meaningless. When facts are integrated into schemata the information may then be used efficiently in working memory. Throughout the remainder of this document the use of the term "learning" will be limited to the construction of schemata (meaningful learning) not the simple accumulation of unconnected facts.

Distinction between Learning and Problem Solving

For consistency and clarity, I will use the terms "problem solving" and "solving problems" to describe the act of arriving at a conclusion or a solution to a problem. In this way I wish to differentiate between learning, the construction of schemata, and problem solving, producing an answer. This distinction is central to the motivation of the development of the cognitive theory, cognitive load theory, used in this study (Sweller, 1988).

Problem solving, as I have defined it above, should not be the focus of teaching but rather should be a by-product of our teaching goals. A computer can be programmed to solve a problem (i.e., produce an answer) but few people would argue that the computer is learning. A computer can only do what it has been programmed to do. People can be trained to solve problems, but we must also train or enable our students to solve novel problems. The ability to solve novel problems requires students to learn new ideas and information, this requires students to construct or modify schemata. As the number of schemata that are available to a student increase in number and in sophistication the student becomes capable of solving more problems. By facilitating schemata construction, we hope to provide a new lens to the students with which to view and understand their surroundings so they can ask and answer novel questions.

Below are three hypothetical situations to make a further distinction between learning and problem solving. Learning and problem solving are independent: one can occur without the other occurring.

No Solution and No Learning

It is conceivable to find an environment that is highly distracting and/or such a poorly written introductory level physics problem that even an expert could not easily solve the problem. The expert did not find a solution, the problem was not solved, nor did any learning occur, due to the level of expertise of the expert.

Solution with No Learning

It would be expected that placing an expert in a suitable environment with a well written introductory level physics problem to solve that the expert would easily arrive at a correct solution to the problem. However, with the given the level of expertise no learning, or new schemata construction, is likely to occur.

Solution with Learning

Finally, give a novice a well written introductory level problem in a suitable environment and it is likely that the student is able to come to a solution. If the student is able to arrive at a solution and takes time to reflect on the process the student is likely to have modified or added to schemata.

Returning to the question of how to train our students to solve difficult problems; Cognitive Load Theory (CLT) provides a theoretical framework and vocabulary to discuss and analyze a wide range of aspects involved in the process of learning. The framework allows a discussion of some aspects of the learning process to maximize the potential for a student to be a successful learner. One of these aspects is a meta-cognitive monitoring or reflection on the process of problem solving.

Motivation for the Development of Cognitive Load Theory

Cognitive load theory is a relatively young theory and continues evolve with significant research having occurred since the late 1990's. Below is my view and understanding of cognitive load theory, which may not fully represent the theory as viewed by the developers or current researchers in cognitive load theory. My

interpretation of CLT is admittedly a reductionist view. My focus has been on aspects of the theory that appeared to be immediately applicable to a physics classroom.

Development of Cognitive Load Theory in the 1980's was motivated by the recognition that an individual may arrive at an answer to a problem with little or no schemata construction. Individuals could answer a new question without learning something new. To quote Sweller and Chandler (1991), "Experiments using puzzle problems began to yield disquieting results." Further, there was evidence that traditional problem solving, was not resulting in the desired learning. It was theorized that individuals were subverting their learning by using means-ends strategy to solve problems (Sweller & Chandler, 1991). Means-ends problem solving is a technique that can occur when students know the starting state of the problem and the desired final state. The problem can then be solved by operating on the starting state to change it into the final state with little reasoning or reflection on the process. Each random step must be connected to the previous and then checked to see if a solution has been found. This method works for simple problems, but can quickly overwhelm the working memory if the problem is sufficiently complex. An example of means-ends problem solving can be seen in introductory physics when students are learning the kinematic equations. Students know what variable they are supposed to solve for and then begin to search for an equation or combinations of equations that allow a solution for the variable. In the process, the students use little or no physical reasoning or intuition. The cognitive effort to solve the problem using a means-ends technique reduces the

resources available to create or modify schemata and thus a solution may be found but no learning results. To quote Sweller (1988):

> It is suggested that a major reason for the ineffectiveness of problem solving as a learning device, is that the cognitive processes required by the two activities overlap insufficiently, and that conventional problem solving in the form of means-ends analysis requires a relatively large amount for cognitive processing capacity which is consequently unavailable for schema acquisition.

Thus, applications, resulting from cognitive load theory, are intended to reduce cognitive processing or cognitive load such that there are sufficient resources remaining to allow for schemata creation or modification.

Overview – Initial Hypothesis

Cognitive load theory is based on the work of George A. Miller regarding the limits of human "capacity for processing information." Miller summarizes several previous experiments that investigated the limits of humans to recall information, distinguish between differences in sensory information (different smells, sounds, number of items seen, etc.), and processes information to arrive at a conclusion. Miller's work showed that it was not the amount of information processed that was limited, referred to as "bits," but rather how many "chunks" of data could be processed before errors were made. These "chunks" can be considered as individual schemata. (Miller, 1956).

Cognitive Load Theory also utilizes Baddeley's model for working memory. Baddeley expanded on previous incomplete models of short term memory. He recognized that the previous models of short term memory could not account for all

experimental data: “The term working memory refers to a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning.”Baddeley’s model assumes that there are three parts to working memory: a central executive, phonological loop, and visuospatial sketch pad. The central executive controls the input into working memory and controls the action of the other components. The phonological loop processes auditory information. The visuospatial component processes visual information. The independence, or partial independence, of the visuospatial and phonological loop is fundamental to some applications and predictions of CLT. (Baddeley, 1992).

This theoretical foundation and assertion that learning requires sufficient cognitive resources for schemata creation is the basis of Cognitive Load Theory:

- Working memory is extremely limited in capacity.
- Working memory is responsible for both learning (schemata creation) and problem solving.
- Schemata creation can only occur when the sufficient cognitive resources are available.
- Long term memory is essentially unlimited.
- Long term memory is used solely as storage for facts and schemata for future recall.

Types of Cognitive Load

As depicted in Figure 1, the processing capacity in working memory can be used in various ways, which are described as cognitive loads. Extraneous, intrinsic, germane and meta-cognitive loads are discussed individually in more detail below. The language of CLT gives a simple and concise vocabulary to describe what we are doing to our students and how they are interacting and reacting. The theoretical concepts of the various loads provide new tools to design instruction or at the very least a new lens to view current instruction practices. It should be noted that the inclusion of meta-cognitive load is reasonably new and was suggested by Martin Valcke (2002). The concept of meta-cognitive load has not been fully adopted in the literature, but the concept enhances the discussion of schemata creation and so will be included in this analysis.

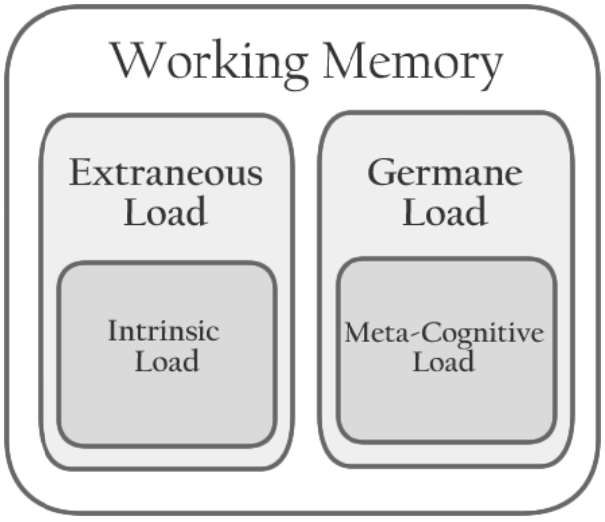


Figure 1 Types of Cognitive Load

Extraneous Load

Extraneous load is defined as cognitive load that is not helping to solve the current problem or to create schemata. Extraneous load can occur from the surrounding environment (noise, motion, etc). It is also related to the format of the problem, which means this does have direct implications for the ways in which we construct the problems we ask our students to solve.

If the problem solver needs to search for information outside of his or her long term memory (e.g., look through the text for an equation) or has to process information from more than one source (visual, auditory, written, pictorial, etc,) this will increase the extraneous load and effectively reduce the capacity of working memory for schemata construction. Visual and auditory working memory, or the phonological loop and visuospatial systems, are only partially independent. A high load from either a visual or auditory source can reduce the capacity of the other (van Merrienboer & Sweller, 2005). Extraneous load can be modified by changing the environment or how information is presented in a problem.

Defining extraneous load is goal dependent. For example, if part of the learning exercise is to learn to integrate or understand different types of notation or representation then the additional load produced by new or difficult representation is not extraneous as it is intended to be a focus of learning. Further, if part of a task is to learn how to use a particular resource then the cognitive load generated by searching through a reference (i.e. a textbook, journal, website, etc) would not be classified as extraneous as that cognitive load is helping to reach the intended goal of the task. This

would suggest that incorporating needed information into a problem or diagram could reduce extraneous load and potentially improve students' performance. For example, in a physics question the numerical value for the mass of electron or charge of an electron may be needed to complete a problem. CLT would suggest that incorporating this information into the problem statement or a diagram would help the students rather than having them search for the information in a text or even on an equation sheet for a test. Further, another implication is that the memorization of equations should reduce extraneous load. The reduction of extraneous load due to the memorization could, if there is a net reduction in extraneous load, result in increased student performance.

Extraneous load is also learner dependent. What constitutes an extraneous load for one individual may not constitute an extraneous load for another individual. The novice learner may need multiple sources of information to help them determine what information is important to solving the problem (i.e. a written description of a problem and a diagram). The expert learner may not need multiple sources; they are able to determine what information is important from one source. For the expert learner, the repetition of sources may cause confusion and result in unnecessary cognitive load. Or, in other words, multiple sources of information may not result in a high extraneous load for novices but can result in a high extraneous load for experts. This effect is often referred to as the "expert reversal effect."

Intrinsic Load

Intrinsic load is defined as cognitive load due to the difficulty of the problem and is a subspace of extraneous load. Intrinsic load increases as the number of concepts or schemata required to solve a problem increase. The number of schemata required is learner dependent. In addition, the degree to which separate schemata are interconnected also affects intrinsic load. The more interconnection between schemata the harder it is to maintain all those schemata in working memory. Or, in other words, the concept is difficult to understand and results in a high intrinsic load. (Sweller, van Merrienboer & Paas, 1998). Simple problems may require 1 or 2 concepts, or more importantly 1 or 2 schemata, thus using only a small portion of the working memory's capacity. The more concepts or schema required to solve a problem the less cognitive capacity remaining for schemata construction.

Intrinsic load cannot be modified, for a given learner, without changing the nature of a problem. The intrinsic load of a problem can be reduced by breaking the problem up into several smaller problems thus possibly changing how many schemata the problem solver must retain in working memory at any one time.

Intrinsic load is learner dependent. As learner matures from a novice to an expert he or she is making connections between concepts and increasing the size of the schemata in long term memory. This results in lower cognitive load since fewer schemata, but the same number of concepts, are required to be brought into working memory from long term memory as the concepts required to solve a problem may be contained all in one schemata.

This is not to suggest that problems should be made as easy as possible to reduce intrinsic load to zero. Rather, problems need to be at an appropriate level of difficulty so that there is sufficient cognitive capacity for schemata construction. If the induced intrinsic load is too large there will not be sufficient cognitive capacity for schemata construction.

Germane Load

Germane load was first introduced by Sweller, van Merrienboer and Paas (Sweller, van Merrienboer, & Paas, 1998). Germane load is the cognitive load due to the problem solving activity and is responsible for the construction of schemata (van Merrienboer & Sweller, 2005). This is the part of the working memory that is solving the problem. Reducing extraneous load, by reducing intrinsic load or removing other distractions, does not automatically increase germane load because the full capacity of working memory does not have to be engaged in all problems. However, a reduction of extraneous load can allow for the possibility of a higher germane load. Germane load is dependent on the type of instruction, type of problem, and the attitude of the problem solver. The amount of available working memory capacity devoted to germane load is largely the choice of the learner, albeit often an unconscious choice. A motivated learner will be more likely to have a high germane load, whereas an uninterested or frustrated student will be more likely to have a low germane load. CLT does not give a prescriptive model of how to increase germane load, thus the art of teaching remains. Forcing the student to be reflective and “think” about the problem they are trying to solve has a tendency to increase germane load. Thus much of research regarding

germane load is around tools and techniques that require the student to be more reflective and less impulsive as they solve a problem.

When there is sufficient working memory available (i.e., the extraneous load is not too great), germane load can be modified by increasing so-called contextual interference. A simple example of low contextual interference is to teach an individual step of a problem solving technique followed by the practicing of that individual step. After practicing the step the next step in the problem solution would be taught and then practiced. This pattern continues until the problem is solved. High contextual interference would be to teach all the steps of problem solving technique then to practice them in a more or less random order. This causes a higher germane load; the student is forced to "think about what they are doing" rather than simply follow an algorithm. Instruction with high contextual interference has been shown to decrease the efficiency of the learning, but has been shown to result in improved performance on retention and transfer tests. (MacGill & Hall, 1990) (de Croock, van Merrienboer, & Paas, 1998). The second of these studies suggested that there was improved schemata construction and higher germane loads.

Germane load can also be increased by requiring students to verbally explain worked examples step by step compared to having the students read the worked examples on there own. A newer but similar technique is to have students work through completion problems, which are partially completed solutions with one or more steps removed. It would be very difficult for a student to correctly finish the remaining step without a relatively high level of understanding of the problem, thus the student has

been forced to be reflective on the problem presented. More recent research has used "fading" in completion problems, that is, as the problem solver progresses more and more steps are left out of the solution with the end goal being the student completing an entire solution given only the problem statement. In addition requiring written explanations of each step of a completion problem improves performance on tests and suggests improved schemata construction.

Meta-Cognitive Load

Meta-cognitive load has been proposed to address the reflective component of learning and is a subspace of germane load (Valcke, 2002). As the problem solver works through a problem they reflect on the processes that are occurring in their working memory. The meta-cognitive load monitors the learning process. (Valcke, 2002). Studies by Van Merrienboer, De Croock, Schuurman and Paas (2002) have shown that students in a "learner-controlled" environment use all available working memory capacity (the portion of working memory not occupied by an extraneous) to process the problem. In other words learners maximize their germane load. In the learner controlled-environment individuals were able to choose different types of problems (completion problems or conventional problems) as they studied. This suggests that as students control or monitor their learning they increase their germane load.

Optimizing Cognitive Load Leads to Maximal Learning

Neither high nor low cognitive loads are ideal for schemata construction. It could be argued that a low cognitive load is good for problem solving as this shows some level of automation and leaves the remaining capacity of working memory for a meta-cognitive load to prevent errors. Van Merrienboer, J.G. Shuurman, de Croock and Paas (2002) showed that test performance was not related to the overall cognitive load, but rather the types of cognitive loads. The best we can do as a teacher is try to optimize our students' learning; to provide an environment that allows the students to learn as much as possible as efficiently as possible. To do this, extraneous and intrinsic loads must be optimized, for the learning goal, to allow for high levels of germane load (including meta-cognitive load). However, if a problem produces too high of a cognitive load, regardless of the type of cognitive load, then the student will experience cognitive overload and will not be able to efficiently construct schemata or be able to solve the problem in a reasonable amount of time, if at all. Cognitive overload also can have a negative effect on the student's attitude which itself can result in low germane load and thus further reduce learning.

Previous Work with Cognitive Load Theory

Early CLT research focused on the reduction of extraneous load. Originally, it was thought that intrinsic load could not be reduced, and this conclusion is still true to some extent. However, a modification of the problem or format of the problem can lead to intrinsic load reduction. Further, with the introduction of the concept of germane load

as critical to learning, new instructional methods are being explored to increase germane load. (van Merrienboer & Sweller, 2005)

Split Attention Effect

In general, techniques such as integrating information sources by, for example, incorporating text within diagram, reduce extraneous load. The source of information is also important to managing extraneous load. A mixture of visual, auditory and text-based sources can optimize the use of the working memory. From Baddeley's model of working memory, it is believed that visual and auditory working memories are partially independent in capacity. Thus, some information presented visually and some information presented verbally may allow a more efficient use of working memory capacity. Overwhelming information in any one source does not allow the problem solver or learner to use all of their working memory capacity. (Sweller, van Merrienboer, & Paas, 1998).

Tarmizi and Sweller (1988) show results that support the hypothesis that having multiple competing sources of information can reduce performance. In one of their experiments students were given step by step assistance as they solved a problem. While this would seem to be helpful, the results showed the students took longer and made more errors. Tarmizi and Sweller argue that the results show an increase in cognitive load, due to the multiple competing sources, and that the increased cognitive load negated the benefits of the assistance. (Tarmizi & Sweller, 1988).

Goal-Free Problems

Problem solvers often employ a means-end technique to solve new problems. This method works for simple problems, but can quickly overwhelm the working memory if the problem is sufficiently complex because this random searching generates a high extraneous load. (Sweller & Chandler, 1991) (van Merrienboer & Sweller, 2005). Moreover, even if the means-end strategy produces a correct solution, it does not assist in schema development and therefore little meaningful learning occurs. One approach to discouraging the means-end strategy is the use of goal free problems. Goal-free problems allow a problem solver to go at their own pace and explore their interests and are not focused on an external goal provided by a teacher. In physics this could be as simple as describing a physical situation, such as a ball on an inclined ramp, defining physical parameters, and then allowing the student to explore and show what they know about the situation.

Work done by Owen and Sweller (1985) with trigonometric problems showed a contrast between typical problems with a stated goal and goal free problems. Their results showed that the students who attempted the goal free problems solved fewer complete problems, solved for more sides of triangles, and had a substantially lower error rate. The students with the goal free problems had an error rate of approximately one-quarter that of the students with the stated goal problems. (Owen & Sweller, 1985). This does suggest that the type of problems used to teach or train students would be different than the types of problems used to assess learning. There are also potential

logistical issues in implementing goal-free problems in courses with large number of students.

Worked Examples

Use of worked examples, which are common in most text books, can result in a lower extraneous load. This is due to the problem solver not needing to employ a means-end strategy. The problem-solver can follow the example without having to recall large amount of information or search additional sources for information. The disadvantage to worked examples is that a learner who tends to be impulsive rather than reflective will likely read through the example without reflecting on the solution. The result is a low extraneous load, but also a low germane load and/or meta-cognitive load. This can result in the problem-solver believing the problem is easy and that they have understood the concepts, yet there was no schemata construction and thus no learning. For a reflective learner, worked examples can be an effective tool to improve understanding. (Sweller & Chandler, 1991) (van Merrienboer & Sweller, 2005).

Cooper and Sweller (1987) show that algebra students who trained on worked examples performed better than students who trained on conventional problems. In addition, they found that the students who trained on conventional problems spent significantly less time training. Further, the students who trained with the worked examples made fewer errors. (Cooper & Sweller, 1987).

It is common in physics to see students quickly look over worked examples and learn little from each example. It is also common for students to ask for more worked examples as a way of studying for tests. One interpretation of these requests is that

students are trying to learn or memorize the solutions to different types of problems rather than learning the concepts tested by the problems. These responses from students can cause a teacher to discount the value of a worked example. It is not that worked examples cannot be a powerful learning tool it is that they are easily misused by students. Cognitive load theory, possibly counter to many teachers intuition or teaching practices, would suggest that worked examples can be a productive and important component of a teaching strategy. The challenge is to manage their use such that students use them effectively.

Completion Problems

Completion problems attempt to address the potential failure of worked examples as an instructional tool. Completion problems are a partial solution to a problem with little or no explanation of steps. A completion problem looks like a "grader's solution;" it is not a thorough solution that might be given to students after an assignment or exam has been returned. The last step or several of the last steps are left incomplete, and the assignment is to finish the problem. This format reduces the extraneous load since the problem-solver has to connect fewer and potentially less distant ideas (van Merrienboer & Sweller, 2005). Further, each step of the problem requires fewer concepts, thus reducing the interconnectivity of schemata and therefore the intrinsic load. Germane load and possibly meta-cognitive load are increased because the learner must understand the early steps in order to complete the last step.

Work has also been done with "fading," that is increasing the amount of a solution that must be filled in by the problem-solver over the time of training or the

course of an academic term. Renkl and Atkinson (2003) examined the effects of fading with completion problems in the domain of physics and math. Their results showed a significant effect size between groups that trained with fading completion problems versus more conventional problems (Renkl & Atkninson, 2003).

It has also been found that having students process a worked example or completion problem verbally greatly improves learning. By explaining their thinking process, problem-solvers are forced to reflect (increasing meta-cognitive load) on the problem and how they are solving the problem. Thus hopefully the problem solver becomes a learner.

Implications of Cognitive Load Theory

Many of the implications of the CLT hypothesis are not new or unique but lend creditability to the theory as an important lens to view instruction. What is somewhat new and unique is that CLT makes testable predictions distinguishing it from some cognitive models.

If learning is defined by the building of schemata and the connections between schemata then prior knowledge is clearly a key part of learning. For an introductory student, the initial vocabulary list of distance, displacement, speed, velocity, etc. can be overwhelming and produce cognitive overload. There is also a tendency to connect these concepts to previous understanding or knowledge. If this is done incorrectly the result is the creation of misconceptions. This is not to say that a student needs to already know something before they can learn it, but rather that learning is most efficient when there is prior knowledge associated with the new knowledge. In terms of

CLT, adding to schemata produces low extraneous and intrinsic loads, compared to the creation of new schemata, thus leaving room for germane load (including meta-cognitive load). Building of new schemata will produce high levels of intrinsic load leaving little capacity for germane load.

A reflective learner is more efficient than an impulsive learner (van Merrienboer & Sweller, 2005) (Valcke, 2002). In terms of CLT, this is about high levels of germane and meta-cognitive loads. Some students may not make the effort to reflect on the problem solving process. For those students who do make the effort, if the extraneous and intrinsic loads are too high then even the hardest working students will not be able to reflect on process of problem solving. Instructional materials need to be designed to increase reflection (i.e. meta-cognitive load) while also facilitating low extraneous and intrinsic loads.

The difference between novice and expert learners is a heavily researched, well documented, and is accommodated in CLT. The expert learner is able to solve more difficult problems than a novice learner. This difference can be explained by the schemata each learner is able to recall from long term memory. As a learner matures, the schemata available to the learner increase in number, size and complexity. There is no increase in working memory as a learner matures, but since the schemata are becoming larger and more complex, more knowledge is available for problem solving. Thus, an expert learner can solve a problem that would overwhelm a novice learner's working memory and result in inefficient problem-solving and reduced learning. This is

due to reduced capacity for germane load and meta-cognitive load and possibly no solution if the problem results in cognitive overload leaving no room for germane load.

Research has shown that some methods that are highly effective for novice learners become less effective and can even become detrimental to more mature learners. For example, extraneous load can be reduced in novice learners by incorporating text into a diagram so that the information can be integrated without searching for information from multiple sources. However, for expert learners the text in the diagram, and even the diagram itself, can become redundant and cause higher cognitive load as the learner tries to understand what is important or necessary. Similar findings have been made with visual and auditory sources. Worked examples and completion problems are instructional methods that can adapt to the expertise of the learner (van Merrienboer & Sweller, 2005). The implication is that a teacher must adapt their techniques and strategies as the learner matures or as the content increases in level of difficulty. This may be particularly true in subjects such as physics where the curriculum tends to spiral; that is, each topic is covered more than once throughout the student's career (i.e. electricity and magnetism are covered in an introductory class and then again in an upper-division class).

EXPERIMENT AND METHODS

Description of Study

The study of the effect of completion problems was done in a Montana State University Introductory Physics classroom. The class was an algebra-based course consisting of three lectures per week designed around a weekly two-hour tutorial. Each lecture is designed to be interactive with the textbook and homework problems written by the professor to both work with and compliment the weekly tutorials. The students normally have their tutorial period after the first lecture and before the last lecture of the week (the middle lecture happens before tutorial for some and after for others). This enables the professor to prepare the students for the tutorial period during the first lecture. The final lecture frequently contains content based on what the students have encountered during the tutorial period. The tutorials are from the series Tutorials in Introductory Physics by the University of Washington's Physics Education Research Group. The tutorials are largely designed around the model that most difficulties students encounter in introductory physics are a result of misconceptions held by the students. Each tutorial has a series of experiments and exercises from which students make predictions or conclusions that must be compared to conclusions made in class, previous tutorials, or results of an experiment. Frequently, a student's conclusion will disagree with a previous understanding and thus the student is forced to address their mistake or misconception. Our study, while not designed to specifically address

misconceptions is compatible with the tutorial model and most of the problems that were modified for our study were originally designed around the misconception model.

There were two sections of the class. Both sections had far greater student populations (n = 115 and n = 75) than past studies done with completion problems. Also, many past studies were implemented in a laboratory setting over much shorter periods of time. The study at Montana State University was conducted over the period of half a semester. One section was a control while the other section was given the treatment. The treatment was given for one unit of the class, a unit being the material covered by one mid-term exam. At the end of the unit the roles of the sections was reversed, the treatment becoming the control and the control becoming the treatment.

In the control section, students were assigned 3 daily homework questions. The following class period the students used iClickers to vote which question they did not want to turn in. A coin was flipped to determine which of the remaining two would be turned in and graded. The question voted to not be turned in was then solved and discussed in class. In the treatment section, one daily homework question was replaced with two completion problems. The question that was replaced was the question that historically was voted off by the students. Thus the replaced question was viewed by the students as the most difficult of the three. A coin was then flipped in class to determine which of the remaining two standard questions would be turned in and graded. The two completion problems assigned for that day were also turned in. Students were not given class credit based on the correctness of the completion problems but rather were given extra credit towards their homework grade for satisfactorily attempting the completion

problems. Determining whether students had satisfactorily attempted a problem is subjective. In this study, credit for attempting the problem was given if at least half of the steps had an explanation and there was some attempt to complete the incomplete step.

Frequently, one of the completion problems was based on the question that was most likely to be voted off by the other section. The second completion problem was designed to complement the rest of the assignment. This was done for two reasons: (1) The format of a completion problem would lend itself to be a solution to a standard question, thus the control group could potentially have a partial solution to the problem they viewed as most difficult. (2) Since the treatment group only had two standard problems they potentially could be disadvantaged by not working through a particular type of question.

Section 1, the larger group, was given the treatment during the unit covering Newton's laws, while section 2 was given the treatment during a unit covering energy and momentum. Both treatment sections were assigned a total of 16 completion problems.

Given the nature and size of our intervention (we are making a small change to the homework while leaving the lectures, exams, and tutorials the same) the size of the effect was not expected to be large. Improvements on unit exams scores of 10-20% would be considered very large. The expectation was that an improvement on the order of 2-5% on unit exams would indicate a positive effect.

Questions to be Answered by the Study

Given the implementation of the completion problems, there are several questions that can be answered from our study:

- Do completion problems improve performance on unit tests for the class as a whole?
- Do completion problems improve performance on unit tests for high, average or low achieving students?
- What level of participation is needed for improvement to be measurable?

Assessment of Student Performance

The exams at the end of each unit were used to measure student performance and thus the effects of the treatment. In addition, the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992), a 30 question multiple-choice test designed to assess students' understanding of Newtonian mechanics, was given during the second class period of the semester and then at the end of the semester during a tutorial period.

The difference between the average score for each section of the first unit exam was used as a base-line to measure effects of the treatment. Thus an increase or decrease in the difference would be assumed to be a result of the treatment. The initial assumption was that the two sections would be statistically equal and the difference in the average scores for the pretreatment unit exam would not be statistically significant.

The FCI provided an extra measure of students' knowledge gained during the second unit as the FCI tests content covered in unit 2 with no overlap of the material covered during the remainder of the semester. The FCI also served as a covariant in a statistical analysis of the final data, as the pre-test FCI is assumed to be a measure of knowledge prior to beginning the class. FCI gain scores are a widely accepted measure of effects of instructional treatments and provide measure of an effect of an intervention (Francis, Adams, & Noonan, 1998) (Hake, 1998).

Explanation of Statistics Used

Many of the results of the study require a comparison of means on unit exams, pretests, and posttests. The simple comparison of means is not sufficient as differences in means could be attributed to random variation. An analysis of variance, or ANOVA test, is conducted to determine a percent chance that two means are different. The ANOVA test is based on the assumption that the data are normally distributed, the data sets are independent, and that the variances are equal. In effect, the ANOVA looks at the resolution of the peaks of the two distributions and gives a percent chance that the means of the two peaks are different. This percent chance is often referred to as the confidence level. The significance level is defined as the chance that the two peaks are different. Their relationship is simply:

$$1 - \text{significance level} = \text{confidence level}$$

A threshold for accepting that two means are different must be chosen before analysis of a study is conducted. A confidence level of 95% (significance p = 0.05) or 99%

(significance p = 0.01) are the most frequently used thresholds. In our results below we have chosen to use a confidence level of 95%.

An ANOVA test can also produce a measure of effect size, referred to as eta or partial eta-squared. Both values give a measure of the variance in the dependent variables that can be attributed to the independent variable. The value of partial eta-squared gives a percent of the variance of the dependent variable that is attributed to the independent variable. In our results below we will use values of eta rather than partial eta squared. According to Cohen (1998) $\eta > 0.10$ represent small effect size, $\eta > 0.24$ are medium effect size and $\eta > 0.37$ are large effect size. In some sense the effect size gives a measure of practical difference in means. There may very well be a statistical difference in means based on an independent variable, but if the effect size is very small the difference may be of little or no value.

An analysis of covariance or ANCOVA was also used in the analysis below. The difference between an ANOVA test and an ANCOVA test is the inclusion of a covariant. The covariant is used, at least partially, to account for initial difference between groups. For example, an initial hypothesis for our study was that the two sections would be statistically similar in performance on the first unit exam. However, in our study there was a significant difference between sections on the first unit exam, which was before the intervention. It is possible that some of the difference between sections could be attributed to differences in prior knowledge, which is partially measured by the pre-test FCI. Thus, the pre-test FCI could be used as a covariant to explain some of the initial differences. The use of a covariant can also have the effect of statistically removing

initial differences between groups and allowing a more straightforward interpretation of the results. Results from an ANCOVA test are interpreted in the same manner as ANOVA results.

RESULTS AND ANAYLSIS

Complete Results and Analysis

The means and standard deviations of all 6 assessments are shown below in tables 1 and 2. Only results from students who had scores for all 6 assessments were included in the analysis. The results are given in the chronological order that the students took the exams. The fourth exam functioned both as a unit exam and as a final covering material since the third unit exam but also contained questions based on material from the three previous unit exams.

Table 1 Means and Standard Deviations for Section 1

	Pretest FCI	**Test 1**	**Test 2**	**Test 3**	**Posttest FCI**	**Test 4**
Average	10.32	62.37	59.37	60.19	17.27	78.56
STDEV	4.11	10.98	11.32	14.20	6.02	17.42
n	115	115	115	115	115	115

Table 2 Means and Standard Deviations for Section 2

	Pretest FCI	**Test 1**	**Test 2**	**Test 3**	**Posttest FCI**	**Test 4**
Average	10.12	65.43	62.57	65.47	18.69	80.35
STDEV	5.40	10.98	10.50	12.88	6.41	18.11
n	75	75	75	75	75	75

The initial assumption was that the two sections of the introductory physics class would be statistically similar and that any difference between the sections would be a result of the intervention. Both sections of the class were taught by the same professor the only difference between the sections was the time of day that the class met. The

two sections intermixed for tutorial periods. The teaching assistants for the tutorials periods were assigned randomly. A one way ANOVA test was conducted to determine if there was a statistical difference between the sections. A value of $\alpha = 0.05$ was used for the tests. The results are shown below in table 3; a negative difference implies that section 1 performed better than section 2.

Table 3 Differences in Test Scores

	Pretest FCI	Test 1	Test 2	Test 3	Posttest FCI	Test 4
Difference in Average (%)	-0.67	3.83	4.00	6.60	4.73	1.79
Significance	0.771	0.041	0.041	0.012	0.122	0.388

As expected, the pretest FCI scores indicate that the sections were identical in their pre-knowledge of Newtonian Physics. However, the results from the first three unit exams show that there is a significant difference between the two sections, also shown in figure 2 below. The results for Test 1 show that there was a difference between the groups before the first intervention. It would appear the classes diverged in their understanding after the pretest FCI was given. In contrast, the results from the posttest FCI and Test 4 show that there is once again no significant difference between the groups (variance of the scores for the pretest FCI is significantly different). These results would suggest that the intervention during the second unit had little impact on the performance of section 1. The results do suggest that the intervention did have an impact on section 2, as seen on unit test, as the difference between the groups

increased by 2.08 or 2.6% which is an effect size that is reasonable considering the size of intervention and the nature of the class. However, further tests need to be conducted to determine if the change can be attributed to random events or is a possible result of the intervention.

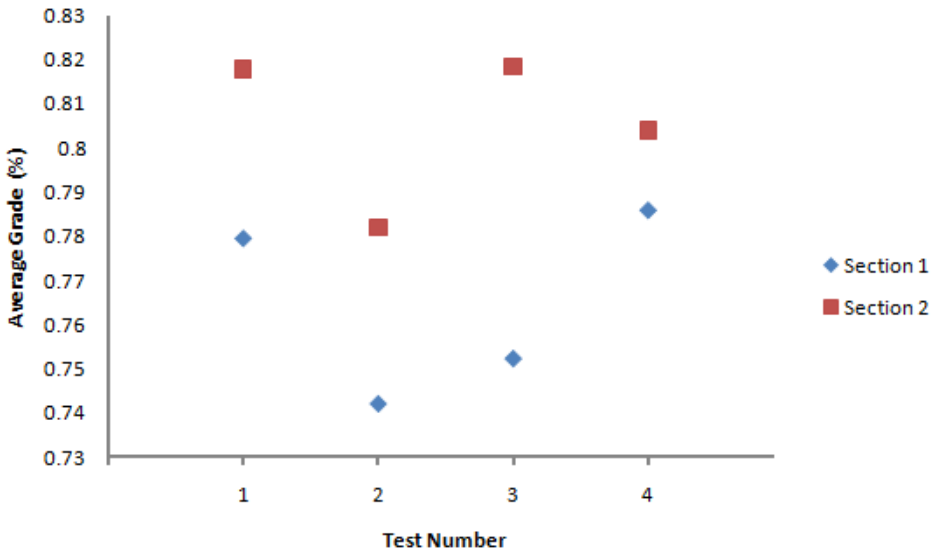


Figure 2 Test Averages by Section

An ANCOVA test was conducted using the pretest FCI as a covariant to try to account for some of the initial differences between sections. Using the covariant produced the adjusted means as show below in table 4. Boxed scores indicate the sections that received the completion problems.

Table 4 Adjusted Means with Pretest FCI as Covariant

	Test 1	Test 2	Test 3	Test 4
Section 1	62.31	59.31	60.13	78.55
Section 2	65.52	62.70	65.56	80.50
Difference (%)	4.01	4.24	6.79	1.95

The significance was recalculated along with values for effect size (eta squared) and observed power. The results are shown in table 5 below. The results of the ANCOVA show that there is still a significant difference in the means between the sections on the first three unit exams. Again there is not a significant difference between sections on the final exam.

Table 5 ANCOVA Results with Pretest FCI as a Covariant

	Test 1	Test 2	Test 3	Test 4
Significance	0.038	0.031	0.006	0.432
Eta	0.152	0.158	0.198	0.055

According to Cohen, values of eta greater than 0.10 and less than 0.24 are considered to be small effects. The eta values, for the first three tests, indicate that the section a student attended played a small, but possibly significant, role in the score on tests.

The interpretation of the results is difficult due to the initial differences between the two sections. While there is a significant difference between the two groups for the

first three unit exams it is still unclear if the increase in the difference from test 1 (and from test 2) to test 3 is due to the intervention or to random chance. The increases in the values of eta imply that the section a student attended had a larger effect on test for test 3 than for the other tests. Overall the results are suggestive but inconclusive.

The results leave two questions unanswered. First, did the completion problems help the students? Second, are there groups of students that were helped and other groups that were not helped by the completion problems? To attempt to answer these questions the students were blocked into six group based on their pretest FCI scores. The table 6 below shows the divisions of the groups and group size. The assumption is that pretest FCI scores give some measure of the knowledge an individual has before the class.

Table 6 FCI Groups and Group Size

	FCI Group 1	**FCI Group 2**	**FCI Group 3**	**FCI Group 4**	**FCI Group 5**	**FCI Group 6**
Pre FCI Score	0-5	6-10	11-15	16-20	21-25	26-30
Number in Section 1	13	47	45	8	2	1
Number in Section 2	15	31	17	10	1	0

The group size for FCI group 5 and 6 are small; results from these groups will not be considered in the analysis. The group sizes for FCI group 3 are significantly different and potentially could influence the interpretation of the results for FCI group 3. The percent differences between groups based on FCI group are shown in table 7 and figure

3 below. Percents were used because tests 1, 2 and 3 had different totals from test 4. Negative differences imply that section 1 performed better than section 2.

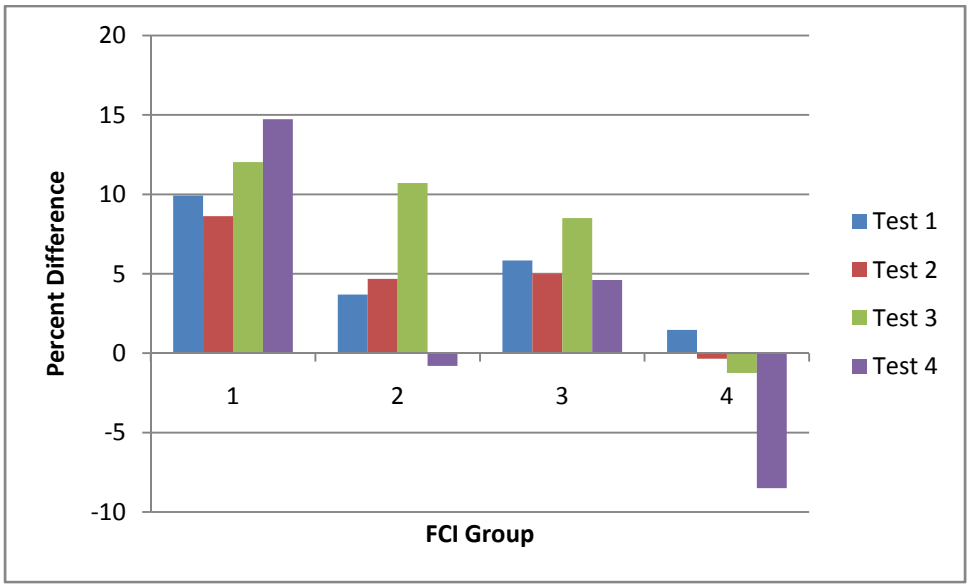


Figure 3 Percent Difference in Unit Exams

Table 7 Percent Differences Based on FCI Groups

	Test Diff. 1 (%)	Test Diff. 2 (%)	Test Diff. 3 (%)	Test Diff. 4 (%)
FCI Group 1	9.93	8.63	12.03	14.73
FCI Group 2	3.69	4.68	10.71	-0.80
FCI Group 3	5.84	4.98	8.51	4.61
FCI Group 4	1.46	-0.35	-1.25	-8.50

If the completion problems were effective the difference between sections would decrease from test 1 to test 2. In addition the difference between sections would increase from test 1 to test 3. These changes in the difference would suggest that the completion problem intervention had a positive outcome on student's performance. In all groups except FCI group 2 the difference between sections decreases from test 1 to

test 2. Similarly, in all groups except FCI group 4 the difference between sections test 1 and test 3 increases. This is suggestive that the completion problems had their intended effect.

To determine if the differences between sections based on FCI group is significant and not attributable to chance, ANOVA tests were conducted, a significance level of $\alpha = 0.05$ was used. The results are shown below in table 8.

Table 8 ANOVA Results for Test Differences Based on FCI Groups

	Test 1	**Test 2**	**Test 3**	**Test 4**
FCI Group 1	0.186	0.123	0.041	0.020
FCI Group 2	0.277	0.140	0.048	0.847
FCI Group 3	0.074	0.164	0.056	0.422
FCI Group 4	0.787	0.959	0.895	0.436

From these results we can see that differences are significant between sections on test 3 for FCI groups 1 ($p = 0.041$ $\eta = 0.389$) and 2 ($p = 0.020$ $\eta = 0.437$). The results indicate that 15.1% and 19.1% of the variation of scores on test 3, for FCI groups 1 and 2 respectively, can be attributed to the section that the students attended. Based on the given eta values the effect size, according to (Cohen, 1998), is a large sized effect. Since there is not a significant difference between sections on test 1 and test 2 based on FCI the groups these results strongly suggests that the completion problems had a positive impact on FCI groups 1 and 2 for test 3.

In addition, there is a significant difference between FCI group 1 on test 4. This may be explainable by the small sample size ($n = 13$ and $n = 15$) and also by the

distribution of scores. The distributions of scores for section 1 are approximately normal whereas the distribution for section 2 is not.

The significance level for FCI group 3 on test 3 ($p = 0.056$ $\eta = 0.245$) is also close statistically significant and not very different from the significance level of FCI groups 1 and 2. Group size for FCI group 3 are not approximately equal, the contribution from section 1 is roughly three times the contribution of section 2. With a larger contribution from section 2 or more equal contributions the results for FCI group 3 on test 3 might become significant.

A second blocking of student was done to further explore which students had potentially gained from the completion problem. The students were blocked into two groups by average test grade. The first block was those who had averaged a C grade or better ($n = 95$ and $n = 64$) and the second group was those who averaged below a C ($n = 20$ and $n = 10$). An ANOVA test was conducted to determine if there was a significant difference between groups, a significance of $\alpha = 0.05$ was used. The results are shown in table 9 below.

Table 9 ANOVA Results for Difference Between Section Based on Test Averages

	Test 1	Test 2	Test 3	Test 4
Averaged a C or better	0.037	0.058	0.011	0.349
Averaged less than a C	0.950	0.342	0.168	0.171

There is a significant difference between sections on test 1 and test 3. The significance between sections is close to the 95% confidence threshold for test 2. This blocking has included a large majority of the student in the "C or better" block so it is not surprising that these results are very similar to the original results in table 3. The results are inconclusive with regard to the effectiveness of the completion problem intervention.

A further refinement of the blocking into students who averaged A's, B's and C's was done to determine if there was any difference between sections based on test grade averages. An ANOVA test was conducted to determine if there was a significant difference between groups, a significance of $\alpha = 0.05$ was used. The results are shown below in table 10.

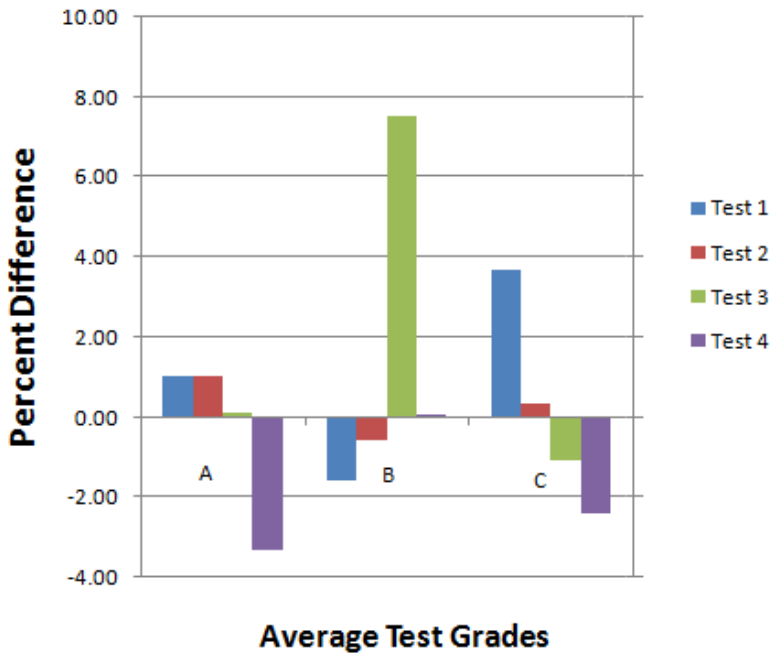


Figure 4 Percent Differences Based on Average Test Grade

Table 10 Percent Difference Between Sections Based on Test Grade Averages

	Test 1 (%)	Test 2 (%)	Test 3 (%)	Test 4 (%)
Averaged an A	-0.34	1.14	-0.40	-5.04
Averaged a B	-0.10	-0.87	5.39	0.71
Averaged a C	5.95	-0.95	-1.08	-2.74

Table 11 ANOVA Results for Differences Between Sections Based on Grade Averages

	Test 1	Test 2	Test 3	Test 4
Averaged an A	0.438	0.441	0.959	0.134
Averaged a B	0.461	0.792	0.005	0.986
Averaged a C	0.360	0.923	0.831	0.442

These results show a significant difference ($p = 0.005$ and $\eta = 0.386$) between sections for test 3 for students who averaged a B throughout the semester. The results

further suggest that 14.9% of the variability in scores is due to the section that the student attended. Test averages by section for students who averaged a B are shown in table 11 below.

Table 12 Test 3 Scores by Section for Students Averaging a B

	Test 1	Test 2	Test 3	Test 4
Section 1	64.59	60.09	62.25	79.31
Section 2	63.32	59.63	68.26	79.37
Difference (%)	-1.58	-0.58	7.51	0.06

There is virtually no difference between sections except for test 3, in which case there is clearly a difference by section. This would seem to be more evidence for the emerging pattern that students in section 2 had an increase in performance on test 3, the same unit that they received the completion problems.

A final aspect of interest is student participation in the intervention, that is did they actually attempt and turn in completion problems. It would be expected that if a difference between groups is to be observed that difference would be largest when considering students who actively took part in the intervention. Each section was assigned 16 completion problems. The mean number of completion problems completed and done correct by section is shown in table 12.

Table 13 Completion Problem Participation by Section

	Mean Number Attempted	Standard Deviation	Mean Number Correct	Standard Deviation
Section 1	11.91	4.28	5.82	3.92
Section 2	12.48	4.34	10.23	4.28

There is not a significant difference in the mean number attempted. However there is a significant difference in the number correct ($p = 0.000$ and $\eta = 0.470$). The difference in the number correct may indicate why there has been no observed difference between sections on test 2, the unit in which section 1 received completion problems. This will be discussed later in more detail.

To investigate differences on test performance by number of completion problems done the students were blocked into four groups. The groups consisted of students who had done all 16 problems ($n = 42$ and $n = 29$), less than 16 ($n = 73$ and $n = 46$), more than 12 ($n = 98$ and $n = 70$) and less than 12 ($n = 41$ and $n = 20$). An ANOVA test was conducted to determine if there was significant differences between sections, a significance of $\alpha = 0\ .05$ was used. The results are show in table 13 below.

Table 14 ANOVA Results for Test by Number of Completion Problems Done

	Test 1	**Test 2**	**Test 3**	**Test 4**
All 16	0.485	0.977	0.074	0.653
Less than 16	0.082	0.026	0.054	0.250
More than 12	0.196	0.156	0.004	0.936
Less than 12	0.276	0.360	0.977	0.524

There is no significant difference between sections for students who attempted did all 16 completion problems. However, there is close to a significant difference between sections for students who attempted less than 16 completion problems on test 3 and the other significance values are close to the 95% threshold. This is again similar to the original results in table 3. This can be at least partially explained by the sample size, as most of the class did less than 16 completion problems. There is a significant

difference ($p = 0.004$ and $\eta = 0.253$) between sections on test 3 for students who completed more than 12 completion problems. The average score on test 3 by section and by the number of completion problems attempted is shown in table 14 below.

Table 15 Average Score on Test 3 by Section and Number of Completion Problems Done

		Average Score on Test 3	Difference
More than 12 done	**Section 1**	62.74	6.26
	Section 2	69.00	
Less than 12 done	**Section 1**	55.63	0.12
	Section 2	55.75	

These results further support the conclusion that the completion problems had a positive effect on student performance on test 3.

Summary of Results

There was an initial and significant difference between the two sections on the first unit exam. This was unexpected given the size of the groups and the only difference between the sections was the time of day that the class was held. Both sections had the same professor, homework and unit exams. There was a change in the difference between sections during the intervention, but it is difficult to attribute this change to the intervention. Statistical tests can provide a measure of difference between means on a single exam. However, since different exams were used at the end of each unit the statistical tests cannot determine if a change in the difference is significant (i.e. change in the difference from exam one to exam two). Thus, the initial goal of the analysis was

block the data in groups or use a covariant to statistically minimize the initial difference on the first unit exam such that a difference on a later unit exam could potentially be attributed to the intervention.

It was found that during the second unit the difference between sections did not change substantially (less than 0.2%), thus suggesting that the intervention had little or no affect on the class performance, see table 3. However during the third unit the difference between the sections changed by more than 2.5%. The section receiving the intervention improved their performance on the unit exam relative to the other section. The size of the improvement was on order with expectations (that is between 2-5%). This would seem to suggest that the intervention had the desired effect, but the initial difference on Test 1, makes it difficult to reach a conclusion regarding the effectiveness of the intervention.

Use of the FCI pretest scores as a covariant did not account for differences in scores on the first unit exams between sections, there was still a statically significant difference between sections. In another attempt to account for initial differences, and to determine if some groups of students had been helped by the intervention more than other groups the students, the students were blocked into sub-groups based on FCI pretest scores. Blocking was done in groups of 5 (i.e. scores of 0-5 , 6-10, etc.). The results show that there was no significant difference between sections for either the first or second unit exams ($p > 0.05$). However, for the third unit exam there was a significant difference between sections for the first two FCI groups ($p < 0.05$) and the

third FCI group was almost significant ($p = 0.056$). This was suggestive that the intervention did have an effect on student performance for the third unit exam.

Further blocking was done based on the students average test grades. The results of this blocking once again show that there was no significant difference between sections for the first two unit exams. However, on the third exam for those students who average a “B” there was a significant difference between the sections ($p = 0.005$). No other groups showed a significant difference.

The initial results as well as the results from blocking suggest that the intervention was effective at improving performance on the third exam, but had little or no effect on students’ performance on the second exam.

CONCLUSION

Conclusion, Improvements and Recommendations

The intent of the completion problems is to slow the student down, require them to recall fewer ideas independently, and most importantly to force them to reflect and/or explain each step of the problem. The results from the study are highly suggestive that the completion problem intervention did have a positive effect on test performance, but only for the students with the intervention for test 3. In particular students who averaged a B on tests were observed to have significant improvement. Likewise students in FCI groups 1 and 2, those who began the class with little previous knowledge, also improved performance on test 3. Considering the nature of the class and size of the intervention, the effect size was approximately what was expected, that is an improvement of 2-5%. The effect size was considerably larger, roughly 7.5%, for students averaging a B on tests.

This leaves the remaining question as to why there was no observed effect for test 2. Given the sample size and limited factors that would bias the sections it is unusual that the two sections would perform so differently on test 1 given that there was no significant difference in the pretest FCI scores. This may suggest that the sections had equivalent pre-knowledge but were not equal in motivation, study habits or other academic factors. Beyond the initial differences, completion problems, if there are too be effective, in increasing test performance must be not only attempted by students but largely done correctly. It seems unlikely that a student will gain much by

doing a problem wrong or being unable to complete a problem. The students in section 2, on average, got nearly twice as many completion problems correct as the students in section 1. This statistic alone, suggests not that completion problems are ineffective, but rather the implementation of the completion problems for section 1 was ineffective.

The implementation of the completion problems for section 1 was a first attempt. Many of the completion problems were based on more difficult homework questions. After the first 4 sets of completion problems it was apparent that students were not getting the problems right despite the attempt to provide scaffolding. As a result, the final 4 set of completion problems had a final numerical answer included, given that the answer was numeric. There was a slight increase in the percent correct after this change. There may also be a slight inflation of the effect size for test 3 relative to test 2, as the completion problems for section 2 were intentionally designed around relatively simpler problems rather than designed around the more difficult problems.

Simplifying the completion problems for the unit covering Newton's Laws would seem a likely way to improve the results and further test the initial hypothesis that completion problems are a useful tool to improve student performance. Simplifying of the completion problems for energy and momentum may result in further gains. Over simplification of the completion problems could also result in lower gains if the problems become too simple and no longer require the students to actively reflect on the process.

In this study the completion problems were voluntary. I believe it has been reasonably shown that the completion problems do not have a negative effect on test

performance. If the act of completing a completion problem is useful making the completion problems mandatory would seem to be a simple improvement that may result in further or more widespread gains. Further, I believe that completion problems are realistic to implement for an entire semester or year-long course, in terms of time invested in creation of the problems compared to the possible gains made by students. The study has also shown that completion problems can be implemented without significantly altering the rest of the course (i.e. lectures, exams and tutorials).

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APPENDICES

APPENDIX A

COMPLETION PROBLEMS FOR UNIT EXAM 2

CP #1

Zack (the wonder frog) sits still on a scale and the scale reads 5 Newtons. He is so excited by this discovery that he leaps straight up into the air with an acceleration of magnitude 5 m/s/s.

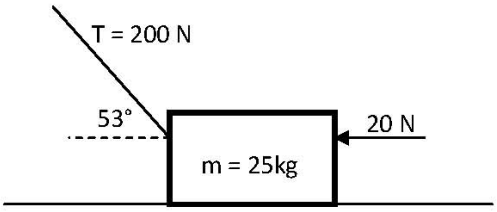
What does the scale read as he launches himself into the air?

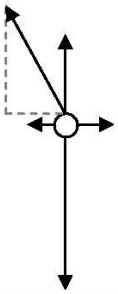
Step 1 – FBD while sitting still	**Label the forces.**
	
Step 2. $F_{net}^{Zack} = ma = \not{0}$ $N_{scale,crate} - W_{earth,crate} = \not{0}$ $5N - mg = \not{0}$ $m = 0.5kg$	**Explain Step 2.**
Step 3 – FBD while jumping	**Label the Forces.**
	
Step 4 . $F_{net}^{Zack} = ma \neq \not{0}$	**Complete and explain the final step.**

CP #2

A father is pulling a crate of mass m = 25 kg with a rope. The force of the rope on the crate is 200N and angled at 53° as shown. His son is also helping to move the crate and is pushing from behind with a force of 20N. A friction force of 40N acts on the crate.

Find the acceleration of the crate in the horizontal direction.



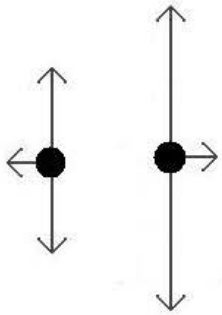
Step 1 . 	**Label the forces.**
Step 2. $T_x = T_{rope,crate}\cos(53°)$ $= 200N\cos(53°)$ $= 120N$ $T_y = T_{rope,crate}\sin(53°)$ $= 200N\sin(53°)$ $= 160N$	**Explain step 2.**
Step 3. **vertical:** $F_{net}^{crate} = m_{crate}a_{crate} = \emptyset$ $T_y + N_{ground,crate} - W_{Earth,Crate} = 0$ $160N + N_{ground,crate} - (25kg)(10m/s/s) = 0$ $N_{ground,crate} = 90N$	**Explain step 3.**
Step 4. **horizontal:** $F_{net}^{crate} = m_{crate}a_{crate} \neq \emptyset$	**Complete and explain the final step.**

CP #3

A father (80kg) and his child (40kg) are facing each other in the middle of a frictionless pond of ice. The child pushes horizontally on the father with a force of 20N.

What is the magnitude of the father's acceleration?

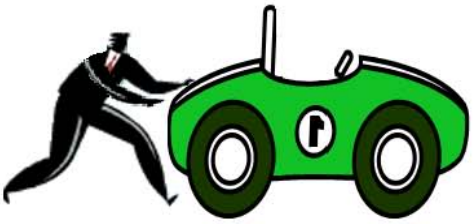
What is the magnitude of the child's acceleration?

Step 1.	**Label the forces.**
	
Step 2. x-direction: $F_{net}^{father} = ma \neq \not{0}$ $N_{child,father} = (80kg)(a)$ $20N = (80kg)(a)$ $a = 0.25m/s/s$	**Explain step 2.**
Step 3. $N_{father,child} = -N_{child,father}$ $= -20N$	**Explain step 3.**
Step 4 .	**Complete and explain the final step.**

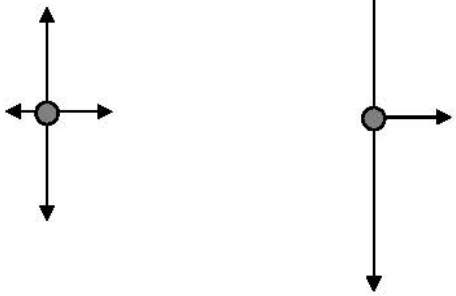
CP #4

Hank is trying to push his gas-less car to the gas station. The car is initially at rest and has a mass of 1000 kg. Hank is a very slender 50 kg and can only push on the car with a force of 250N. The car begins to speed up at a rate of 0.25 m/s/s.

Find the frictional force of the ground on Hank.



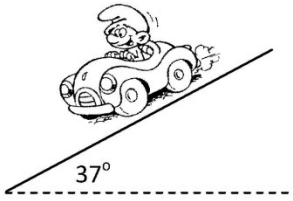
Step 1 – Label the forces (forces not drawn to scale).



Step 2.	**Explain step 2.**
y-direction: $F_{net}^{car} = m_{car}a_{car} = \not{0}$ $N_{ground,car} - W_{Earth,car} = \not{0}$ $N_{ground,car} - (1000kg)(10m/s/s) = \not{0}$ $N_{ground,car} = 1000N$	
Step 3.	**Explain step 3.**
y-direction: $F_{net}^{Hank} = m_{Hank}a_{Hank} = \not{0}$ $N_{ground,Hank} - W_{Earth,Hank} = \not{0}$ $N_{ground,Hank} - 500N = \not{0}$ $N_{ground,Hank} = 500N$	
Step 4.	**Explain step 4.**
$N_{car,Hank} = -N_{car,Hank}$ $= -250N$	
Step 5.	**Complete and explain the final step.**
x-direction: $F_{net}^{Hank} = m_{Hank}a_{Hank} \neq \not{0}$	

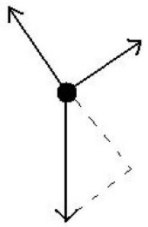
CP #5

Completion Problem

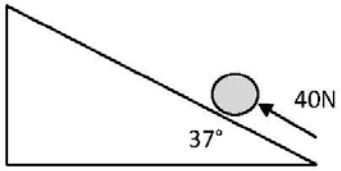


Professor Steve Eiger is speeding down the freeway at Homestake Pass at 45 m/s. He sees an elk on the road ahead and quickly slams on his brakes, locking all the wheels such that the car slides to a stop. The mass of the car (including Steve) is 1200 kg. The coefficient of kinetic friction between the tires and the road is $\mu_k = 1.5$. The road is very steep, making an angle of 37° with the horizontal.

Find the acceleration of the car after the wheels lock.

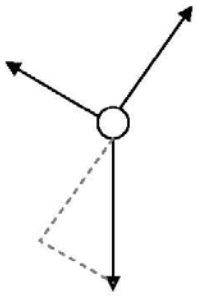
Step 1. 	**Label the forces.**
Step 2. $W_{earth,car} = mg$ $= (1200kg)(10m/s/s)$ $= 12000N$	**Explain step 2.**
Step 3. $W_x = W_{earth,car}\sin(37°)$ $= 7200N$ $W_y = W_{earth,car}\cos(37°)$ $= 9600N$	**Explain step 3.**
Step 4. y-direction: $F_{net}^{car} = m_{car}a_{car} = \not{0}$ $N_{road,tires} - W_y = \not{0}$ $N_{road,tires} = W_y$ $= 9600N$	**Explain step 4.**
Step 5. $f_{road,tires} = \mu_k N_{road,tires}$ $= (1.5)(9600N)$ $= 14400N$	**Explain step 5.**
Step 6. **x-direction:** $F_{net}^{car} = m_{car}a_{car} \neq \not{0}$	**Complete and explain the final step.**

CP #6



A bowling ball of mass 5 kg is be pushed up a ramp by a force parallel to the ramp and magnitude of 40N. The ramp has an angle of 37°.

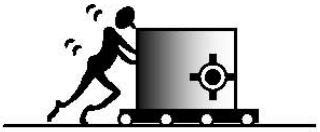
Find the magnitude and direction of the acceleration of the bowling ball.

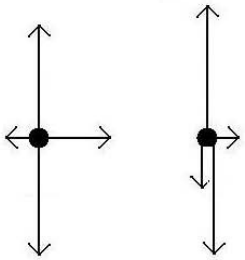
Step 1. 	**Label the forces.**
Step 2. $W_x = W_{Earth,ball}\sin(37°)$ $= 30N$ $W_y = W_{Earth,ball}\cos(37°)$ $= 40N$	**Explain step 2.**
Step 3. **y-direction:** $F_{net}^{ball} = m_{ball}a_{ball} = \not{0}$ $N_{ramp,ball} - W_y = \not{0}$ $N_{ramp,ball} = W_y$ $= 40N$	**Explain step 3.**
Step 4. **x-direction:** $F_{net}^{ball} = m_{ball}a_{ball} \neq \not{0}$	**Complete and explain the final step.**

CP #7

Steve Eiger has invented a Shop-Dolly with "frictionless wheels." The wheel bearings are so good, in fact, that the Dolly will roll at constant velocity on a level surface. Steve is using the Dolly to move a large safe full of silver. The mass of the safe (including silver) is 435 kg. The mass of the Shop-Dolly (including wheels) is 15 kg. The coefficient of static friction between the safe and the Dolly is large ($\mu_s = 1.2$) so that the safe does not slip relative to the Dolly. Steve pushes on the safe with enough force to cause it to accelerate at 0.5 m/s/s.

Find the friction force between the safe and the Dolly.

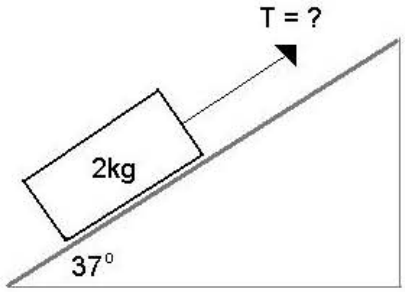


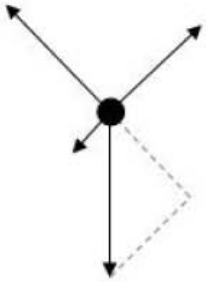
Step 1. 	**Label the forces.**
Step 2 y-direction: $F_{net}^{safe} = m_{safe}a_{safe} = \not{0}$ $N_{Dolly,safe} - W_{Earth,safe} = 0$ $N_{Dolly,safe} = 4350N$	**Explain step 2.**
Step 3. y-direction: $F_{net}^{Dolly} = m_{Dolly}a_{Dolly} = \not{0}$ $N_{ground,Dolly} - W_{Earth,Dolly} - N_{safe,Dolly} = 0$ $N_{ground,Dolly} = 4350N + 150N$ $N_{ground,Dolly} = 4500N$	**Explain step 3.**
Step 4. x-direction: $F_{net}^{Dolly} = m_{Dolly}a_{Dolly} \neq \not{0}$	**Complete and explain the final step.**

CP#8

A crate is being pulled up a ramp by a string and is speeding up at 1m/s/s. A friction force of 5 N is acting on the block.

Find the magnitude of the force the string exerts on the crate.



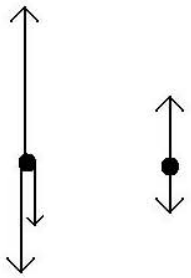
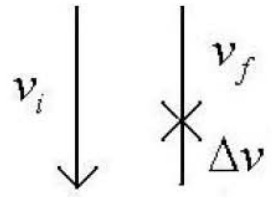
Step 1 . 	**Label the forces.**
Step 2. $W_x = W_{Earth,crate}\sin(37°)$ $= 12N$ $W_y = W_{Earth,crate}\cos(37°)$ $= 16N$	**Explain step 2.**
Step 3. **y-direction:** $F_{net}^{crate} = m_{crate}a_{crate} = \not{0}$ $N_{ramp,crate} - W_y = 0$ $N_{ramp,crate} = 16N$	**Explain step 3.**
Step 4. **x-direction:** $F_{net}^{crate} = m_{crate}a_{crate} \neq \not{0}$	**Complete and explain the final step.**

CP# 9

You are in an elevator moving downwards and are carrying a 5 kg box of rocks cradled in your arms. The elevator begins to slow at a rate of 5 m/s/s.

Is the net force on the box of rocks greater than, equal to or less than the net force on you?

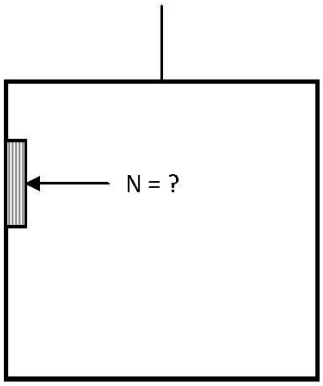
At this instant, what is the apparent weight of the box of rocks?

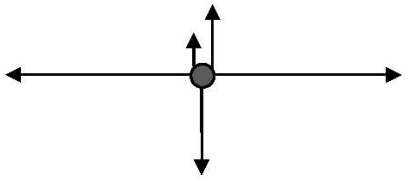
Step 1.	**Label the Forces.**
	
Step 2. $F_{net}^{you} = M(5\ \text{m/s/s})$ $F_{net}^{rocks} = m(5\ \text{m/s/s})$ $F_{net}^{you} > F_{net}^{rocks}$	**Explain step 2.**
Step 3.  *Acceleration must be upwards.*	**Explain step 3.**
Step 4. $F_{net}^{rocks} = m_{rocks} a_{rocks} \neq \emptyset$	**Complete and explain the final step.** *(ans. 75N)*

CP #10

Hank is holding a book of mass m = 2kg against the wall of an elevator. The friction force between Hank's hand and the book is 4N. The coefficient of friction between the book and the wall of the elevator is μ_s=0.3. The elevator begins to move down and its speed increases at a rate of 2 m/s/s.

What is the minimum force Hank needs to apply to the book for the book to not slide up or down the wall?

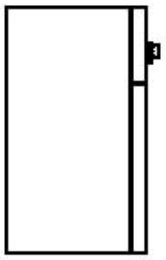


Step 1. 	**Label the Forces.**
Step 2. **Horizontal:** $F_{net}^{Book} = m_{book}a_{book} = \not{0}$ $N_{wall,book} - N_{Hank,book} = 0$ $N_{wall,book} = N_{Hank,book}$	**Explain step 2.**
Step 3. $f_{wall,book} = \mu_s N_{wall,book}$ $= \mu_s N_{Hank,book}$	**Explain step 3.** *Why does the equation have an "equal" sign and not a "less than or equal to" sign?*
Step 4. **Vertical:** $F_{net}^{Book} = m_{book}a_{book} \neq \not{0}$	**Complete and explain the final step.** *(ans. 40N)*

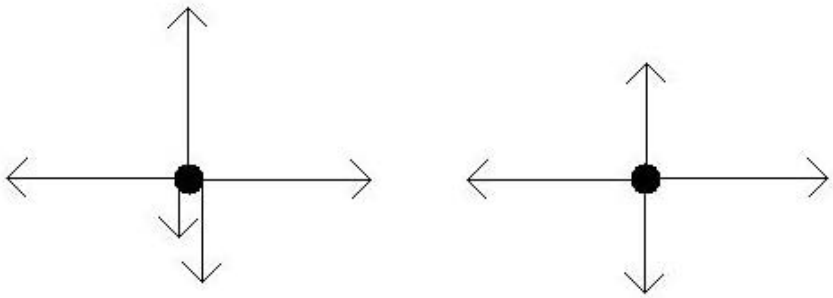
CP # 11

Your grocery list of mass 30 g is held to the face of a refrigerator door (as shown) by a magnet of mass 40 g. The grocery list and magnet are at rest.

Find the friction force of the refrigerator on the grocery list.



Step 1 – Label the forces.



Step 2.

$$\text{y-direction: } F_{net}^{magnet} = m_{magnet}a_{magnet} = \not{0}$$

$$f_{list,magnet} - W_{Earth,Magnet} = \not{0}$$

$$f_{list,magnet} = W_{Earth,Magnet}$$

$$= (0.040kg)(10m/s/s)$$

$$= 0.4N$$

Explain step 2.

Step 3.

$$f_{magnet,list} = f_{list,magnet}$$

$$= 0.4N$$

Explain step 3.

Step 4.

$$y-direction: F_{net}^{list} = m_{list}a_{list} = \not{0}$$

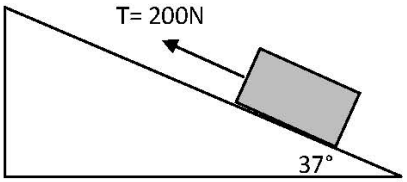
Complete and explain the final step.

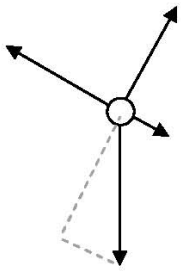
(ans. 0.7N)

CP # 12

A block of mass m = 25 kg is being pulled up a ramp of angle 37° by a massless rope at a constant speed. The rope exerts a force of 200N on the block. The surface is not frictionless.

Find the coefficient of friction between the block and the ramp.

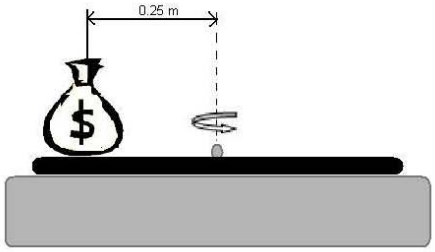


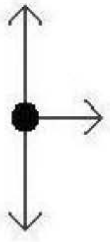
Step 1. 	**Label the forces.**
Step 2. $W_x = W_{Earth,block}\sin(37°)$ $= 150N$ $W_y = W_{Earth,block}\cos(37°)$ $= 200N$	**Explain step 2.**
Step 3. **Y direction:** $F_{net}^{block} = m_{block}a_{block} = \not{0}$ $N_{ramp,block} - W_y = 0$ $N_{ramp,block} = 200N$	**Explain step 3.**
Step 4. **X direction:** $F_{net}^{block} = m_{block}a_{block} = \not{0}$	**Complete and explain the final step.** *(ans. $\mu_s = 0.25$)*

CP # 13

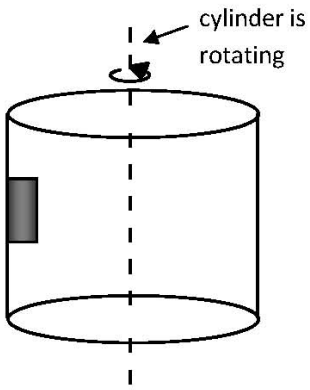
A bag of coins is spinning around on a record player such that it is moving with speed v = 1 m/s. The bag of coins has mass m = 1 kg, and is located a distance of 0.25 m from the axis of rotation. The coefficient of static friction between the bag and the record player is large ($\mu_s = 1.5$).

Show that the bag does not slip.



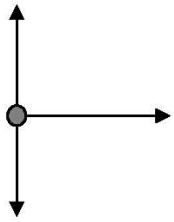
Step 1. 	**Label all the forces.**
Step 2. **y-direction:** $F_{net}^{bag} = m_{bag}a_{bag} = \not{0}$ $N_{player,bag} - W_{Earth,bag} = 0$ $N_{player,bag} = W_{Earth,bag}$ $= 10N$	**Explain step 2.**
Step 3. $f_{player,bag}^{\max} = \mu_s N_{player,bag}$ $= 1.5(10N)$ $= 15N$	**Explain step 3.**
Step 4. $a_{bag} = \frac{v^2}{r} = \frac{(1m/s)^2}{0.25m}$ $= 0.4m/s/s$	**Explain step 4.**
Step 5. $F_{net}^{bag} = ma \neq 0$	**Complete and explain the final step.**

CP #14



A cylindrical room of radius 4.5 m is rotating at a constant speed. A block of mass 5kg is placed on the wall. The coefficient of friction between the block and the wall is μ_s= 0.6.

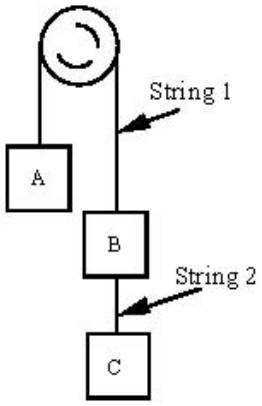
Show that the block will not slide if it has a speed of 9 m/s.

Step 1. 	**Label the forces.**
Step 2. **Horizontal** $F_{net}^{block} = m_{block}a_{block} \neq \emptyset$ $N_{wall,block} = m_{block}\left(\frac{v^2}{r}\right)$ $= (5kg)\left(\frac{(9m/s)^2}{4.5m}\right)$ $N_{wall,block} = 90N$	**Explain step 2.**
Step 3. $f_{wall,block} \leq \mu_s N_{wall,block}$ $f_{wall,block} \leq 0.6(90N)$ $f_{wall,block} \leq 54N$	**Explain step 3.** *Why did we need to do this step?*
Step 4. **Vertical** $F_{net}^{block} = m_{block}a_{block} = \emptyset$	**Complete and explain the final step.**

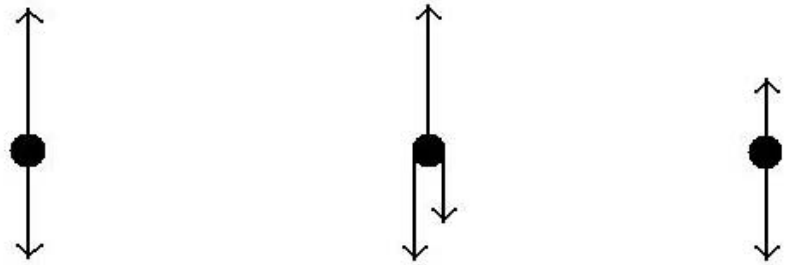
CP #15

The diagram at the right shows a system of pulleys (modified Atwood's machine) composed of a massless frictionless pulley, two massless strings, and three blocks. Blocks A and B each have mass 1 kg and block C has mass 3 kg. Assume that the strings do not stretch and that the blocks are released from rest and accelerate at 6 m/s/s.

Find the tension in string 2.



Step 1 – Label the Forces on each of the blocks



Step 2.

$$F_{net}^{A} = m_A a_A \neq \emptyset$$

$$T_{string1,A} - W_{Earth,A} = m_A a_A$$

$$T_{string1,A} - (1kg)(10m/s/s) = (1kg)(6m/s/s)$$

$$T_{string1,A} = 16N$$

Explain Step 2.

Step 3.

$$T_{string1,A} = T_{string1,B}$$

$$T_{string2,B} = T_{string2,C}$$

Explain Step 3.

Step 4.

$$F_{net}^{B} = m_B a_B \neq \emptyset$$

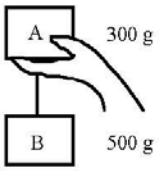
Complete and explain the final step.
(ans. 12N)

CP # 16

Two blocks are tied together with a massless string. A hand is used to lift one block so that both speed up while moving upward. Block A has a mass of 300 g and block B has a mass of 500 g. Ignore air resistance.

Without doing any calculations, compare the magnitudes of the net forces acting on the two blocks.

Calculate the magnitude of the force of the string on B and compare that to the weight of B. Assume that the speed is changing 2 m/s/s.

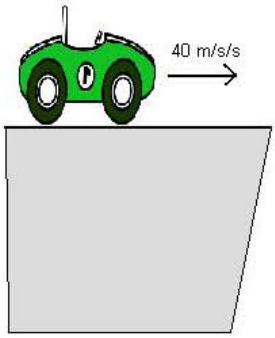


<table>
<tr><td colspan="2">Step 1- Label the forces.
</td></tr>
<tr><td>Step 2.
$a_A = a_{string} = a_B$</td><td>Explain step 2.</td></tr>
<tr><td>Step 3.
$F_{net}^{A} < F_{net}^{B}$</td><td>Explain the reasoning of step 3.</td></tr>
<tr><td>Step 4.
Vertical $F_{net}^{B} = m_B a_B \neq \emptyset$</td><td>Complete and explain the final step.
(ans. $T_{s,B}$ = 6N)</td></tr>
</table>

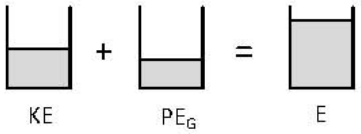
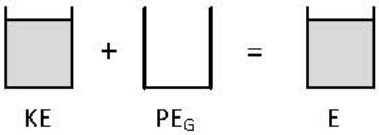
APPENDIX B

COMPLETION PROBLEMS FOR UNIT EXAM 3

CP #1



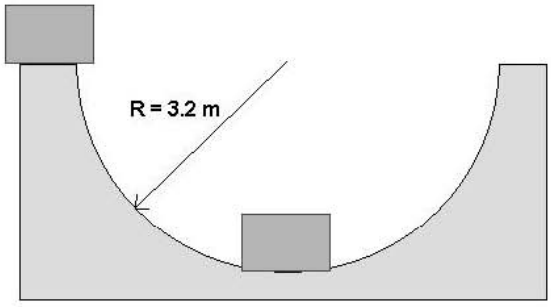
A car drives off a cliff at a speed of 40 m/s. Just before the car hits the ground it has a speed of 50 m/s/s. How far did the car fall?

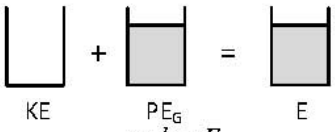
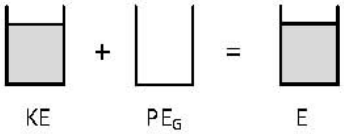
Step 1.  $\frac{1}{2}mv_i^2 + mgh = E_i$ $\frac{1}{2}m(40\text{m/s})_i^2 + m(10\text{m/s/s})h = E_i$	**Explain step 1.**
Step 2.  $\frac{1}{2}mv_f^2 = E_f$ $\frac{1}{2}m(50\text{m/s/s})_f^2 = E_f$	**Explain step 2.**
Step 3. $E_i = E_f$ $\frac{1}{2}m(40\text{m/s})_i^2 + m(10\text{m/s/s})h = \frac{1}{2}m(50\text{m/s/s})_f^2$	**Explain step 3.**
Step 4.	**Complete and explain the final step.** *(ans. 45m)*

CP #2

A 1 kg block slides down a frictionless half-pipe. The half-pipe has a radius of 3.2 m.

How fast is the block sliding at the bottom of the half-pipe?



Step 1.  $mgh = E_i$ $(1kg)(10\text{N/kg})(3.2m) = E_i$ $32J = E_i$	**Explain step 1.**
Step 2.  $\frac{1}{2}mv_f^2 = E_f$	**Explain step 2.**
Step 3. $E_i = E_f$	**Complete and explain the final step.** *(ans. 8 m/s)*

CP # 3

A block of mass m = 2 kg initially at rest is pushed on a frictionless surface for 4 m and has a final speed of 4 m/s.



How far does the block have to be pushed with the same force to have a final speed of 12 m/s?

If you quadruple the velocity how many times does the distance increase?

Step 1. $E_i + werk_{external} = E_f$ $0 + F \cdot d = \frac{1}{2}mv^2$ $F \cdot 4m = \frac{1}{2}(2kg)(4\text{m/s})^2$ $F = 4N$	**Explain step 1.**
Step 2. $E_i + werk_{external} = E_f$ $0 + F \cdot d = \frac{1}{2}mv^2$ $4N \cdot d = \frac{1}{2}(2kg)(12\text{m/s})^2$ $d = 36m$	**Explain step 2.**
Step 3.	**Finish and explain final step.** *(ans. 16)*

CP #4

A block of mass m = 2 kg compresses a spring 1 m from the equilibrium point. The spring constant is 10 N/m. The block is released and slides along a frictionless surface and up a frictionless ramp.

How far above the horizontal surface does the block slide?



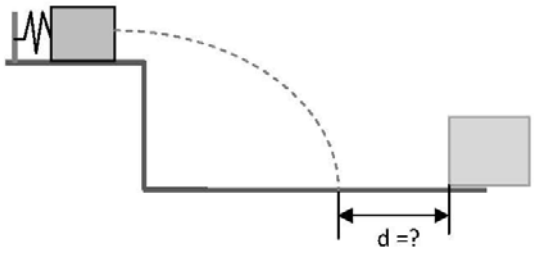
Step 1.	**Explain step 1.**
$E_i = \frac{1}{2}k\Delta s^2$ $E_i = \frac{1}{2}(10\text{N/m})(1\text{m})^2$ $= 5J$	
Step 2. $E_i = E_f$ $E_f = 5J$	**Explain step 2.**
Step 3.	**Explain step 3.** *(ans. 0.25m)*

CP #5

A block of mass m = 2 kg is launched off a small ledge of height h = 5 m by a spring with k = 22 N/m. The spring is originally compressed 2 m from equilibrium. When the block lands on the ground it begins to slide and comes to a stop. The coefficient of friction between the block and the ground is $\mu_s = 0.5$.

What is the block's speed when it hit the ground?

How far does the block slide before coming to a stop?



Step 1. $E_i = \frac{1}{2}k\Delta s^2 + mgh$ $E_i = \frac{1}{2}(22\text{N/m})(2m)^2 + (2kg)(10\text{m/s/s})(5m)$ $E_i = 144J$	**Explain step 1.**
Step 2. $E_{later} = E_i = 144J$ $E_{later} = \frac{1}{2}mv^2$ $\frac{1}{2}(2kg)v^2 = 144J$ $v = 12\text{m/s}$	**Explain step 2.**
Step 3. $E_i + werk_{external} = E_f$ $144J + werk_{external} = 0$	**Explain step 3.**
Step 4.	**Complete and explain the final step.** *(ans. 14.4 m)*

CP #6

A car with mass m = 1000 kg rolls down a hill a 2.2m hill with an initial speed of 10 m/s and runs into an experimental road barrier. The road barrier is a heavy duty spring (k = 8,000 N/m) attached on one side to a building.



What is the car's speed just before it hits the spring?

How far does the spring compress?

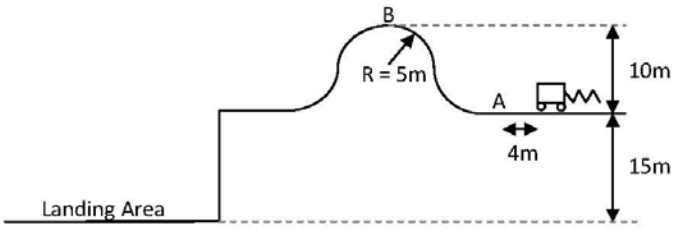
Step 1. $E_i = \frac{1}{2}mv^2 + mgh$ $E_i = \frac{1}{2}(2000kg)(10\text{m/s})^2 + (2000kg)(10\text{m/s/s})(2.2m)$ $E_i = 144,000J$	**Explain step 1.**
Step 2. $E_{later} = E_i$ $E_{later} = \frac{1}{2}mv^2$ $\frac{1}{2}(2000kg)v^2 = 144,000J$ $v = 12\text{m/s}$	**Explain step 2.**
Step 3. $E_f = E_i$	**Complete and explain the final step.** *(ans. 6 m)*

CP #7

A new roller coaster with mass m = 100 kg is launched by a compressed spring. The spring is compressed 4m and then released. The coaster is launched at point A and goes over the semi-circular bump at point B. When it reaches point B, its speed is 4 m/s.

What is the acceleration (magnitude and direction) of the coaster at point B?

Find the spring constant of the launching spring.



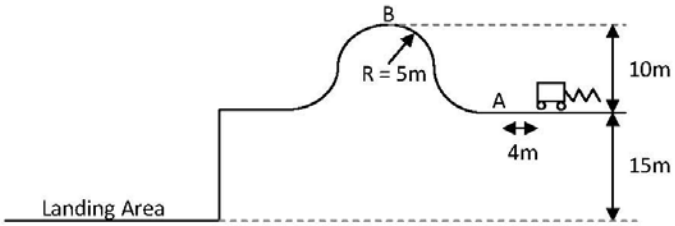
Step 1.	**Explain step 1.**
$a_{coaster} = \frac{v^2}{r}$ $a_{coaster} = \frac{(4\text{m/s})^2}{5m} = 5.2\text{m/s/s}$	
Step 2. $E_i = \frac{1}{2}k(4m)^2 + (200kg)(10\text{m/s/s})(15m)$ $E_i = 8k + 30000J$	**Explain step 2.**
Step 3. $E_B = \frac{1}{2}(200kg)(4\text{m/s})^2 + (200kg)(10\text{m/s/s})(25m)$ $E_B = 51600J$	**Explain step 3.**
Step 4. $E_i = E_B$	**Complete and explain the final step.** *(ans. 2700 N/m)*

CP #8

A new roller coaster with mass m = 100 kg is launched by a compressed spring. The spring is compressed 4m and then released. The coaster is launched at point A and goes over the semi-circular bump at point B. When it reaches point B, its speed is 4 m/s.

Find the normal force of the track on the coaster at point B.

How fast will the coast be traveling when it hits the landing area?



Step 1. **Vertical (at point B):** $F_{net}^{coaster} = m_{coaster} a_{coaster}$ $N_{track,coaster} - W_{B,coaster} = m_{coaster}\left(\frac{v^2}{r}\right)$ $N_{track,coaster} - (100kg)(10m/s/s) = -100kg\left(\frac{(4\text{m/s})^2}{5m}\right)$ $N_{track,coaster} = 680N$	**Explain step 1.**
Step 2. $E_B = \frac{1}{2}(200kg)(4\text{m/s})^2 + (200kg)(10\text{m/s/s})(25m)$ $E_i = 1600J + 50000J$ $E_i = 51600J$	**Explain step 2.**
Step 3. $E_f = \frac{1}{2}mv^2$ $E_f = \frac{1}{2}(200kg)v^2$	**Explain step 3.**
Step 4. $E_i = E_f$	**Complete and explain the final step.** *(ans. 22.7 m/s)*

CP #9

A car with mass m = 1500 kg crashes into a wall at 30 m/s and rebounds off the wall at a speed of 5 m/s. The car is in contact with the wall for 0.05 sec. The hood of the car is squished in by a 0.5 m during the impact.

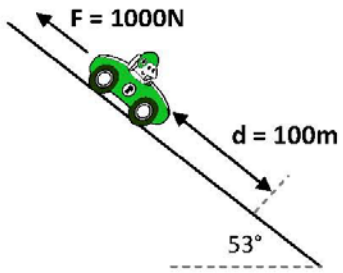
How much does the momentum of the car change from just before the collision to just after the collision?

What is the magnitude of the average force exerted by the wall on the car during the collision?

Step 1. $p_i = m_{car} v_i$ $p_i = (1500kg)(30\text{m/s})$ $p_i = 45000kg \cdot \text{m/s}$	**Explain step 1.**
Step 2. $p_f = m_{car} v_f$ $p_f = (1500kg)(-5\text{m/s})$ $p_f = -7500kg \cdot \text{m/s}$	**Explain step 2.**
Step 3. $\triangle p = p_f - p_i$ $\triangle p = -52500kg \cdot \text{m/s}$	**Explain step 3 and comment on the meaning of the negative sign.**
Step 4. $\triangle p = f_{ave} \triangle t$	**Complete and explain the final step.** Why does the compression of the hood not matter? *(ans. 2625N)*

CP #10

A car with mass 1000kg is descending a VERY steep hill with angle of 53°. The driver applies the brakes such that the tires exert a frictional force of 1000N on the road. When the driver first applies the brake the car is traveling at 15 m/s.



Find the total external werk done on the car-earth system when the car travels 100m down the road.

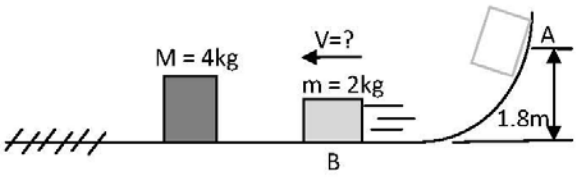
Find the change in potential energy of the car-earth system as the car travels 100m down the road.

Find the speed of the car after 100m of applying the brake.

Step 1. $werk_{ext} = F_{average}\,\Delta x$ $werk_{ext} = -(1000N)(100m)$ $werk_{ext} = -100000J$	**Explain step 1.**
Step 2. $PE_i = (1000kg)(10\text{m/s/s})(\sin 53°)(100m) = 80000J$ ( ) $PE_f = (1000kg)(10\text{m/s/s})(\sin 53°)(0m) = 0J$ $\Delta PE_G = PE_f - PE_i = -800000J$	**Explain step 2.** What have we done by choosing *h* as 100m?
Step 3. $\Delta E = E_f - E_i = werk_{ext}$ $E_f - E_i = -100000J$	**Explain step 3.**
Step 4. $E_i = PE_i + KE_i$ $E_i = 800000J + \frac{1}{2}(1000kg)(15\text{m/s})^2$ $E_i = 912500J$	**Explain step 4.**
Step 5. $E_f = PE_f + KE_f$	**Complete and explain the final step.** *(ans. 40 m/s)*

CP #11

A small block of mass m = 2kg starts from rest and slides down a frictionless ramp of height 1.8m. After sliding down the ramp the block collides with a large block of mass M = 4kg. After the collision the small block comes to rest and the large block has a speed of 3 m/s.



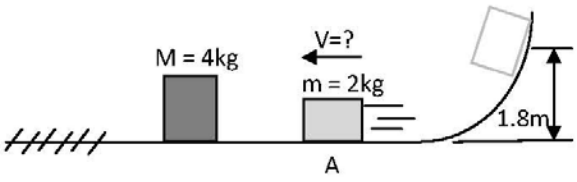
How fast is the small block moving at point B?

Show that the collision is inelastic.

Step 1. $E_A = E_B$ $PE_G = KE$ $(2kg)(10\text{m/s/s})(1.8m) = \frac{1}{2}(2kg)v^2$ $v = 6\text{m/s}$	**Explain step 1.** *Justify that the energies must be equal.*
Step 2. $KE_i = \frac{1}{2}mv_A^2 + \frac{1}{2}mv_B^2$ $KE_i = \frac{1}{2}(2kg)(6\text{m/s})^2 + \frac{1}{2}(4kg)(0\text{m/s})^2 = 36J$	**Explain step 2.** *Where is the block at the time we are considering "initial?"*
Step 3. $KE_f = \frac{1}{2}mv_A^2 + \frac{1}{2}mv_B^2$	**Complete and explain the final step.** *What comparison is necessary to show that the collision is inelastic?*

CP #12

A small block of mass m = 2kg slides down a frictionless ramp of height 1.8m. After sliding down the ramp the block collides with a large block of mass M = 4kg. The large block moves with a speed of 3 m/s after the collision. The large block then slides over a rough section and comes to a stop in 1.2 sec.



Find the coefficient of friction of the rough patch.

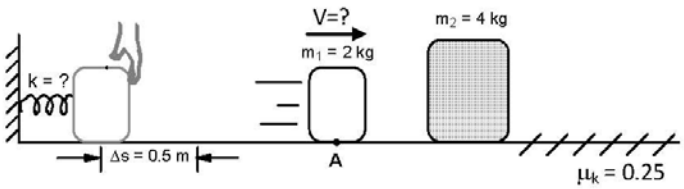
How many meters does the block slide before coming to a stop?

Step 1. $\triangle p = F_{ave}\triangle t$ $\triangle p = p_f - p_i = -12kg\cdot m/s$	**Explain step 1.** Why is the final momentum zero?
Step 2. $F_{ave} = f_{surface,block}\triangle t$ $F_{ave} = \mu_k N_{surface,block}$ $-12kg\cdot m/s = -\mu_k(40N)(1.2s)$ $\mu_k = 0.25$	**Explain step 2.**
Step 3. $E_i + werk = E_f$ $E_f = 0J$ $E_i = werk = F_{ave}\triangle x$	**Explain step 3.** Why is the final energy zero?
Step 4. $E_i = \frac{1}{2}(4kg)(3\text{m/s})^2$ $E_i = 18J$	**Explain step 2.**
Step 5.	**Complete and explain the final step.** *(ans. 1.8m)*

CP # 13

A small block of mass m_1 = 2 kg is pushed by a hand such that it compresses a spring, with spring constant k = 288 N/m, a distance Δs = 0.5 m. The hand then releases the block and the spring launches it across a frictionless surface toward a large block of mass m_2 = 4 kg that initially is not moving. After the collision the small block comes to rest.

The large block then slides over a long, rough section of the track having a coefficient of kinetic friction μ_k = 0.25, and is eventually brought to a stop after some time interval Δt.



How many seconds will the large block slide across the rough section?

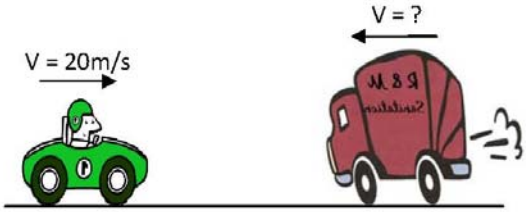
Is the collision elastic, inelastic or maximally inelastic?

Step 1. $E_i = E_A$ $\frac{1}{2}(288\text{N/m})(0.5m)^2 = \frac{1}{2}(2kg)v^2$ $v = 6\text{m/s}$	**Explain step 1.**
Step 2. $p_i = p_f$ $(2kg)(6\text{m/s}) = (4kg)v$ $v = 3\text{m/s}$	**Explain step 2.**
Step 3. $\Delta p = F_{ave}\Delta t$ $\Delta p = p_f - p_i = 12kg\cdot\text{m/s}$ $F_{ave} = \mu_k N_{surface,block}$ $F_{ave} = (0.25)(40N)$	**Complete the step to find the time taken for the block to come to a stop.** *(ans. 1.2s)*
Step 4. $E_i = KE_{\text{small block}}$ $E_i = \frac{1}{2}(2kg)(6\text{m/s})^2 = 36J$	**Explain step 4.**
Step 5. $E_f = ?$	**Complete and explain the last step.** *(ans. inelastic)*

CP #14

A car of mass m = 1000kg with speed 20 m/s collides head-on with a truck with mass M = 5000kg. After the collision the two vehicles stick together and continue moving as one vehicle with speed of 10m/s to the left.

What was the speed of the truck before the collision?



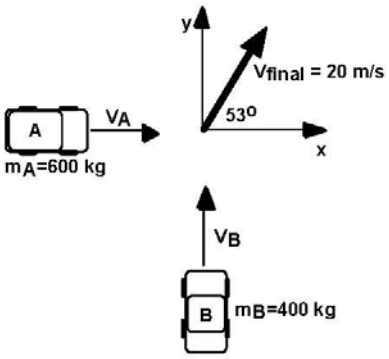
Step 1. $p_i = (1000kg)(-20\text{m/s})$ $p_i = -20000kg \cdot \text{m/s}$	**Explain step 1.** *What is the significance of the negative sign of the velocity?*
Step 2. $p_i = (5000kg)(v_i)$ $p_i = 5000kg \cdot v_i$	**Explain step 2.**
Step 3. $p_f = (1000kg + 5000kg)(10m/s)$ $p_f = 60000kg \cdot \text{m/s}$	**Explain step 3.**
Step 4. $p_i = p_f$	**Complete and explain the final step.** *(ans. 40m/s)*

CP # 15

SUV (car A) is moving East when it collides with a Volvo (car B) that is moving North. The cars collide at the point represented by the origin of the coordinate system and lock bumpers (becoming one ugly car with eight wheels). Just after the collision they have velocity 20 m/s at an angle of 53° North of East, as shown. The cars then slide across the pavement and come to a halt.

Find the speed of the SUV (car A) just **before** the collision.

Find the speed of the Volvo (car B) just **before** the collision.

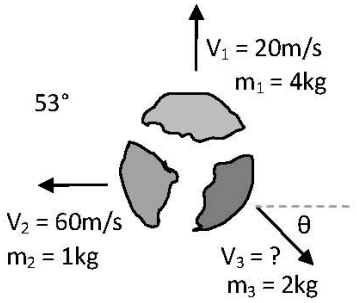


Step 1. $p^f = mv_f$ $p^f = (600kg + 400kg)(20\text{m/s})$ $p^f = 20000kg \cdot \text{m/s}$	**Explain step 1.** *Why do we need to start with the final momentum?*
Step 2. $p^i = p^f$ $p^i = 20000kg \cdot \text{m/s}$	**Explain step 2.**
Step 3. $p^i_{suv} = p^i_x = p^i \cos 53°$ $p^i_{suv} = (20000kg \cdot \text{m/s})(\cos 53°)$ $p^i_{suv} = 16000kg \cdot \text{m/s}$	**Explain step 3.** *Why is all the initial momentum in the x direction equal to the SUV momentum?*
Step 4. $p^i_{car} = p^i_y$	**Complete and explain the final step.** *(ans. 30m/s)*

CP #16

A demolition team is experimenting with a new bomb. The bomb is initially at rest. Immediately after the bomb explodes it breaks into three chunks. Chunk 1 has mass m_1 = 4kg, chunk 2 has mass m_2 = 1kg and chunk 3 has a mass of m_3 = 2kg.

Find the velocity (magnitude and direction) of chunk 3 **after** the explosion.



Step 1. $p_i = p_f = 0$ $p_x^i = p_x^f = 0$ $p_y^i = p_y^f = 0$	**Explain step 1.**
Step 2. $p_x^f = (1kg)(60\text{m/s}) - (2kg)(v_{3,x}) = 0$ $v_{3,x} = 30m/s$	**Explain step 2.**
Step 3. $p_y^f = (4kg)(20\text{m/s}) - (2kg)(v_{3,x}) = 0$ $v_{3,y} = 40m/s$	**Explain step 3.**
Step 4. $\theta = \tan^{-1}\left(\frac{40\text{m/s}}{30\text{m/s}}\right)$ $\theta = 53°$	**Explain step 4.**
Step 5. $v_3 = ?$	**Complete and explain the final step.** *(ans. 50m/s)*