FORMAL MODELLING IN AN INTRODUCTORY COLLEGE PHYSICS COURSE

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Abstract

Many science education researchers suggest that students taking introductory physics courses should emulate the behaviour of professional scientists by learning to construct (and use) formal models. Largely this research has been done at the high school level. I believe that this approach must also be tested at the college level for two reasons. First, many college students may never have done a physics course before. Second, those who have probably did not learn via modelling but by a less sophisticated method. The result is that neither student is distinguishable on a conceptual test about the nature of the physical world. The main goal of my research is to determine the feasibility of the high school modelling method proposed by Hestenes and Wells when the approach is applied to a technical college's introductory mechanics course. During the fall and winter of 1997 and 1998 I trained a young physics instructor in this method. During that time I monitored his efforts with fresh and repeating students in the same course. In the fall of 1998 I repeated the study with fresh students of my own. The conceptual gains of both groups were cross-referenced and then checked with a non modelling control. My results showed that modelling did significantly improve conceptual understanding of the Newtonian world. However, the prescribed method is not practical given the time and content constraints of the typical college level course.

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Acknowledgments

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Chapter 1: Modelling in Physics Education

Introduction.

One often hears the question, "should we be satisfied with the current state of physics education?" Many people think that we should never accept the status quo when it comes to the reproduction or continuance of our society. According to Miller and Seller (1990) a core of educational theorists, known as the social-change group, believe that schools should develop student autonomy and not reinforce conformity. This is a main goal of any modelling curriculum. Sometimes people of this mind set preach that things are in shambles so we must fix them. Such claims may or may not be true. Other times they merely ask, "Can we do things better?" Typically a social-change theorist wants to know if our schools will lead our students to a good sense of efficacy (Miller and Seller, 1990). Depending on the country of research, we can find people making both types of claims about changing the way we teach introductory physics. While I do not believe the situation in Newfoundland is critical, I do feel that we must look out for new ideas and practices that may enhance how we teach and learn physics. We need to ask if our teaching practices promote student autonomy. One method that might do this is modelling oriented instruction. Before I can continue with the purpose of this study, I must clarify some critical concepts about physics instruction and scientific modelling.

Traditional approaches to physics teaching.

In most of the literature on modelling in science education one sees warnings about "the traditional physics course." These researchers assume that the "traditional physics course" is a universal experience. I have no doubt that there is a general collection of practices we consider "traditional." However, the precise details of delivery and content of these so called traditional courses are not uniform.

Many practices are almost entrenched universal habits of physics teachers. From my experience these include an appearance of knowing the answers, always being right and as the source of physics knowledge, i.e., a reservoir of facts. As a result we often expect physics teachers to lecture or pass out their scientific wisdom. We expect students to absorb all that the teacher says and then regurgitate these facts. It may be argued that society falsely believes that this is the mark of a master student. From my experience I recall spending four weeks teaching radiography students how to structure their knowledge in concept maps. I was disappointed to discover that they felt that this was just another set of facts to memorize. These students failed to appreciate that I was not teaching them "facts of scientific knowledge," but a way to think. As a result they did well on a national factual-based examination. Yet, I still believe that some of them learned little else. In a traditional sense I achieved a high degree of success, high scoring students, but I do not think that this had been a successful experience. Simply, lecturing fails to promote student reflection (Richards, Barowy and Levin, 1992).

Another mark of the traditional physics course or teacher is the use of "cookbook laboratories." Such laboratories have explicitly presented a purpose of study, procedure and concluding questions. The purpose of study is usually to verify that some principle in science works as a textbook says. Usually students have two to three hours to complete these laboratories. Time constraints do not normally allow for further exploration of arising phenomena or detailed analysis of more fundamental ideas. In keeping with a factual orientation, students may attempt to plow through many of these laboratories. Often they are going through the motions without time to reflect upon their findings.

Finally, many traditional physics courses emphasize problem solving. This often means we instruct the students to do many problems found at the end of the appropriate chapter in a textbook. Then we give them assignments and tests that have similar problems. We know such problems as "type-problems" which are often of contrived situations. As a result our students learn that all physics problems are solvable using a formula-seeking algorithm. This constraint-based reasoning relies on listing known and unknown quantities, then seeking a formula that uses the quantities. The best students are the ones who discover this algorithm first, while the poorer students often do not realize these algorithms until it is too late. Unfortunately students who rely on these algorithms to seek equations usually do not understand what they have done. According to White (1993) and Hestenes (1992) this approach blinds students to the underlying concepts and structures of the physical world.

In a traditional physics course a student learns that physics (science) is the pursuit of numerous fragmented facts, experimental proof that shows these facts are true and that understanding physics comes down to being good at mathematics. We disservice our students, if this is all they get out of a physics course. One might expect a student of such a course to be a good copy, but no more, of an introductory textbook. The trouble with most traditional approaches is their failure to promote autonomy and self efficacy.

Smoke and mirrors: the illusion of new approaches.

I asked myself if the new approaches to teaching physics remedy the short comings of the so called traditional method? The answer to this question may not depend on the overall nature of a new curriculum but on its details. Alternate approaches to teaching physics such as cognitive conflicts, cooperative learning and inquiry, are, on their own, insufficient to cause conceptual changes in students (Richards et al., 1992).

Inquiry programs will achieve little if they do not engage the student's brain with their hands. Furthermore inquiry is not a random, discovery-oriented exploration of nature. One cannot just tell students to go out and observe, then expect them to learn all there is to know about physics. While some induction is acceptable, we must find a way to get students to look beyond the obvious. One may run the risk of not leading the students to learn beyond the obvious.

Another attempt to break out of the reproductive nature of physics education is the problem-solving curriculum. Again I ask if these programs take students from a factual oriented to a process oriented perspective? Let us look at the details more closely. Doing countless problems without paying attention to the reasons why we are doing them is not helpful. It does not seem to matter if the problem is realistic or from a textbook. According to Halloun and Hestenes (1986) the issues, concepts and misconceptions addressed by the problem have the biggest impact on conceptual shifts in the student. We often wish that our students learn some general analysis techniques that they can apply in a universal way. All too often they attempt to memorize each solution as a template. This is a futile effort because of the infinite number of variations they must learn to become expert problem solvers. For example, say a physics teacher assigns 24 textbook problems and a 12-question assignment. Then he or she promises the students that one question on their next quiz will be an exact copy of an assigned question. Rather than work on all these questions diligently many students will look up the solutions in an answer manual or get tutors to solve these problems for them. Then they will commit the questions and corresponding solutions to memory. When they take the test, they will match the quiz questions to their list of questions and then replicate a memorized answer. What will they do with the unseen questions? Chances are they will try to fit a different memorized solution to them without a clue about what they are up to and what they should be doing instead!

With both problem-solving and inquiry curricula, the key to their success lies in the details. These programs may only improve either autonomy or self efficacy but not necessarily both. How we manage our classrooms and what we have the students do, may be the most critical element towards curriculum success. Hestenes (1992) criticizes the "general cooperative" approaches, such as inquiry and problem solving, for failing to promote reflective and critical thinking because they often lack a focus on student misconceptions and their correction. Furthermore, reflective thinking often seems absent in most inquiry and problem-solving approaches (Hestenes, 1992). Without such planned refection time for the students one cannot expect them to change the conceptual frameworks. Before we can focus on those critical details needed in any new approach, we must agree upon the desired outcomes of a successful curriculum.

Curriculum outcomes.

We all know the three T's of curriculum: transmission, transaction and transformation. I believe the main goal of a good physics curriculum is transformation of a student's view on the physical world. However, I must elaborate on the nature of the transformation I seek or I will be guilty of ignoring the details.

Almost any form of education will produce a transformation of some sort in a student. However, I am not interested in just any change. I want to see a physics curriculum that produces specific changes in our students. First, a good physics course should emphasize the processes that scientists use to create knowledge (Hestenes, 1992). These processes include the physical procedures used to collect data and analytical procedures that control the data collection process. The analytical skills seem weakest in novice physics students. We can easily teach the analytical skills through a modelling method.

Suggesting that the next transformation issue of a good physics curriculum is bringing students from a naive conception of nature to a formal conception accepted by many professionals in the field is reasonable. Many papers I have read allude to this theme as a goal of a modelling curriculum. This process is not strictly in the domain of modelling. I believe that it is more in the domain of classroom management. However, modelling can serve as a focal point for causing conceptual change in a student. It is here where the precision of modelling theory and the art of teaching must mingle. The boundary between these concepts becomes vague and illusive to both the teacher and student. Making this boundary clear for the teacher may be a significant factor in the successful application of a modelling oriented curriculum. However, we can cause conceptual change in many ways. In the true spirit of transformation this change has to originate in and be controlled by the student. This means that modelling must be student-centred to achieve the transformations we want. If this occurs, students will have an increase in their autonomy. One may consider this a positive side effect of the method.

In summation, a good physics curriculum should lead students to act more like professional scientists, i.e., good self and skill-efficacy. I am not suggesting that all physics students will turn into miniature physicists. All I am suggesting is that they come to understand is some small way how physicists view the world around them. That is, what things make a physicist different from a fiction author. As they gain insight into how the scientists behave, they will also gain insight into what scientists believe or think. The purpose of such a curriculum is not to produce new scientists but dispel the population's general ignorance of science.

Terminology.

Before I elaborate on what modelling might do for learning, I must illustrate what it is. Throughout this thesis I refer to models, modelling, the modelling cycle, theories and reality. It is important that the reader understands how I use these terms when I write and think.

Many modelling researchers share a similar definition for the term model. Models are tools that scientists use to simplify reality when conducting research and solving problems (Richards et al., 1992). Specifically models are representations of how a theory exists in what we know of reality. Models might help us visualize the very abstract such as vectors to represent forces. Also, models provide simple and quick icons of real things. In physics we use dots to represent real world objects such as automobiles. Because models are representations of complex things and concepts, they may only have the attributes with which we are most concerned. For example, a particle model reduces all complex objects to tiny points of mass that we can map onto some reference system. This model is good for translational motion. Things such as an object's colour and shape that may not influence motion, are not portrayed by our model. In science we may use many models. Table 1 lists some common types of models.

Table 1

Common Models in Science Education

- Analogies
- Concept Maps & Concept Webs
- Vector Diagrams
- Iconic Models
- Graphs
- Mathematical Equations
- 3-D Scale Models

While this list contains some common types of models, I should also point out some classes of models. Webb (1993) notes three ways to group models: concrete, mental and formal. Concrete models have a tangible nature and represent physical structure. They usually do not tell us much in a quantitative sense. Mental models are transitional representations in our minds. They exist as mental representations that aid in the transformation of our schema of reality. Finally, we have the formal models. These models are the ones we use to make predictions about nature. Often they are quantitative and depend upon mathematics for their structure. Such models do not attempt to describe reality but do predict the outcomes of specific phenomena.

Modelling is synonymous with the modelling cycle. These terms refer to the routines used in creating a model. However, the routine details will vary as a function of the model one is trying to create. Usually a modelling cycle would begin with a situational analysis, followed by the model development stage. Models can develop as products of experiments. Once we create a model to deal with some phenomena, we must test its soundness. Finally we may deploy proven models in related problems. When modelling, analytical and critical thinking skills are crucial.

Theories and models are often viewed as interchangeable. Many textbook authors such as Giancoli (1998) say that they are not. Models translate theory for direct comparison to reality. Theories and laws are our ideas on how things exist in reality. Some problems arise from such a definition of theories and laws. These problems are the focus of metaphysics and philosophy. It suffices to say I treat them as distinct ideas. For example a free-body diagram is a model. The general interpretation of the free–body diagram is often the theory or law.

At this point my definitions have shifted onto some philosophical issues. However, it is my opinion that one cannot ignore these issues. An important issue is defining reality and comparing it with objective reality. Barnett (1948) and many others claim that we are incapable of observing an objective reality because we filter all observations through human perception. Many arguments show that our perception and experience guide what we see and know. Therefore, objective reality is mythical. For purposes of introductory modelling, we express reality as the tangible things and outcomes that surround us. However, one should not get hung up on this weak definition at this early stage. I hope to explore it in depth later. Please recognize some functional models have no observable connections to reality other than real outcomes that match the outcomes predicted by the model. For example, no one has seen a light wave although we talk about light as a wave and have made correct predictions using this model. Ultimately our perception of reality, models and theories are all a part of the abstract. The challenge is in learning to deal with these abstractions.

Modelling curricula.

One may ask, "What is the big deal about modelling curricula?" Modelling-oriented curricula are not new or indeed a curriculum. This idea should at best only be a component of an inquiry / problem-solving curriculum. Modelling provides the details that can cause transformation outcomes in the new curriculum designs. Without a modelling focus new curriculum designs run the risk of being no more effective than the traditional approaches.

When students model, they must actively assess a situation. They must distinguish between what is important to know and what is trivial. To be able to decide, they need to be aware of and control the direction of learning. They cannot just blindly do laboratories. Students often do not interpret inquiry activities as we would like them to (Richards et al., 1992). Models help students relate experiment to theory. Pre- and post-laboratory analysis is critical to making the inquiry experience purposeful. This is the situational analysis that I referred to in the description of the modelling cycle. Modelling can contribute to the success of inquiry programs (Webb, 1993). Another goal of modelling is to create descriptive or causal models. This goal should be perpetually in the spotlight. Students need to know why such models are important and that their efforts to create such models are valuable.

This type of curriculum should relate mathematics and art to science in a meaningful way. Teach the students that algebra, graphs, vectors and eventually calculus, are the modeller's most powerful analytical tools. Using them in the pursuit of scientific knowledge may add to the student's motivation. A result of this should be that students learn to create solutions rather than fit formulas. As often seen, the novice student engages a formula fitting algorithm, mindlessly checking a list of known variables and unknown variables to a list of formulas. Problem-solving in a modelling curriculum initially may be the same. However, now the student must compare novel situations with modelled situations. When they make matches, they then understand how to continue with a solution.

Next, modelling-oriented curricula make students engage their critical thinking skills. They must evaluate their models against reality. Also, modelling gives students a chance to explore their preconceptions in a more scientific way. This can lead to a change from their everyday beliefs to views that have become more accepted by physicists. Ultimately, modelling is a process that leads to some domain-specific, critical-thinking skills and improved scientific literacy.

Support for these claims is offered in Chapter 2 in the section on Modelling Curricula page 29. I assure the reader that researchers such as Hestenes, Webb, Wells, White and many others have verified these claims experimentally. Based on my literature search, I contend that it appears that those students who model are better off than non-modelling students. They learn more about scientific process, have a deeper understanding of content and learn the value of criticism better than non modelling peers.

The crux of my study.

In this study I examined the application of a modelling curriculum as described by Hestenes and Wells (1995) to an introductory level college physics course. I explored three major questions:

The first thing I wanted to know is if the modelling method as described by Hestenes and Wells is applicable to introductory college physics? One issue with the modelling method is that it requires more time than the traditional approaches. Many high school modellers require seven months to cover approximately 90% of the curriculum covered in a typical introductory college level course in mechanics. At the college level we cover more content than high school but perhaps in less detail. Also, we cover it in thirteen to fifteen weeks. I suspect that this method needs radical modifications for college use. During this study I looked for possible modifications for efficiency and their impact on the student's responsibility to learn. Remember that student-centred learning is a central issue in the high-school application of modelling. It should remain a goal for the college course too. So in asking if the method is applicable to college I will want to know if student autonomy increases.

At the college level, does a model-based approach cause a greater conceptual change in students than a traditional lecture-based method? It has been shown that at the high school level (Wells and Hestenes, 1995) and even elementary students (White, 1993) who model learn far more than their non-modelling counterparts. If modelling can be successfully applied to the college level then I believe that superior conceptual changes should result. Answering my first research question is not enough. We need to know that modelling at college is more than possible but that it is worthwhile.

Finally I asked how does modelling impact the college teacher? During this exploratory study I trained an instructor in the theory of models and modelling. This training was similar to Dr. Hestenes's workshops except that I placed a greater emphasis on the issues underlying modelling. During the mechanics semester I wanted to see if he adopted these techniques as a part of his teaching practice. This was done by observations and informal interviews. Finally, I wanted to know if my training program changed the teacher's views and beliefs about models in science education. For this I used Smit's (1995) teacher survey on scientific modelling knowledge.

Chapter 2: Literature Review.

Introduction.

Earlier researchers looked at several major themes in modelling pedagogy. The most prevalent research is on the development of modelling curricula. Hestenes's modelling cycle, the MARS project and ThinkerTools are just a few such curriculums. A close second in popularity is software evaluation, namely software that can serve as modelling environments (STELLA, ThinkerTools) or models of extraordinary environments (the Virtual Frog). Some researchers wrote about the nature of scientific modelling, while others researched our knowledge and preconceptions on scientific models. Finally one can find a collection of articles that look at special and unique aspects of modelling in teaching. These articles include how modelling improves the quality discourse between students, its role in special education and the role of model clarity in learning. I have begun this chapter by reviewing those articles that help frame the nature of modelling, the roles of models in science education and the motivation for most modelling research.

Formal definitions.

I have already laid out some informal ideas about models and modelling. Most researchers attempt to define these terms philosophically. This is often found in a preamble about modelling and what it is. Generally they all say the same thing with only slight variations.

The first question many researchers attempt to answer is, “what are models?” "A model is a surrogate object, a mental and/or conceptual representation of a real thing (Andaloro, Donzelli and Sperandeo-Mineo, 1991)." Andaloro et al. acknowledge that this is not as precise as some might wish but it is sufficient for creating a definition of modelling. I believe that it is also a good starting point for a more precise definition of a model. Richards et al. (1992) defines models by what they allow us to do and some common characteristics. He claims models are constructs that aid in explanation and understanding, analogical devices, often visual, that simplify a situation. A model is a set of rules that describes or explains the potential behaviour of a system (Richards et al., 1992). Webb (1993) defines models as formal representations of problems, processes, ideas or systems. Models are never complete replicas of the modelled subject. However, she limits her definition by excluding models that cannot give precise representations. Hestenes in a presentation (1997) said that "Models are units of coherently structured knowledge used for analysis, description, and comparison of experience." From my own experience I see that a definition of a model is difficult without putting it into context. Many authors have defined models in the terms of how we use them and not about what they are. This is similar to many fundamental concepts in physics, such as energy and force.

If asked "What is a model?" I would reply that a model is a simplified representation of either a real world process or object. However, I doubt that this is the definition I would use. My functional definition of a model would start the same but I would include how one uses a model. Models are simplified representations of real world objects or process that one can use in situational analysis and to relate the implications of theoretical knowledge to observable features in the real world. In theory, net force is the only thing that can change momentum. In reality, we can see changes in momentum but not the actual forces responsible. Using the vector as a model of force and vector analysis techniques, we can make predictions about the motion of an object from our theory and check them against reality. Most of the researchers I have read would agree upon the general usage that I suggest. Often they address four uses for models: a pre-analysis tool for inquiry, a post-analysis tool to validate the inquiry, a tool to explore the implications of a theory and as a guide for dealing with problems (Webb, 1993; Andaloro et al., 1991; Hestenes, 1987).

Other researchers try to classify types of models. It is here where different researchers have multiple meanings for some key expressions. Webb (1993) divides models into three distinct categories: concrete, conceptual and mental. Concrete models are formal external representations of phenomena or objects. Most of the models presented and developed in modelling-oriented curricula are of this type. Conceptual models are the unifying theories and laws that concrete model transcribe. Mental models are short-lived models that we use to grapple with new experiences. Similarly, Andaloro et al. (1991) write of mental models as physical intuitions that serve as bridges between our schema and the physical world. The notion of mental models as physical intuitions is troublesome. Both Andaloro et al. and Webb view mental models as positive concepts in learning. However, it is physical intuition or common sense that most often acts as an inhibitor when learning physics. One's intuitive knowledge is often in conflict with scientific knowledge (Richards et al., 1992).

Next, many researchers address the question, "What then is modelling?" Richards et al. (1992) claim that modelling is a way of thinking. While this is true, it is not particularly informative. Modelling is a fundamental intellectual scientific activity that enables people to simplify the complexities of the real world (Paton, 1996). My goal now is to illuminate these phases of this activity. According to Webb (1993), modelling is a six-stage process: identify the target subject, define the purpose of the model, determine the modelled attributes, develop relationships between the attributes, evaluate the model by testing and examining outcomes of the model in relation to its stated purpose and revise the model. Hestenes (1987) proposed a four-stage cycle of modelling. The first stage, called model description, encompasses Webb's first three points of problem identification and detailed situational analysis. All of this is done from the perspective of a chosen purpose. Next is the formulation stage. At this point a model is created using appropriate analytical techniques and empirical data. Then one would determine the implications of the new model. Finally, one would apply this model to new phenomena and see if it can increase our understanding of the unknown. Always, this model may be adjusted or improved. In short, modelling starts with a real world problem, goes to an abstract creation and explanation phase, and then is supported with real world observations (Andaloro et al., 1991). We declare the modelling process successful if we create a model that can: represent the studied experience, validate the representation and continue the exploration of new problems (Andaloro et al., 1991; Prior, 1986). Finally modelling allows us to use imaginative visualizations and projections of problems (Osborne and Gilbert (Webb, 1993)). Table 2 offers a summary of uses for models in science and science education.

Table 2

Uses for Models
• simplify reality
• impose structure so connections and patterns can be found
• suggest new perceptions of reality
• relate theory to the observed world
• reapply models to the real world organize data around a framework
• promote the construction of theory
• facilitate the communication of ideas
(Hagget and Chorley (Webb, 1993))

One final issue that is found in the preamble of most modelling studies is speculation on the need for modelling in science education. Many reports have shown that these speculations are justified. Again these points are often presented as philosophical arguments.

The need for modelling in science education can be broken down to two ideas. First science should be taught as science is done. Scientists use modelling and model-based reasoning to make the abstract concrete, to simplify complex phenomena, to predict and to explain mechanisms and process (Raghavan and Glasser, 1995). On reading this one might rightly say that if the scientist does this, then why not have the student use model-based reasoning? Modelling is a major technique in science where scientists try to create their unifying theories (Webb, 1993). Modelling allows us to create knowledge and teaches us about the nature of knowledge. Therefore, a science student should come to appreciate this fact through the practice of modelling (Webb, 1993). When delving into the unknown, scientists must have ways of seeking and creating new information. Rather than just report what is seen scientists speculate on the reasons why. These reasoning games lead us to greater understanding than induction alone. It is only right to show this to students, by making them play these modelling games and not to tell them how the game should end.

Second, modelling is the critical element in conceptual change. When modelling, students are in command of their own learning, we give them the means to create knowledge and learning. Teachers guide students to the means to create knowledge and not just the raw facts (Webb, 1993). A constructivist teaching cycle, as portrayed in the Children Learning Science Project (CLSP), has five main elements: focusing student attention on an issue, eliciting student ideas on the issue by encouraging students to verbalize them, using situations that allow them to assess their ideas, applying new ideas in a wide range of contexts and having students monitor their own learning (Webb, 1993). The modelling process, cycle, meets these criteria. Modelling demands that the student critically examine his or her ideas. Niedderer, Schecker and Bethge (1991) claims that model construction and concept formation go hand in hand.

I have presented the previous material because it underlies most all of the modelling studies I have read. It also underlies my own research. From this point I will try to present some significant findings that have come from the research studies I have read.

Scientific fluency.

One concern in many educators' minds is scientific literacy. Norris (1997) suggested that the general populace often defines scientific literacy as the ability to understand or comprehend scientific information presented by experts. In a presentation of his paper on scientific literacy Norris said that this level of scientific understanding is impossible, even for the experts (Norris, 1997). He proposes scientific literacy is our ability to rate a scientist's certainty about his/her claims. We may then ask, how can we achieve this goal? Practice in modelling helps the student realize that scientific knowledge is manufactured and that the skill applied in its production relates to its reliability.

Another aspect of scientific fluency is the ability of a student to express information in an effective way. Modelling can give learners the skills to clarify and present his/her ideas (Webb, 1993). After all, it is a way of thinking and working in science. Keys (1995) studied the role of models and modelling in student discourse as a part of a post-laboratory analysis. Her study had three pairs of varied-ability, ninth-grade science students write a collaborative laboratory report. She found that models and modelling guided the form and content of student discourse during these sessions. Their discourse, which concentrated on ensuring group understanding, was based upon their system of models. Most researchers seem to agree that scientists express their ideas through models. Students can also learn to do this by using models as a focal point in group activities. However, I will note that here, models are not the only factor that could account for improved communication. Apparently, they will only help in an environment where student discourse is demanded.

Newton (1995) wanted to know if the textual presentation of casual models could help bring students to accept them. Newton acknowledges that the formation of models in a student's mind is ultimately a result of student effort. However, he argues that a text description of a particular model can influence the ease at which students develop their own models of understanding. He claims that understanding in science means being able to take a generalization and apply it to a specific situation. His results show that the description of a model can aid adolescent students as they create their own mental models. Models for light were used in this study. However, student motivation and effort are too critical to ignore. Also, he claims that a textual account is not enough to lead to student models. Unfortunately, he did not examine these other possible factors. Newton's study does seem to provide evidence that contradicts our beliefs about textbooks. Often we think that textbooks promote factual knowledge because authors cannot efficiently explain procedural knowledge (Andaloro et al., 1991). Newton's conclusion suggests that textual accounts of scientific phenomena can play a role in a student's modelling activities.

Modelling software.

This body of research supports much of the other research that follows. These researchers have analysed the logistics of software that can promote and support scientific modelling in the classroom. While important, they often place the cart before the horse. A clear modelling strategy must precede the software and its deployment in a classroom.

Andaloro et al. (1991) focused on the role of simulation and programming as modelling tools. They have a well-developed understanding of modelling theory and is very contentious about the relationship between modelling theory and pedagogical issues around computers. They caution us that computers can easily handle the most difficult models we can create. The problem is making sure that the computer will help the students' assimilate such models. One way a student may achieve greater understanding of physical models is by writing or modifying computer simulations of these models. Some, such as Niedderer et al. (1991), believe that programming is not the way to learn physics, although physics problems may be good opportunities to learn programming. According to Andaloro et al. (1991), a simulation would allow a student to control the initial conditions of a model and observe the outcomes. They describe a simulation as application software for modelling. It is not a general purpose piece of code. Andaloro et al. pose two crucial questions at the start of his paper. First, how can we make physics easier to learn? Second, what is essential to learn in an introductory course? Clearly they feel simulations will allow students to develop descriptive modelling skills and interpretation skills on model outputs. However, details that control the functioning of the model may remain concealed. I would wonder if programming in macros could overcome this shortfall? Another possible implication of simulations is their role as a focal point for student discourse. Unfortunately, this study was purely philosophical. For that reason we could not make any claims about the validity of the ideas expressed.

Richards et al. (1992) also write about software simulations in science education. Their article has a general outline about modelling, a simulation pedagogy and anecdotal descriptions of "The Explore System" simulation software for Macintosh. They do not support the idea that model construction is fundamental in learning. Richards et al. claim that many students lack essential prerequisite skills for model construction. However, they do not tell us anything about these students, e.g., grade level. Despite this, they claim that novice physics students can easily learn to use and analyse models. Several times they deem such rationalizing and analytical skills as critical for learning. Richards et al. states that students are unprepared for model construction because they lack the complex mathematical skills and/or do not understand the modelled experience (Richards et al., 1992). However, I believe on this count Richards et al. have made a slight error. The analytical features of "The Explore System" use mathematical techniques such as graphing and tabulating data that are at the core of models construction in an introductory physics course. I think the real issue here is whether or not the students have the essential experimental skills. Another critical element about using simulations is relating them to reality, i.e., comparing the outcomes suggested by a simulation to the outcomes from an experiment. In short, they argue that simulations are an effective way to reap the benefits of modelling when a student lacks essential modelling skills. This software is most useful when analysing phenomena and making comparisons to experimental situations.

I will now introduce a different class of application software for modelling. In the late 1980's High Performance Software developed STELLA, a dynamic modelling software (DMS). Niedderer et al. (1991) and Schecker (1993) have attempted to assess and apply this program to physics education. Unlike simulations, students must assemble a model on the computer before they can analyse it. STELLA uses five icons, Figure 2:1, to construct formal models that appear as concept maps, Figure 2:2. Each icon has a built-in mathematical process such as rate function, variable name or user defined function. Students can run these models to generate graphs of the key variables as a function of time. The advantage of this system is that the student can construct relationships between key variables. They may even control the exact nature of the relationship, e.g., linear or squared. The drawback is that these models often require that students know a relationship such as **F = ma** before they can construct models of real world situations. As a deployment tool, the dynamic modelling software may be extremely useful but as a creation tool it is no better than a simulation. The main advantage to STELLA is that it can show how a chain of concepts are related, e.g., force effects acceleration, which affects velocity, which determines position. These chains allow us to examine very complex situations without getting lost in the mathematics. Other advantages of this program include that models can be saved and shared to promote student-centred learning, discourse and allow for model revision. Niedderer et al. used this software on 16 - 19-year-old German students and claimed improvements in the physics they learned. However, they only provide qualitative evidence as to the effect of modelling on STELLA. In 1993 Schecker wrote a report that summarized the advantages of STELLA in the classroom and commented on how we should teach from a modelling perspective. Both Niedderer et al. and Schecker have suggested a modelling cycle with similar stages to Hestenes's cycle.

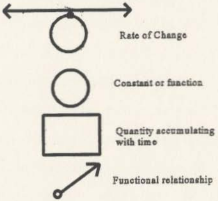

Figure 2.1: Basic STELLA icons

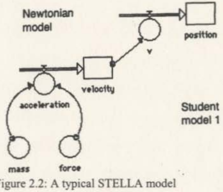

Figure 2.2: A typical STELLA model

Around the same time Dynamic Modelling Systems (DMS) made their first appearance, an early spreadsheet was developed called the Cellular Modelling System (CMS). Holland (1988) tried to compare dynamic systems with the Cellular Modelling System. This report was like an automotive review between competing sedans. In his report he claims that computers are ideal for modelling because these machines can serve as flexible platforms for our ideas. He argued that this technology would be most useful if we can get the student to use it as is. Before this, modelling on a computer required knowing how to program. This task is so difficult to master at first, he suggested, that students modelling by writing programs would lose sight of the physics they were creating and become focused on the code they were writing. The overall gist of his article is that DMS of the day lacked certain features about the display of data and information. This amounted to an ability to explain and describe the terms in the model to an end user. He wrote his CMS to compensate for these problems. However, he wrote this for the BBC machine (a once popular British computer in their public education system) that has become obsolete. Furthermore, modern DMS and spreadsheets have made great strides in correcting their early deficiencies. Holland gives one final note regarding the role of experimentation and CMS. He says that relating the output of CMS (or any modelling software) to real experimental outputs is important.

In 1993, Webb outlined the findings of the Modulus Project regarding student computer use and modelling. At this time she examined five families of modelling software: DMS, Spatial Distribution (SD), Qualitative Logical Reasoning (QLR), Probabilistic Event (PE) and Data Analysis (DA). DMS requires the construction of relationships in iconic diagrams and more importantly the writing of mathematical statements. Often students cannot handle these mathematical problems. Either through STELLA, spreadsheets or other programs this form of modelling proved too advanced for middle-school children. However, Model Builder, which has the analytical abilities of a DMS but uses fewer abstract models, i.e., it focuses on the objects and not just the interactions, proved better for this age group. SD systems illustrate the position of objects in space and their physical motion. Such packages are helpful in the study of physics. PE systems focus on the bases of a model and not just its outcomes. These packages are often used in genetics research. Again she states that these are far too complicated for use in middle schools. QLR systems do not have quantitative outputs as do the previous modelling systems. While they do not help students generate formal relationships, they can be used as simulations that can help develop a student's scientific intuition. Students can choose their hypothesis, apply logical reasoning and draw conclusions. At the time, programs such as Prolog were not graphical. Thus, it was uninviting to student users. The notion behind this type of software seems promising but it needed further development. Finally, she examined DA packages. While such systems do not provide information about making models, they can help students develop certain analytical tools to create and validate formal models. Overall, Webb (1993) concluded that the DMS approach was the most useful at middle school but it needed refinement.

Webb (1993) concluded that STELLA was easy to use and the students had no trouble with the interface. However, it was not helpful when it came to understanding the underlying principles of modelling. That is the justification of the mathematics behind the models. She also examined the CMS that Holland designed. It was better at showing the importance of mathematics in formal modelling. However, its abstract nature was troublesome to the students. She said they would resort to paper sketches to illustrate their models. These two systems lead to the creation of the Model Builder, a program with the graphical abilities of a DMS while using the descriptive features of the CMS. The Modulus Project tested this program on level eight students in Britain. Students created descriptive and predictive analogies for thermal regulation in humans based on the similar regulation in a typical house. However, this paper was a software review. The effectiveness of the Modulus Project was evaluated in another article.

One might ask why I am looking at information technology when my interest is in student modelling of phenomena? The simple answer is one cannot ignore the current push to use IT in the academic environment. Having a basic understanding of what is available is important for teachers. Now they can decide if the software is useful. It appears to me that frequently simulations and modelling software do not contribute to the creation of student models. These programs are more effective as validation and deployment tools. Programming is not conducive to learning physics because one has to learn to program before one can understand the physics being programmed. Therefore, application type software appears to dominate the literature. Two examples of more useful software for model construction are the data analysis programs such as Graphical Analysis and modern spreadsheets. Another important point when using modelling software is to keep in mind the purpose the program must fulfill. When it comes to model creation, students need to control the collection of data, data analysis options and understand how to interpret the data. These are functions of the student mind. The software must only act as a platform to conduct such tasks, and not to remove them from the student's hands. A final point that is universal to all the software reviews is the need for an interaction between the computer models and reality. A student needs to know that implications of a model must be evident in nature. Otherwise, the model is not useful.

Modelling curricula.

A major focus of modelling research is on developing student-centred, model-based curricula. Teachers must be exposed to the different developments in this field. They must get a working knowledge on how to teach via modelling.

Science as model building was a major theme in Stewart, Hafner, Johnson and Finkel's (1992) study. Stewart and his cohorts devised a computerized modelling unit for introductory genetics. This unit focused on problem solving in genetics through model-revision. The unit had the classic markings of the modelling approach, i.e., showing students the contents of basic genetics through strategic student-centred learning and the true nature of scientific knowledge. Learning came through mirroring the practice of science, i.e., pose a problem, invoke a solution based on a known model and then public, though not peer, defence of the solution.

Four high school females and two males who displayed some competency at basic genetics were selected for specialized training. The training included thinking aloud while problem solving and thinking in the terms of basic genetic models. Each participant had several 50-minute periods to practice on familiar problems. The remaining three periods were used to explore new, often student-generated, problems in genetics. For example, given that certain genes exist in a population what is the likely outcome in the next generation? Students would describe the genetic makeup and present characteristics of the offspring. They would have to use predetermined models or invent new causal relationships to explain the outcome of problems. Finally they would need to assess the acceptability of their final models, i.e., Do their models merely explain or can they make predictions? One research problem was to see how the students accounted for anomalies between their models and the experimental outcomes.

Stewart et al. collected data with a tracking modelling software package, audio recordings of students' descriptions of their thinking, post problem interviews and student notes. They were looking for successive model revisions in an evolving situation, student justification for actions, sequencing of student action and overall problem solving trends. Their analysis procedure has been independently tested and verified.

"Model revising problem solving is a complex and challenging endeavour that involves a highly coordinated search between an experimental space consisting of all possible crosses and a model space in which explanatory models are evoked, revised, tested and evaluated (Stewart et al., 1992)." This attests to the nature of the student's task. This is apparently true throughout the data. Though a complicated process Stewart et al. discovered that problem-solving usually leads students to sound models of either an accepted or alternative branch of genetics thinking. Next, student revisions were cumulative over many problems. Finally, students typically found that model adequacy depended on the model's explanatory nature and not its predictive nature.

While this study addresses the nature of student thinking, Stewart et al. acknowledge the need for other types of learning research. Namely we need to study the role of persuasion in student-centred learning, modelling as a cooperative activity, and the teacher's role in this process. These are issues tackled by many other researchers.

The first article that I read on modelling curricula was written by White (1993). She proposed that pre-formal-operational students (sixth-graders) could learn to make and use sophisticated causal models. Students would create and employ alternate representations of force and motion on a program called "ThinkerTools." "ThinkerTools " has a clear entertainment value. It is structured as a game. After students gain a degree of expertise in using these models then they will apply them to real world problems. The key to her curriculum design is enhanced conceptual understanding and then linking new ideas to experience. According to White, modelling curricula should do three things. First, students must develop generally applicable (abstract) models. Second, while doing this, they should learn skills important in constructing models. Finally they must link their abstract models to the real world.

White's instructional cycle includes a motivation phase, model evolution phase, formalization phase and transfer phase. The motivation phase allows the students to analyse the problem situation and make predictions about the future. Next, models must evolve, i.e., students must make models that they can use to predict the behaviour of the dot object. They then conduct a test and evaluate their models. In the third phase students will derive formal rules to predict the behaviour of an object under the influence of different types of impulses. In the last stage, students will apply their new rules to real world problems. This curriculum cycle shows many similarities to the modelling cycle of Webb (1993) and Wells and Hestenes (1995).

White's force model is the datacross. This is a device that can represent the size of the x and y component of a net force. Moving objects are dots on a screen. Their motion is shown as a wake of small dots, placed at equal intervals. The wake looks like a ticker tape output. Finally, small arrows appear on the dot object when impulses are applied. The arrows point in the direction of the impulse. These are illustrated in Figure 2.3.

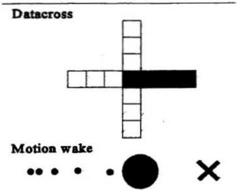

Figure 2.3: White's datacross and motion wake

White tested "ThinkerTools" in five classes of grade-six students in suburban Boston. One class was a pilot group with student-centred learning. Of the other four, two were control groups (37 students) and two were experimental (42 students). All students studied introductory mechanics for 2 months with 45 minutes of instruction per day. Finally, "ThinkerTools" students were compared with high-school students starting mechanics. Forty-one of the high-school students had done mechanics while 45 were starting mechanics. White obtained her data from classroom observations and three written posttests. The test featured analysis of models for implications and translation into English. Also, the tests looked at transfer of model knowledge to real world problems. The first two examinations showed that understanding a model is a prerequisite to learning a general law.

The third test looked at principle-based reasoning and not constraint-based, algebraic problem-solving. Two-way ANOVA showed that modelling had a significant effect on scores ($P < .0001$). White chose training and gender as factors of interest. Her results clearly show no interaction between training and gender. She also shows that being older or younger was not a factor.

As shown in Figure 2.4, grade-six "ThinkerTools" students were better at transfer problems than high school students. However, White does acknowledge that other reasons such as age, training styles, and selection, may account for the difference. Three-way ANOVA compared the grade six students based on the factors of training, gender and ability (according to the California Ability Test). Again no interactions were found. White found a high correlation between the test scores, treatment and gender.

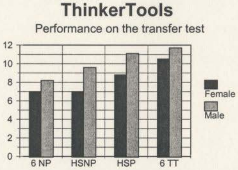

Figure 2.4: Performance results for White's study

The overall conclusion is that even young children can create models that help them explore the way the world works. While mathematical models were never created, these grade-six students did come to a clearly Newtonian explanation of the causes and nature of motion. More programs of this sort may help prepare students for more formal reasoning in high school.

The Modulus Project was an attempt to develop computer-based modelling across the curriculum. Webb (1994) used this project to set the goals and prerequisites for primary-school modelling. While she did not assess the success of this program, she used classroom observations to uncover the factors contributing to the success of some students. First, she stated that students at the primary level often need to learn qualitative cause and effect models. Mathematical models come after students understand how causes and dependencies are sorted out.

While Webb does state that this was not a perfect program it is intriguing because it starts with young children. The fact that these 9 to 11-year-old children can begin to model is quite remarkable. Using in-class observations, she found that successful modellers used multiple resources, kept cross-referencing reality with their models, kept on task, used language precisely, worked in an orderly manner, spontaneously engaged in inquiry, looked for flaws in their own models and used models as problem solving templates. Those who were less successful at modelling failed to achieve these behaviours.

The MARS Project was another American modelling project. During 1993 and 1994 Raghavan (1994) piloted a Model-based Analysis and Reasoning in Science curriculum. This program was intended to get grade-six children to use diagrammatic models to help understand and explain how or why things happened. The researchers used posttests on the children, classroom observations via video, student work and student interviews to find the effect of model-based education. While this research is only at the preliminary stages, the researchers felt that they had evidence showing outcomes and consequences to such an approach. First, modelling requires more time and covers less material. Next, spontaneous use of models requires experiences where models help concretize the abstract. Thirdly, most novice students view models as copies of an original. With practice they learn that models are tools for making real-world predictions. The fourth and final point was that student-centred learning was critical to the program. Teachers serve as facilitators by challenging false student ideas, and directing student attention to model inconsistencies.

Before I present Hestenes and Halloun's work, I must point out that Raghavan's study is not clear cut. We are not told much about the students involved except that they were in five different grade six classes in suburban Pittsburgh. Nor does the researcher suggest if this curriculum improved the children's learning.

The last reviews of modelling curriculums will be on those of Hestenes and Halloun of Arizona State University. These researchers along with others have been trying to address the problem of designing a physics curriculum that addresses student misconceptions effectively. Their research began in the early eighties and continues today. Originally they tackled the problem of understanding students' common sense views of the world at large. They devised a conceptual mechanics test that tested specific problems and offered Newtonian, Impetus and Aristotelian solutions. Later this test evolved into the Force Concept Inventory (FCI), which is an effective indicator of students' conceptual understanding (Halloun and Hestenes, 1985) (Hestenes, Wells and Swackhammer, 1992). It also can serve as a gauge for the effectiveness of a physics course. Based on the FCI, these researchers developed a mathematical mechanics test. The Mechanics Baseline Test (MBT) assesses student abilities to solve problems with various mathematical techniques such as graphing and formula analysis. After designing these instruments they then set about to explain how student answers to the questions could be interpreted. The final phase of their research is to develop a curriculum that causes a significant conceptual shift as shown with these or other instruments.

Halloun and Hestenes (1985) set out to study the effect of student misconceptions on learning physics. Unlike previous studies about misconceptions they intended to look at a broad range of mechanics misconceptions. To do this, one needs instruments for gathering student beliefs. The first instrument developed was the Mechanics Diagnostic Test. This was a conceptual multiple-choice test on motion and its causes. The distractors were based on written answers given by a thousand students to the same questions in a prototype test. Once compiled as a multiple-choice test they gave it to several physics professors and graduate students. These professors and students checked these questions for accuracy and correctness based on Newtonian principles. All agreed that the questions were well-framed and the correct answers were correct. Next, novice students were interviewed and asked to interpret the questions and distractors. None of these students showed any misunderstandings about the meanings of either the questions or answers. After this, the researchers interviewed different students, who also took the test. This time the goal was to see if the answers on the test were random or their true beliefs. Most students persisted with answers that were similar to their choice on the pen and paper test and did not show signs of getting the right answers for wrong reasons or the wrong answer with Newtonian reason. Finally, the comparison between the original open-response test and the final multiple-choice test showed that both would get at the same beliefs. Also, they used the Kunder-Richardson Test and got a 0.86 and 0.89 pretest and posttest coefficients. These high coefficients suggest high reliability in the test. Finally Hake (1998) determined that the probability of scoring higher than 20% on the FCI through random guess was low.

In the late eighties and early nineties Hestenes, Wells and Swackhammer (1992) sought to improve the Mechanics Diagnostics Test. The result was the Force Concept Inventory (FCI). The authors of the FCI used over half the original MDT questions. To ensure the validity of the instrument Swackhammer repeated the tests done on the MDT by having the test reviewed by experts. Also, he interviewed students who took the test to ensure they understood the questions, all possible answers and did not choose correct answers for non-Newtonian reasons or incorrect answers based on the rules of classical mechanics.

While Hestenes and Halloun developed the MDT, they also developed a pure mathematical skills diagnostic test. Eventually, this test was replaced by the Mechanics Baseline Test (MBT). The MBT examines the mathematical components of the ideas in the FCI. However, the questions are structured such that merely knowing the formulas is not enough to do well. Consequently, I believe that both the FCI and MBT are valid and reliable instruments. They have gained wide spread use by many researchers throughout the world. In many studies pre- and post-test grades have been following very repeatable patterns. This is despite the wide variation in teachers and locations (Hake 1998). These repeatable outcomes also lend support to the validity of these instruments.

Hake (1998) has studied the FCI and MBT because he used it as a part of his studies on interactive-engagement, including Hestenes modelling study. He had five things to say on the validity of these tests. First is that adequate testing on question ambiguity and motivation for responses have been done via teacher and student interviews. He feels the questions and corresponding choices are not misleading to the student. Furthermore, the answers are usually chosen out of some conviction in the student's mind that it justifies the scenario. Second, he does not see teaching to the test as a factor, considering how poor the test scores of all the groups were. This is not a reflection of the test itself but the data that I have chosen as a reference for this study. These figures are quote on page 60. Third, he had checked to see that all groups spent essentially the same amount of time on mechanics. The few groups who did spend more time did not necessarily do any better. Fourth he looked to see if students were given grades for the post test. Again very few groups were and those who did receive grades did not do better. I will also note the grades never accounted for more than 10% of the final mark. Usually they were around 5%. Finally he noted that MDT scores were typically 15% lower than FCI posttest scores. Problem solving lags behind conceptual knowledge.

Returning to Hestenes and Halloun's (1985) paper, the original mechanics and mathematics diagnostic tests were first employed to see if they were good predictors on success in an introductory course. It was found that the mathematics test was not an accurate predictor while the mechanics diagnostic test was a powerful predictor of scores. While a physicist's knowledge of the world is closely linked to a mathematical representation, this is not true for students (Halloun and Hestenes, 1985). Low pretest scores on the mechanics test show that misconceptions dominate a student's belief system. However, misconceptions of the physical world are independent of mathematical ability.

Through pre- and post-testing with the FCI, we can gauge instructional effectiveness. Halloun and Hestenes' results show that whatever the level of the course (high school to university), conventional instruction causes only small conceptual changes in students. The average gain on the FCI was in the order of 14%. Pre- and post-test correlations ranged around 0.60 to 0.76, showing little improvement from instruction. The low improvements suggest that student misconceptions are deeply rooted (Halloun and

Hestenes, 1985). Note that Halloun and Hestenes defined conventional instruction as three to four hours of lecture, problem-solving tutorial and some laboratory work.

Furthermore, they were concerned that instructor style may have caused an interaction effect. The four instructors they studied had very different styles. One instructor lectured, another used problem solving, the third used many demonstrations and the last followed the book very closely. All instructors in their study taught the same course with the same content-laden course outline. Since all teachers produced equal gains in the mechanics diagnostic test, Halloun and Hestenes concluded that these teaching styles did not affect learning. Essentially, the pre-test post-test comparison showed that students learned few new ideas from their teachers (Halloun and Hestenes, 1985). This suggests that their preconceptions remained intact despite these varied but common approaches to teaching physics.

A third important aspect of these tests was the classification of misconceptions and student belief patterns. Three main areas of beliefs displayed by most novice students are Aristotelian, Impetus and Newtonian. All students believe portions of all three ideologies. For example many students agree that objects prefer not to move at all (Aristotelian), but also believe that objects continue to move on their own because an external agent had transferred an internal driving force called impetus. The impetus belief is most dominant in novice students. Impetus acts to keep the object moving in the direction that the acting agent made it move. This includes circular paths. Students often explain changes in direction by the gradual erosion and replacement of impetus. About 65% of the students think predominately in terms of impetus, while 17% are predominately Newtonian (Halloun and Hestenes, 1985[2]).

Apart from thinking with merged belief systems, students were notoriously inconsistent with the application of their ideas. For example, students occasionally thought that with no net force objects would slow (65%) and that a constant force would result in constant velocity (66%). Fewer than 5% of students held this belief consistently. Also, 40% consistently and 15% inconsistently believed in the impetus explanation of motion. Students have incoherent belief systems no matter which one dominates. Unlike Newton, students use different rules to deal with similar situations, whereas Newton would apply the same rules.

Halloun and Hestenes (1985[2]) carefully looked at the mechanics diagnostic test and posttest interviews. They found some conceptual errors students held. Students have a vague definition of the idea of force. They think force is the cause of constant velocity and determines the size of constant velocity. Some said forces do not act immediately, i.e., it takes time for a force to have an effect. Students do not clearly distinguish between distance, velocity and acceleration. Those students with dominate impetus beliefs often think impetus will either fade away immediately after a causal agent is removed or gradually fades if an object encounters some resistive agent. This study provides some bases to analyse future student belief systems.

When designing any curriculum one should ask, at least two questions. First, what is the essential content? Second, how can this information be delivered? Traditionally, the essential content includes lists of formulae, special terms, definitions and laws. However, these scientific contents only form half the knowledge. The other half is the process used to create this information. It is this half that is absent from the traditional physics course. Transmission of factual knowledge can be problematic because missing subtle details, such as assumptions, is easy and often no challenge is made to a student's belief system. The way to improve the learning of factual knowledge is by using a curriculum that allows the student to learn and apply procedural knowledge. The difference between traditional teaching and student-centred teaching is akin to the parable about giving a man a fish versus teaching him how to fish. Therefore, new physics curricula should teach students how to analyze situations, conduct tests and analyse data. The "content" of the physics course will be the result of the student's interpretation of their own work.

It is my impression from most of the researchers I read that any modelling curriculum should teach a procedure similar to the ones used by expert physicists when creating information. This is a problematic statement because learning theory does not necessarily follow working theory. However, it is my premise that it does. A learning cycle that begins with situational analysis, hypothesizing, testing, then data analysis, interpretation, and concludes with model deployment, would show students how to create their own knowledge (Hestenes, 1987). This knowledge would essentially be models and theories. Finally the student could learn when to use this information when problem-solving by comparing their models with other situations. This should form the general structure of a modelling oriented course. The initial situational analysis should be on simple problems that get at the heart of what knowledge we want the student to create. Analysis of a few "paradigm problems" with multiple representation, will teach more than endless drill and practice on textbook problems (Halloun and Hestenes, 1987). This basic teaching pattern is evident in all the modelling curriculums I have studied.

Wells and Hestenes (1995) devised a detailed modelling curriculum by joining the general principles of modelling (Hestenes, 1986) and student-centred learning. Wells actively taught his students in the skills of modelling, i.e., graphical and vector analysis, situational analysis, assessing the soundness of solutions against their models. However, he then devoted plenty of class time to student articulation of what they were learning. They publicly explained all that they planned and did, articulated their assumptions and defended their conclusions to experiments. When problem solving they had to defend their solutions with the explicit models they created. Key to the success of this course was the instructor. The instructor had to guide the students into model-oriented thinking without blatantly telling them what they had to do or say. To do this, the instructor must be well versed in the appropriate model and the most likely student misconceptions (Wells and Hestenes, 1995). For Wells it appears as if the public demand for student articulation may have been the true key to success. However, modelling was important because it became the language students and instructor spoke. Models formed the structure to the cooperative learning. We see evidence for the success of this approach in the gains on the Mechanics Diagnostic Test. Remember that traditional approaches, which often only pays minimal recognition to underlying models, cause a 14% gain. Model-focused lectures, where the instructor explicitly references the model used in problem-solving and offers alternate model-solutions, cause a gain of 20%. Likewise general cooperative approaches result in a 20% gain. The combinations of student-centred learning and modelling methods did cause a gain of more than 30% (Wells and Hestenes, 1995).

Teachers and scientific modelling.

Few papers have been published on the relationship between the teacher and scientific modelling as an educational tool. One article that I read and found important as a guide to my study suggested that most science teachers have a poor understanding of models and the modelling process. Smit (1995) examined 196 South African physics education students. He noted that most of these soon-to-graduate physics teachers had only done a couple of introductory physics courses and would be expected to teach high-school courses of almost the level that they had done.

Smit's study had the participants state and defend whether or not they agreed with general statements on scientific models and modelling. Then he cross-referenced their theoretical modelling knowledge with statements applied to optical models. He assessed the data-based on knowledge about the function of models, nature of models and knowledge of the optics models. He found that most of these students believed that models were very near to the real thing, and that these potential teachers thought models were not important in the development of scientific knowledge. Also, students who majored outside physics defined the word model differently. Finally, he saw that most participants had a poor understanding of the explicit optics models. He claims that in the South African education experience, models are never explicitly taught, so new teachers learn nothing of them. I speculate that this may be a global phenomenon.

Currently one must major in their subject or have a high concentration of courses to teach it at the institute. Peter and Alfred, the two instructors in this study, have both majored in physics. By assessing their responses to the Smit survey I can say they both have a sound understanding of models in physics. However, their better than typical knowledge of models may have amounted to little. Both instructors never openly placed any value for this knowledge prior to my research. I suspect that they, like myself, were never taught models and modelling directly. However, at least on some level they tacitly used models though they were not overtly aware of their own modelling experiences. Since they never had to express their modelling knowledge in a direct way before my research, they could not have conveyed such knowledge to their students. In any event it was clear from Smit that ignorance of models is a self replicating phenomena. Most novice teachers probably could not spontaneously determine the nature of modelling let alone apply it to their classroom practice.

Chapter 3: Methodology Research Design

Given my own background in the physical sciences I chose to conduct a quantitative, exploratory study. After researching my design options and considering the limitations with collecting a sample, I chose to attempt a pretest-posttest nonequivalent control group quasi-experiment. Essentially I had little choice in the matter because I could not randomly assign my participants. Instead I used several large intact groups.

At my disposal were two college level instructors for first year physics. I explained to them a modelling approach to physics education and asked for a volunteer to learn and apply this method to their own mechanics course. One instructor, Peter, agreed to try the approach while the other, Alfred, did not wish to try the new method. Fortunately Alfred offered to serve as a control for this study. Their names have been changed to protect their identity.

My first concern about this method was whether the students for both instructors were equivalent. My instinct said they should be, but to make sure I gave all their students the FCI and compared the mean scores of the two groups. The FCI or the Force Concept Inventory, is a multiple choice conceptual test. It is presented in Appendix B. Using the t-test for equivalent groups, I established that initially all groups were equivalent (Table 14 and Table 24). For good measure I conducted an ANOVA on these students and a group from the following year (Table 3).

In the summer of 1997, I attended a 4-week intensive workshop on modelling in physics education. The workshop was offered by the University of Akron with experienced modellers acting as instructors. This was an opportunity for me to talk with and learn from experienced and novice modelling teachers. This workshop mainly focused upon the techniques of teaching via modelling. However, the facilitators did lead explorations into pedagogic issues of modelling. A goal of the workshop was to develop teachers as resource people for the propagation of this method of instruction.

Between the end of this workshop and the start of classes, Peter and I discussed the pedagogic theory of models as presented by Hestenes, Stankevitz, Swackhammer and Turner during the Modeling Workshop. We reviewed several specific models that are central to introductory mechanics. Finally, I showed him the methods that should invoke student usage of these models. As the course progressed, I continued to offer him advice on modelling and pedagogy, helped in instruction of experimental modelling techniques and monitored his classroom performance at several critical points in the course.

At the end of the semester all students took the FCI and MBT. With the FCI I was looking for greater improvements in the modelling classes than in the control. I intended to see if the students' conceptual knowledge translated into improved problem solving by looking at their MBT scores. The MBT or Mechanics Baseline Test is a quantitative multiple choice test that examines the mathematical side of the concepts in the FCI. It can be found in Appendix B.

Participants (1997)

As I already said, the sampling method was to use intact groups. I used 186 students in this study. Since I examined the entire population at this college, there was some attrition.

Forty-eight students were dropped from my study. Twenty National Defence students were excluded because they were much better than all of the students at the Institute. Furthermore, these students did not share the characteristics of most of our civilians. First they were highly motivated. Second they were taking a different physics course from the rest of the civilians. I dropped the remaining 28 (civilians) because they wrote the FCI only once. However, I believe that the number of civilian students dropped had an insignificant impact on the overall results.

The students in this population had a wide range of characteristics and backgrounds. Most of the students were young adults between 18 and 24 years of age. Also, they came to the Institute with a wide range of physics backgrounds. This experience included no physics at all, high school mechanics and/or first year college level mechanics. Among those with previous physics experience a wide range of skills and abilities, from marginal to near mastery, was displayed. I will examine this characteristic in detail later. The population was predominately male. However, the distribution of females was consistent in all groups. The Institute accepted students for enrollment on a first come first serve basis. Provided an applicant meet a minimum standard of a 60% overall average in high school, two credits in third level matriculation algebra and four credits in third level science, or was over the age of 21, they were allowed into the institute. Once enrolled, students were assigned to sections by the registrar. They had no say with regards to who's physics class they got. Our school did not stream based on high school grades or mathematics proficiency tests. Because of our province's geography only a few students came from the urban regions. With many rural students we can say that virtually all were having a similar experience with regards to social changes and adjusting to life on their own in a small city. For most this was their first time away from home. Many of our students come from a middle class environment. All the physics students in this college were studied.

The two classroom instructors and I were the key leaders. Both instructors volunteered for this study and were not rewarded for their participation in this study.

Peter was a 25-year–old male with a B.Sc in mathematics and physics and a B.Ed in secondary education. He had a total of 1.5 years of teaching experience all of which was at the college level. During this time Peter would lecture and work out many problems on the blackboard. Students would remain silent and copy out notes. He also used verification laboratories and assigned problems from the back of a textbook during the two hour laboratory periods. The problem solving periods appeared to be particularly ineffectual. Students did not work hard at these times and often viewed this as a detention. Also, Peter would share instructional control with the laboratory demonstrator.

Alfred was a very experienced college physics teacher, with only three years to retirement. He has a M.Sc in physics and a Vocational Education Certificate. Alfred would lecture from overheads with little blackboard work. He used the same verification laboratories and textbook problems as Peter. He was very fond of the textbook problems and assigned many during his frequent problem solving periods. While discipline in these periods was less of a problem than for Peter it was apparent to me that these periods lacked the effectiveness sought. Unlike Peter, Alfred often wanted to be in control of the student's learning. He would rarely permit the laboratory demonstrator to lead the hands on learning.

I personally knew both instructors and had been their laboratory demonstrator before and during this experiment. I worked with and have known Alfred for more than seven years and Peter for almost two. I designed the laboratory manual both instructors used and had introduced them to microcomputer laboratories. Peter allowed me to conduct the laboratory as was necessary for modelling. Alfred expected me to act as a technical advisor and did not want me to deliver the content of his course. I acted as expected for both instructors. Finally I am an experienced college physics instructor teaching at the introductory and more advanced levels (X-ray and ultrasound). However, for 1997 I acted as the laboratory demonstrator.

Peter was the experimental instructor and used a modified model oriented instruction. He focused his classes on the essential Newtonian models and encouraged more student activity than he had in the past. Alfred acted as the control and followed a more conventional physics curriculum. Essentially he taught as he always did.

Participants (1998)

In 1998 I instructed two more groups in the modelling method. These students were given the same pretests as in the previous year to see if the groups were equivalent to the previous year's groups. The t-test results showed no significant difference between the groups. The general make-up of the population, age and gender distribution and background in physics was similar. Because of the similarity, I chose to keep the 1997 control group as the control for 1998. Alfred was teaching the remaining 1998 students and I have no reason to believe anything in his classroom had changed.

Again this year the DND students and 35 civilians were excluded from the study. The reasons were the same as in 1997.

As the principal instructor I tried to incorporate modelling in the classroom fully. Laboratories were used to develop the fundamental models, while class time was used to deploy and ramify these models. On these occasions students worked in small groups on key problems, then later would present their solutions to their peers.

The new laboratory demonstrator was not a critical element in the study this year. Since he was fresh out of the university with no experience for his job or the technical details of running the computers for the laboratory, he was not assigned any direct activities for the study. Essentially I ensured that the laboratory conditions were sufficient for the students to create their models.

Internal Validity

An important question I asked of this study was, "How certain could I be that any affect seen in the FCI could be attributed to the instructor's successful adoption of a modelling curriculum?" Internal validity assesses whether the model-oriented approach could account for the results.

1. Prior physics education is most likely in a conventional format and therefore ineffective at bringing on conceptual change. Results obtained by Halloun and Hestenes (1985) show that a student's schema of the physical world is not easily dislodged by conventional instruction. Students learn to appease the instructor and do things his or her way but do not accept their views as legitimate. The expression "it's all good in theory but not in practice," is the basic mode of

operation for many first time physics students. Furthermore, the main measure of success in this study is the gain in knowledge and not the initial state of knowledge. Thus, I do not consider prior physics courses as a threat.

2. The two teachers are different in age, attitude and experience. This is a major threat. Apart from this the overall concurrent history for all students at the Institute is about equal. Subjects were told they were a part of a study that evaluated teacher effectiveness. The FCI is a short well laid out test and probably does not have an effect on the validity of the scores as they relate to the students understanding of the physical world.

3. The selection of instructors is a threat because they were volunteers and not randomly chosen. This is a major reason for the experimental design choice.

External Validity

External validity is the generalizability of my findings. I would like to think that this is applicable to students headed to community colleges within the province of Newfoundland. These colleges offer similar physics programs from instructors with a range of backgrounds. However, they all draw from the same population of students and often attract the students who fail to meet the entry requirements for the Province's University. Occasionally a gifted student enters the college system because they recognize that these colleges offer career opportunities that a university degree would not, for example ship's officers.

Selection treatment interaction is not an external threat due to the relatively random placement of students. Neither I, the participating instructors nor the students had any say in their initial placements. A few students did change their timetable a little while into the semester for various reasons such as looking to change instructors and avoiding classes during Friday afternoon. However, the number of these changes were usually small because class sizes were limited to 48 students and all but one section was full.

1. A possible experimental effect was that all students in the treatment groups were told that they were being treated equally and fairly when compared with the control group. However, some treatment students with friends in the control group noted that the control class was conducted in a different style. This may have been a problem because these treatment students may not have perceived the equality of the course to be true. A few students were resistant to the treatment because they felt that this put them at a disadvantage for placement in programs and scholarships.

2. The most dangerous experimenter effect I anticipated was teaching to the test. Both instructors assured me that they did not. Furthermore, I would not expect such low posttest scores if they had. Also, I removed personal interpretation from the test by using a multiple choice test. Either the answer was right or wrong and not subject to the experimenters interpretation of what the student knows.

3. I am fairly confident that multiple-treatment interference is not a factor affecting validity. Within the institute we used modelling or traditional approaches. No teacher-led tutorials were offered during the semesters of the study. However, I

do not know how many, if any, students availed of private tutorials. If students used a mass tutorial that has become popular at the university I doubt that it would have helped very much. These tutorials use old tests and examinations from the university. They then train students to solve certain questions based on the historic frequency of their usage. We attempted to redesign our examination questions from year to year making the teach to the test approach of the private tutors difficult to apply.

4. Finally the instruments I used, were subject to tests for validity and reliability. I have stated earlier that efforts were made by Hestenes, Halloun and Hake to gauge the effectiveness of the FCI. I am satisfied that it is both valid and reliable. From reading the questions I am also satisfied that it is not culturally biased.

A Detailed Procedure (1997)

Two weeks before the beginning of classes I began to instruct Peter in the theories of models and their pedagogical uses. I clearly pointed out that models are alternate but simplified representations of the real world. Their importance in education was three fold. First, models serve as a focal point for classroom discussion on the Newtonian understanding of reality. Second, models eventually become a language for science. All our understandings are expressed through models and not realities. Finally models allow us to compare the results of experiments with a theory of nature. Peter was told that he had to attempt to show this to the students by example. This meant using multiple representations of solutions to problems, i.e., graphical, equations and iconic. Also, he needed to point out that a complete solution was a model and not just a numeric answer.

We then reviewed the major models for this project. First we examined the role of graphs and how students could use them to teach themselves the fundamental ideas of motion. Next we examined the motion map as a new style of model. We concluded that these maps were best left semi-quantitative and that students should use them to support their interpretation of graphs. We felt that the ability to analyse a graph may be more easily displayed in a motion map than in written words. Furthermore the second representation should encourage students to believe that there is more than one right way to do things. We then examined the models Hestenes (1996) calls a system schema. Peter did not accept this as a necessary precursor to the free-body diagram but did agree that careful and consistent use of the free-body diagram would be a powerful tool in dynamics. Finally, we discussed the nature and role of extended body models and energy bar charts. Since we only had two weeks to do all this, it was a hurried affair with most of the emphasis on the models that would appear first. Throughout the semester we would revisit the other models for further discussion. Peter was very keen on learning how the students should use models and did discover some interesting ideas along the way.

On the first two days of the 1997 fall semester, all of the first year physics students at the Institute were given the FCI and VASS surveys. The VASS is the Views About Science Survey which can be found in Appendix C. They were told that these tests were designed to give the instructors an idea about what they already understood about the physical world. After they completed the FCI we told them that they would have to take it again later this year so we can see if their understanding changed because of how we taught them. I emphasized that the data would be used to test a hypothesis about alternate learning strategies. Also, I said this test was not intended to determine their final grade. The reason for this action was to put the students at ease and hopefully alleviate any possible test anxiety.

After the first week, I would sit in on Peter's classroom sessions to see how he developed and used the models with his students. When the class was over, we would discuss things that worked and things that needed changing. I feel that this sort of peer coaching is necessary when trying to learn a new method of teaching. These sessions declined as the semester progressed. Later we would be inclined to talk about classroom experiences that I had not observed. This reflective behaviour was also a planned part of training Peter. However, it was not scheduled.

Peter and I agreed that the students would engage in model construction before the models were presented in the classroom. We attempted to follow the guidelines set down by Hestenes and Wells. That is, we gave the students a pre-laboratory demonstration and conducted a large group situational analysis. Next the students were broken into two smaller laboratory groups and they then attempted to design and conduct experiments to test a common hypothesis. After they collected their data, they used graphing techniques to develop the underlying mathematical models. In a post-laboratory discussion four-person laboratory groups would present their findings, explain how they arrived at them and the implications of their new models. Their classmates, Peter and I would then ask questions to improve the clarity of their presentations.

In the first week the students began situational analysis of Uniform Linear Velocity, experimentation and model development through data and graphical analysis. During the second week Peter deployed and ramified the Uniform Linear Velocity model with the addition of motion maps and detailed graphical analysis. Also, during that week we began to repeat the experimental process, only this time the target was the Uniform Linear Acceleration model. This cycle continued for the remainder of the semester. Every third week students were given a chance to deploy their new models in problem solving rather than more experimentation.

A key aspect to all laboratory work (experimentation and problem solving) was the student-centred environment. Peter and I worked hard to contain our need to tell them what to do. At the end of each laboratory session, student groups would present their findings and any formal models that they created or the solution to an assigned question, on a whiteboard. When it was a solution to a particular question, it had to be based on proven formal models. The presenting group would have to explicate the formal model they were using. After a group conducted such a presentation, the other students would ask questions for clarification. We would ask the last questions to draw out any missed points. Before the student presentations we developed a list of prompting questions. This would allow us to decide what we most valued and wanted the students to know. An important note here is to establish rules for polite conduct between the students.

To reinforce the importance of models all assignments and tests demanded that the students deploy their model knowledge to answer questions and solve problems. Peter also demanded that solutions were to be defended in writing and that models were to be the main means of defence. In all our interactions with the students we would demand that they speak in terms of the models they understood and that they use technical terms correctly. We had good reason to believe that when students use a term like distance they do not have the same meaning as a physicists would have. To many students distance is viewed as change in an object's position and not the length of the path travelled. Also, they speak of distance or displacement as something measured directly off a ruler and not calculated. We demanded explanations and not just terminology. Making them explain their models helped them with this sort of task.

Procedure (1998)

This time the goal was to attempt to repeat what Peter had done, with a few changes. As with last year, I gave the initial FCI and VASS. Afterwards, I explained how this was not a graded item but warned that at the end of the semester I would repeat the FCI. Also, I told them that this was a part of a study to evaluate the effectiveness of my instruction and not their learning. This was done to put them at ease. I accept that this may influence their effort but since I did not over exaggerate the fact they were being studied I doubt that it had a major influence.

Unlike Peter, I tried to get the students to deploy their causal models in every class, rather than present examples and then get them to practice weeks later in a problem period. Also, I tried to deploy system schemas before I introduced free-body diagrams. I used energy bar charts to a greater extent. The final difference between our two classes was that I elected not to do the MBT, to save a little time at the end of the semester. I do not think that dropping the MBT was unacceptable. This only gave me an extra half hour in a thirteen-week, 65-hour, course to conduct more practice problems. Again I think that the additional half hour is probably not a significant issue.

Chapter 4: Data and Analysis

I have had the great fortune to examine in detail three groups of students. Group one and three were primarily made up of students taking their first introductory college physics course in the fall of 1997 and the fall of 1998. The second group was our repeat students taking the course in the winter of 1998.

The primary instrument of this study has been the Force Concept Inventory (FCI). I analysed the results of this test with overall scores and the frequency distribution of responses to individual questions. Next I used the final examination as an instrument to measure conceptual knowledge. Again overall scores were used and key questions were cross referenced to the FCI. Finally I attempted to use the Mechanics Baseline Test (MBT) and the Values About Science Survey (VASS). I decided after giving the VASS that the information it made available was not pertinent to my study and thus I have not reported it here. I have included the MBT and VASS in the appendices so the reader may see everything that I considered using. It may be of future interest to reexamine these items.

Besides the previous instruments used to measure the student's conceptual change, I will also have a look at the modelling instructor. I formally assessed his knowledge of models using a pretest only of the Scientific Modelling Knowledge Survey. Throughout the academic year of 1997/1998 I gauged his knowledge using informal interviews. While not a focus of this study this data is of some interest and it is briefly discussed in the following paragraph. The main purpose of these informal interviews was to see if Peter was attempting to use the modelling method and if he understood what he was doing. I am satisfied from our conversations that he did honestly attempt to employ modelling and was deeply aware of what he was doing. Also, the modelling knowledge survey was done by several colleagues of mine and all seemed to indicate similar correct responses. Peter's did not reveal any weaknesses in his conceptual vision of models and models in physics. Unfortunately, I am unable at this time to compare them with Smit's results directly.

Fall 1997 and 1998

We administered the FCI and VASS to 138 students in the very first class of their physics course at the Institute. All students had a half hour to complete each test and these tests were not held on the same day. I asked the students of each class to choose carefully what they believed were the most plausible explanations for each situation posed in the FCI. Furthermore I told them that these tests would not count towards their final grades. Finally I explained that these results were a way to evaluate the effectiveness of their instructor's method.

I will first present the descriptive data for the control group (Alfred's). Figure 4.1 shows the frequency distribution of his students' pre-test and post-test FCI scores. Next, in figure 4.2 the reader can see the pattern of changes or gains in the mean FCI scores for this group. Figure 4.3 is another way to show improvement in student knowledge. The fourth graph (figure 4.4) shows the distribution of MBT scores. In the fifth graph (figure 4.5) I have correlated MBT and FCI posttest performance. I did this to see if the student's conceptual knowledge correlated with their problem solving abilities. Finally I have looked at the correlation between posttest FCI scores and the final exam marks (figure 4.6).

When I use the word "gain" in this document I am referring to the percentage a student or group of students improved on their FCI score. For example, if a student scored 30% on the pre-test and 65% on the post-test then they would have had a 50% gain. If the reader needs clarification, I refer you to Equation 1 (Hake, 1998). The calculation compares a student's maximum room for improvement on the original FCI score with the actual improvement they had. I appreciate that this seems a little odd but I did this to make comparison with Hake's results easier.

$$
\begin{aligned}
\frac{FCI_{posttest} - FCI_{pretest}}{100 - FCI_{pretest}} * 100 &= Gain \\
\frac{65-30}{100-30} * 100 &= Gain \qquad (1) \\
\frac{35}{70} * 100 = 50\% &= Gain
\end{aligned}
$$

Hake (1998) published a paper on the effectiveness of Interactive-Engagement. He used the class mean on the FCI and MBT as his main measurements. This study examined many high-school, college and university introductory physics courses, totalling nearly six thousand students. He stated that a poor amount of gain would be anything less than 30%, medium levels of gain were between 30 and 69.9% and high gains would be 70% or better. His study showed for regular high school and non calculus college courses taught in a traditional mode, the average gain was 23% with a standard deviation of 4%. However, interactive lecturing and modelling courses saw average gains of 48% with a 14% standard deviation. These are figures often cited by Hestenes.

Finally, before I continue with the presentation of the data, I will present the findings of the pretest and posttest analysis of variance, Table 3. I did this along with t-tests to confirm that all students in my study came from the same population.

Table 3

Pre-test ANOVA on FCI Scores for all Students Entering the Institute in 1997 and 1998

	SS	df	MS	F
Between	332.04	2	166.02	1.32
Error	23660.59	188	125.85	
Total	23992.63			

Since $F < 3.04$, I can say that all three groups were from the same population. I verified that these groups were initially similar with the t-test between the mean pretest scores of the control group and the first treatment in Table 14 and between the control and the second treatment in Table 24.

Table 4

Post-test ANOVA on FCI Scores for all Students Entering the Institute in 1997 and 1998

	SS	df	MS	F
Between	2176.28	2	1088.14	4.73
Error	46802.31	188	248.95	
Total	48978.59			

Since $F > 3.04$, I can say that at least one group is different. The t-tests in Table 26 shows that the modelling groups are equivalent to each other. However, the t-tests shown in Tables 15 and 25 show both treatment groups differ from the control group.

Data for the Control Group

First, I have presented the descriptive pretest and posttest FCI data for the control group. This will help put into context their overall change in conceptual knowledge on the workings of the physical world. Figure 4.1 illustrates the distribution of students in terms of correct Newtonian beliefs before and after taking this physics course.

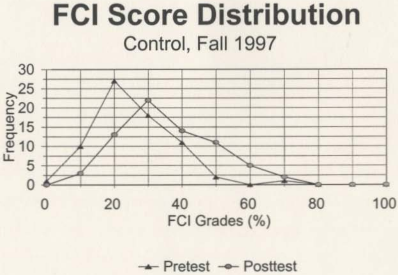

Figure 4.1:FCI histogram for the control group, Fall 1997

Table 5

Descriptive FCI Statistics for the Control Group, Fall 1997

	Pretest	Posttest
Mean	28.81	38.81
Standard Error	1.35	1.70
Median	26.70	36.70
Mode	23.30	30.00
Standard Deviation	11.32	14.21

The equivalent variance t-test, on the pretest and post-test means scores, shows a significant improvement in the control group's understanding of the physical world, $t = 4.60$, $p < .05$. However, while this is statistically significant, these students clearly had a low scientific conception of the Newtonian world to begin with. According to Hestenes and Halloun (1985) such students still had a non-Newtonian (folk) conception of the physical world after taking the course. They would also argue that this is a common outcome of conventional instruction. I would like to note here that after taking the course these students were not quite as sophisticated as American college freshman pre-test scores. In short they were making slow progress to higher understanding.

In keeping with Hake, I decided to use his definition of gain as a gauge of success. He has suggested that along with the means the conceptual shift in the student as shown by the amount the means change, is important. Gains in traditional courses are about 23% while in modelling courses they are around 48% (Hake, 1998).

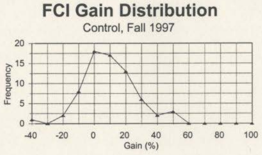

Figure 4.2: Gain histogram for the control group, Fall 1997

Table 6

Descriptive Gain Statistics for the Control Group, Fall 1997

	Gain
Mean	13.70
Standard Error	2.02
Median	12.50
Mode	0.00
Standard Deviation	16.90

I want to point out the mode quoted in Table 6. Yes, zero was the most frequent Gain in this group. Six of the students had exactly no Gain, whereas fewer than six had exactly the same non-zero Gain. Also, the data points plotted in Figure 4.2 are for a range of values. Therefore, the reader will not be able to count the mode reliably.

As seen in Table 6 the mean Gain is about half of what is typically achieved by the traditional approach. Furthermore the standard deviation is very high suggesting that student performance varies a lot. However, the standard deviation seems similar to results reported by Hestenes, Wells and Swackhammer (1992) for high school and slightly larger than those reported by Hake (1998) for college students. Perhaps this is to be expected at the end of a course because not all students will develop at the same rate.

To further illustrate the Gain I have done a correlation between pre-test and post-test scores, Figure 4.3. The sloped line indicates the location of students who showed no change in scores. If the data point occurs below the sloped line then the student has deteriorated over the course. Conversely if the mark is above the line they have improved. The bold horizontal and vertical lines at 60% indicate the boundary between folk and elementary Newtonian beliefs. The bold horizontal and vertical lines at 80% indicate the boundary between elementary Newtonian beliefs and mastery of the Newtonian ideas. As seen here most of the control group stayed within folk belief system and no control student attained mastery. Furthermore only one student had entered the course with a reasonable knowledge of the Newtonian view of the world.

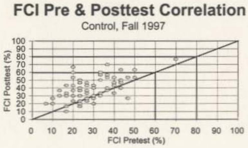

Figure 4.3: Pre & post-test correlation to illustrate gains for the control group, Fall 1997

The MBT was used to see if the students could apply their conceptual knowledge and formal models to problem-solving. According to Hestenes students usually have lower scores on this test than on the FCI. Hake (1998) has shown that traditional courses score around 36% and modelling courses are near 60%. The results shown in Figure 4.4 would agree with Hestenes statements but fall well short of Hake's findings.

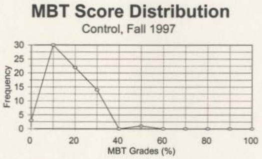

Figure 4.4: MBT histogram for the control group, Fall 1997

Table 7

Descriptive MBT Statistics for the Control Group, Fall 1997

	MBT
Mean	22.36
Standard Error	1.09
Median	23.10
Mode	23.10
Standard Deviation	9.12

Table 7 suggest that Hestenes's statements are correct when we compare the MBT mean with the FCI mean in Table 5. However, I suspect that these results were caused by mortality. I did inadvertently hear a few students after they finished the MBT complain that they got tired of the test and just guessed answers to get out early.

I decided to report this data for now accepting that it is suspect. However, I still believe that this data may be useful for some other future research. In the future I may want to compare MBT and FCI data to see how the conceptual skill relates to the act of problem solving. Figure 4.5 and Table 8 does suggest that a relationship may exist and further exploration could be worthwhile.

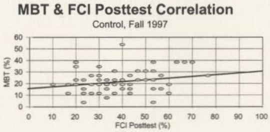

Figure 4.5: Correlation of FCI & MBT for the control group, Fall 1997

Table 8

MBT and FCI Post-test Regression Statistics for the Control Group, Fall 1997

Regression Output	
Y-Intercept	19.96
Slope	0.14
R Squared	0.05

Finally, I was curious to see if the FCI, a purely conceptual examination, would indicate performance on the instructor's traditionally problem-solving-oriented final examination. Figure 4.6 shows a reasonably strong link between the two articles. The interesting thing here is that the final examination consisted of questions remarkably similar to the textbook for the course. The control group spent a considerable amount of laboratory time practising problems from the textbook as Alfred had always done. While their performance on the FCI was poor, they had apparently trained themselves to solve typical textbook problems, without too much regards to the underlying knowledge base. If one draws a vertical line at the 50% on the FCI axis one can easily see that most of the students failed this fundamental conceptual test. Likewise if one draws a horizontal line at the 50% level on the final examination axis one can see that about half the same students could pass the traditional problem solving examination. Table 9 provides the essential data for the regression line shown in Figure 4.6.

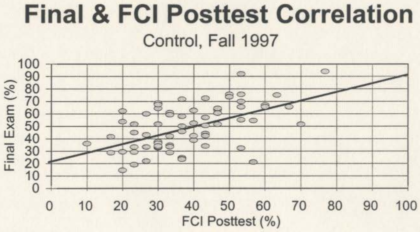

Figure 4.6: Correlation of FCI and final examination for the control group, Fall 1997

Table 9

FCI Post-test and Final Examination Regression Statistics for the Control Group, Fall 1997

Regression Output	
Y-Intercept	22.74
Slope	0.71
R Squared	0.32

In summary the FCI data for the Control group shows that they were generally naive when it comes to the Newtonian view of the world both before and after the course. However, they were still able to pass the course because it depended upon knowing how to handle a traditional problem-solving examination. This boiled down to learning and applying algorithms without thought. Hestenes would argue that students in this group with previous physics background had done this to get through their other course and found it successful. They were never challenged to go deeper than that.

Now I will present descriptive data for Peter's treatment group. The arrangement of graphs and tables follows the same pattern as before. First figure 4.7 shows the frequency distribution of his student's pretest and posttest FCI scores. Figure 4.8 and 4.9 show the gains in the mean FCI scores for this group. The fourth graph (figure 4.10) shows the distribution of MBT scores. In figure 4.11, I correlated MBT and FCI posttest performance. Finally, I have looked at the correlation between posttest FCI scores and the final examination marks (figure 4.12).

Data for the Treatment

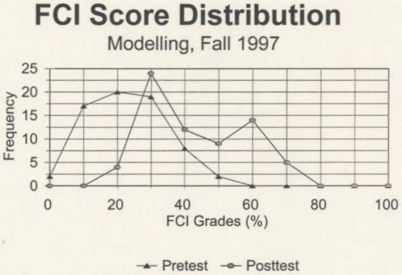

Figure 4.7: FCI Histogram for the treatment group, Fall 1997

Table 10

<u>Descriptive FCI Statistics for the Treatment Group, Fall 1997</u>

	Pretest	Posttest
Mean	26.18	46.03
Standard Error	1.34	1.82
Median	23.30	40.00
Mode	20.00	30.00
Standard Deviation	11.07	15.01

Again the statistic of the one tail t-test suggests improvement, $t = 8.78$, $p < .05$. While it is not a large improvement, it is larger than seen in the control group.

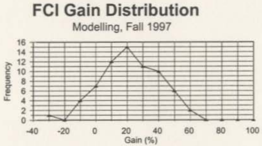

Figure 4.8: Gain histogram for the treatment group, Fall 1997

Table 11

Descriptive Gain Statistics for the Treatment Group, Fall 1997

	Gain
Mean	26.73
Standard Error	2.29
Median	25.99
Mode	0.00
Standard Deviation	18.85

As with Table 6 the reader should note that zero was the most frequent Gain in this group. Three of the students had exactly no Gain, whereas fewer than three had exactly the same non-zero Gain. Even though this is a modelling group the gains are in keeping with traditional lecturing.

As with the control group, I have used figure 4.9 to further illustrate the Gain. I refer the reader to page 64 where the significance of the lines are explained. Here we can see the treatment group had fewer students show a deterioration in score and more students in the elementary Newtonian belief system when compared with the control in figure 4.3. Unlike the control group no students scored at or above the 60% level in the pretest.

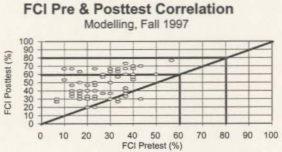

Figure 4.9: Pre & post-test correlation to illustrate gains for the treatment group, Fall 1997

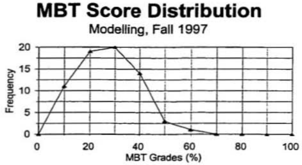

Figure 4.10: MBT histogram for the treatment group, Fall 1997

Table 12

Descriptive MBT Statistics for the Treatment Group, Fall 1997

	MBT
Mean	31.34
Standard Error	1.35
Median	30.40
Mode	23.30
Standard Deviation	11.12

Again I was a little curious if this data would indicate a possible future study. It does follow the pattern suggested to me by Hestenes. These scores agree with Hake's predictions for traditional physics courses but fall well short of what typical modelling classes can do. Hake (1998) said no matter what the course, an MBT score 15% lower than the FCI posttest score is normal.

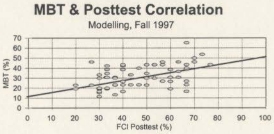

Figure 4.11: Correlation of FCI & MBT for the treatment group, Fall 1997

I repeated the comparison between the final examination and FCI post-test. The Treatment group took the same final examination as the Control. However, they spent their time attempting alternate questions geared to getting at the fundamentals of the models they were learning. Furthermore, they did fewer total problems. These results shown in figure 4.12 and Table 13 indicate that they were not disadvantaged in the final examination. Since both regressions were close, I took this to indicate that the FCI post-test was an adequate predictor of the final examination mark. Evidently, students did worse on the conceptual test than the textbook-oriented problem-solving final examination. Perhaps this is an indication that number crunching is easier than understanding the underlying concepts of physics.

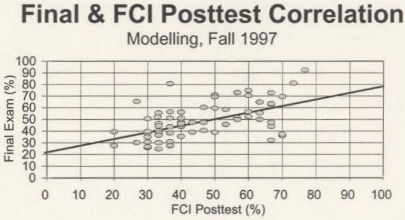

Figure 4.12: Correlation of FCI and Final examination data for the treatment group, Fall 1997

Table 13

FCI Post-test and Final Examination Regression Statistics for the Treatment Group, Fall 1997

Regression Output	
Y-Intercept	23.51
Slope	0.56
R Squared	0.31

In closing, the Treatment group did appear to improve more than the Control group. However, after taking an introductory mechanics course they only made it up to the mark set as average for American freshman entering a course. This is a disappointing "success." Further details on their success are reported in the following section on inferential tests.

Inferential Tests

So far I have provided descriptive statistics for both the control and treatment groups. However, I did conduct several inferential tests. Table 5 and Table 10 provide pretest and post-test mean scores for each group. Also, I compared the pretest and post-test FCI scores for the control group using an equal variance t-test and concluded that the gains made through the semester were significant. Conducting a similar test on the Treatment group also revealed that significant gains were made, $t = 8.78$, $p < .05$. When I conducted an equivalent variance t-test between the control and treatment's pretest average scores, I found no significant difference between the two groups, $t = -1.38$, $p > .05$.

A comparison of the treatment and control group's mean post-test FCI scores shows that the treatment group made significant improvements in conceptual understanding, $t = 2.90$, $p < .05$. These data are reported in the following tables.

Table 14

t-test two Samples Assuming Equal Variance Between the Pre-test FCI Scores of the Control and Treatment Groups, Fall 1997

FCI Pretest	Treatment	Control
Mean	26.1750	28.8086
Variance	122.5246	128.1678
Observations	68	70
Pooled Variance	125.3878	
Hypothesized Mean Difference	0	
df	136	
t	-1.3813	
P(T<=t) one tail	0.0847	
t Critical one tail	1.6561	

The purpose of this test was to see if the two groups were initially different. Given these results I must accept the null hypothesis that both groups are identical, $t = -1.38$, $p > .05$. Furthermore, the analysis of variance between these two groups and the fall 1998 group (Table 3) shows that all are equivalent, $F = 1.32$, $p > .05$.

Table 15

t-test two Samples Assuming Equal Variance Between the Post-test FCI Scores of the Control and Treatment Groups, Fall 1997

FCI Posttest	Treatment	Control
Mean	46.0279	38.8071
Variance	225.2068	201.9195
Observations	68	70
Pooled Variance	213.3919	
Hypothesized Mean Difference	0.0000	
df	136	
t	2.9031	
P(T<=t) one tail	0.0022	
t Critical one tail	1.6561	

Once the data were collected for the post-test I repeated the one-tailed t-test. Here I was expecting the treatment to cause a greater conceptual shift. Therefore, the one-tailed test seems to me the most appropriate because I expected the treatment to be significantly better and not just significantly different. This test shows that my hypothesis was correct, $t = 2.90$, $p > .05$. I continued to use one-tailed t-test for this study with the assumption that modelling would cause better changes and performance than traditional lecturing.

Using the same t-test I compared the FCI gains and mean MBT scores of both groups. With the MBT scores the t-test has shown a significant difference between the two groups, $t = 5.18$, $p < .05$. However, I doubt the importance of this data. As I noted before I did inadvertently hear rumours that students in the Control group did not take the test seriously and just randomly selected answers.

The data for both groups did indicate significant improvements in their FCI scores and it was shown that the treatment group did better than the control group. By examining the Gains, it is possible to conclude that the treatment group evidently made greater strides in overcoming their conceptual deficiencies, $t = 4.27$, $p < .05$.

Table 16

t-test two Samples Assuming Equal Variance Between the MBT Scores of the Control and Treatment Groups, Fall 1997

MBT	Treatment	Control
Mean	31.3382	22.3600
Variance	124.5236	83.0940
Observations	68	70
Pooled Variance	103.5042	
Hypothesized Mean Difference	0	
df	136	
t	5.1829	
P(T<=t) one tail	0.0000	
t Critical one tail	1.6561	

Table 17

t-test two Samples Assuming Equal Variance Between the FCI Gains of the Control and Treatment Groups, Fall 1997

Gain	Treatment	Control
Mean	26.7284	13.6985
Variance	355.1973	285.6941
Observations	68	70
Pooled Variance	319.9347	
Hypothesized Mean Difference	0	
df	136	
t	4.2783	
P(T<=t) one tail	0.0000	
t Critical one tail	1.6561	

While the data suggest that the study was successful, I felt that the success was underwhelming. Therefore, after the preliminary data I opted to try the test again on students repeating the course in the spring of 1998 and the Fall of 1998. I realized that the Repeat students were not an equal comparison to the Fall Group but I thought this might reveal some interesting findings.

Repeat Students Winter 1998

We taught 24 students in the winter semester. Most of these students were repeating the course, only 15 of them took the FCI in September and December. The statistics I am reporting are for these fifteen only except where noted otherwise.

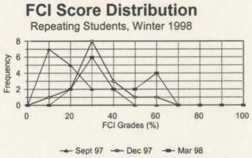

Figure 4.13: FCI histogram for students repeating the course, winter 1998

Table 18

Descriptive FCI Statistics for the Repeat Group, Winter 1998

FCI Scores	Sept 97	Dec. 97	Mar 98
Mean	23.29	35.53	45.09
Standard Error	2.54	3.15	3.82
Median	20.00	33.30	46.70
Mode	16.70	33.30	30.00
Standard Deviation	9.82	12.19	14.79

These students showed a significant improvement from September to December, $t = 3.03$, $p < .05$, and from December to April, $t = 1.93$, $p < .05$.

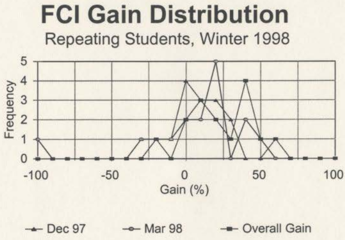

Figure 4.14: Gain histogram for students repeating the course, winter 1998

Table 19

Descriptive FCI Gain Statistics for the Repeat Group, Winter 1998

	Gain 97	Gain 98	Overall Gain
Mean	14.21	11.75	27.31
Standard Error	5.43	8.57	5.64
Median	18.57	20.00	23.89
Mode	0	NA	NA
Standard Deviation	21.02	33.18	21.84

Gain 97 refers to gains in the fall semester, Gain 98 is for the winter semester and the Overall Gain is from September 97 to April 98. These students showed insignificant improvements over each semester, $t = -0.24$, $p > .05$. However, their overall gain is significant because they have achieved a gain similar to the treatment group from the fall semester.

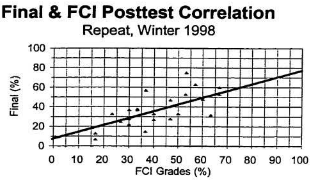

Figure 4.15: Correlation of FCI and Final exam data for students repeating the course, winter 1998

Table 20

Regression Statistics for FCI Post-test and Final Examination Scores, Repeat Group Winter 1998

Regression Output	
Y-Intercept	5.023
Slope	0.7818
R Squared	0.4887

This data correlate the Posttest FCI scores and Final Exam marks for all repeating students. Eventually, repeating students could attain the same level of knowledge as their peers from the previous semester. It took them longer to do this and the reasons are not clear cut. Some had been exposed to modelling before but may have lacked the self discipline to make use of it. Others had come from the traditional class and may have not been exposed to a method more compatible with their learning style.

Fall 1998

I personally repeated the experiment in the fall of 1998 hoping to duplicate or better the outcomes Peter experienced.

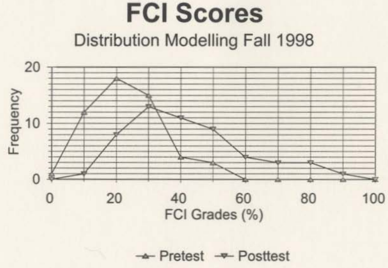

Figure 4.16: FCI histogram for the treatment group, Fall 1998

Table 21

Descriptive FCI Statistics for the Treatment Group, Fall 1998

	Pretest	Posttest
Mean	25.97	45.41
Standard Error	1.55	2.54
Median	23.33	43.33
Mode	30.00	23.33
Standard Deviation	11.27	18.53

The equivalent variance t-test, on the pretest and posttest means scores, shows a significant improvement in the second treatment group's understanding of the physical world, $t = 6.52$, $p < .05$. This is statistically significant and better than the control group but not quite as good as the first treatment.

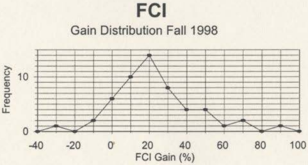

Figure 4.17: Gain histogram for the treatment group, Fall 1998

Table 22

Descriptive Gain Statistics for the Treatment Group, Fall 1998

	Gain
Mean	27.41
Standard Error	3.01
Median	25.00
Mode	26.09
Standard Deviation	21.89

As seen in Table 19 the typical Gain in FCI score was 27%. This is similar to the data collected on the 1997 Treatment group reported in Table 11.

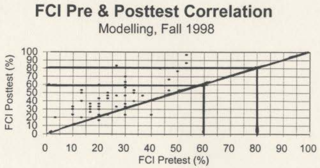

Figure 4.18: Pre & Post-test correlation to illustrate gains for the treatment group, Fall 1998

As with the control and treatment groups in 1997, I compared FCI Pre and Post-test scores with linear regression. Figure 4.18 illustrates the typical Gains made by these students. I refer the reader to page 62 where the significance of the lines are explained. Here we can see the treatment group had few students with a deterioration in score and more students in the elementary Newtonian belief system when compared with the control group in Figure 4.3. Unlike the control group no students performed at a 60% or better level in the pretest.

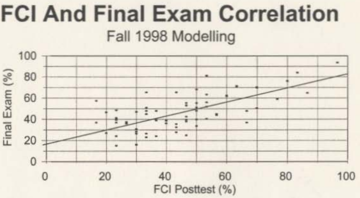

Figure 4.19: Correlation of FCI and final examination data for the treatment group, Fall 1998

Table 23

FCI and Final Examination Regression Statistics for the Treatment Group, Fall 1998

Regression Output	
Y-Intercept	18.70
Slope	0.62
R Squared	0.44

In closing, the 1998 Treatment group appeared to improve more than the 1997 Control group but about the same as the 1997 Treatment group. Again this is disappointing and the results fall below my expectations.

The final comparisons

I compared the 1998 group's pretest to the 1997 control group. Then I compared the 1998 group's posttest to the 1997 control. Finally, I compared the 1998 group's posttest to the 1997 control and experimental group's posttest. These comparisons were done with a t-test assuming equal variance.

Table 24

t-test two Samples Assuming Equal Variance Between the Pre-test FCI Scores of the Control of 1997 and Treatment Group of 1998

FCI Pretest	Treatment #2	Control
Mean	25.9748	28.8086
Variance	127.0763	128.1678
Observations	53	70
Pooled Variance	127.6987	
Hypothesized Mean Difference	0	
df	121	
t	-1.3772	
P(T<=t) one tail	0.0855	
t Critical one tail	1.6575	

Clearly, the t value is below the critical value thus confirming the ANOVA that said the groups were taken from the same population ($t = -1.38$, $p > .05$).

Table 25

t-test two Samples Assuming Equal Variance Between the Post-test FCI Scores of the Control of 1997 and Treatment Group of 1998

FCI Posttest	Treatment #2	Control
Mean	45.4088	38.8071
Variance	343.2592	201.9195
Observations	53	70
Pooled Variance	262.6605	
Hypothesized Mean Difference	0	
df	121	
t	2.2371	
P(T<=t) one tail	0.0136	
t Critical one tail	1.6575	

The t value is much greater than that by chance ($t = 2.23$, $p < .05$). It indicates that the 1998 modelling group learned significantly more than the 1997 control group.

Table 26

t-test two Samples Assuming Equal Variance Between the Post-test FCI Scores of the Treatment of 1997 and Treatment Group of 1998

FCI Posttest	Treatment #1	Treatment #2
Mean	46.0279	45.4717
Variance	225.2068	341.9425
Observations	68	53
Pooled Variance	276.2174	
Hypothesized Mean Difference	0	
df	119	
t	0.1827	
P(T<=t) one tail	0.4277	
t Critical one tail	1.6561	

The final t-test shows that there is no significant difference between the 1997 and 1998 modelling groups posttest mean scores ($t = 0.18$, $p > .05$). One must accept that they shared a similar amount of conceptual change.

Table 27

t-test two Samples Assuming Equal Variance Between the FCI Gains of the Control of 1997 and Treatment Group of Fall 1998

FCI Gain	Treatment #2	Control
Mean	27.4046	13.6985
Variance	479.2034	285.6941
Observations	53	70
Pooled Variance	368.8551	
Hypothesized Mean Difference	0	
df	121	
t	3.9199	
P(T<=t) one tail	0.0001	
t Critical one tail	1.6575	

Using this t-test I can show that the second treatment did have a higher conceptual shift than the original control group ($t = 3.92$, $p < 0.05$).

Chapter 5: Summary and implications

Mechanics of methodology

My first question was, could a modelling method as described by Hestenes and Wells be applied to introductory college physics? Initially their program was intended for use at the high school level where time was less of an issue. Also, they were not obligated to cover a prescribed content. That is, Wells was allowed to decide what was fundamental to know and focused on those models in his classroom. Strictly speaking the answer to this research question is no. However, we did modify Wells' method and applied it with some success.

The first problem that plagued this study was the limited instructional time. We started trying to follow a cycle as Wells would advocate (see Chapter 3 page 55 for details). The problem was that Peter had to wait a week before he could take models developed in the laboratory back to the classroom for deployment. This occasionally meant that Peter would be stalling for time. Later this action meant that we were facing a shortage of time.

Worse still was the way in which the control group was racing through the material. This made Peter and his students uneasy at how much material they could get covered. Peter was obligated to cover the content in the course outline. This meant something had to be done to speed up his classes. We found three solutions to this issue.

First, we decided that the first week and a half of the course would be a time for Peter to introduce via interactive lecturing the ideas of models, modelling, graphing, graphical analysis, significant figures, vectors and vector addition. The control group did not do this. We knew that the control students would have to do this by the fourth week of the course. Therefore, we anticipated that we would catch up near the end of the fourth week. To ensure that we did catch up we wrote out an explicit schedule of laboratory events and stuck to it. Our predictions on pacing were correct.

Second, we allocated laboratory time to cover lecture material via interactive demonstrations. The first instance in which we did this was Newton's First and Second Laws and the connection to kinematics. While Peter was still doing two dimensional (projectile) motion in class, I was introducing Newton's Laws of motion in the laboratory. This session was an interactive demonstration that got students to see that a non zero net force changes an object's state of motion, i.e., caused acceleration. We applied a "constant force" to a dynamic cart via a rubber band. The students clearly recognized that when the band was stretched a force was being applied. Also, the cart's speed was obviously continually increasing. A motion detector and real time graphing showed that the motion was approximately uniform acceleration.

To demonstrate this relationship between force and acceleration further we examined the effects of impulses on motion. Students viewed several scenarios and made observations. Impulses would bring objects from rest to a non zero velocity in the direction of the impulse. Provided the impulse was in the direction of an existing motion, the speed would increase. Weak impulses opposing the motion would cause a loss in speed, stopping and for really strong impulses a reversal of direction. Impulses at some angle to the motion would cause changes in speed and direction simultaneously.

After each demonstration we asked the students to explain what they saw. This included the role of force on motion and not just describing the motion.

We finished by showing what happened when the force was removed. Many students believed a net force of zero results in no motion. Using small pieces of dry ice, low friction dynamics carts and the motion detector, we could demonstrate Newton's First Law. The students were easily convinced that the driving force was zero. They even agreed that the resulting motion was uniform linear velocity. However, many clung to the belief that all objects will eventually come to a stop without a driving force. With Socratic questioning we revealed the role of friction. Finally we got the students to explain why it appears that we need constant force to produce constant velocity. The hope was they would reconcile experience with the scientific law. When I did this in my class, I used a low friction dynamic cart, motion detector and force sensor. The desired relationships between net force and state of motion were more apparent.

We set the misconception of constant force equals constant velocity as the key learning objective of this session. Peter began the following lectures by immediately tackling Newton's Second Law, without the typical lecture preamble on the First Law and defining a force. The obvious question to ask is, "were our modifications at all successful?" On seven of ten FCI items that examined the role of net force and either model of motion or direction of motion, gain in Peter's group exceeded that of Alfred's group. He showed similar outcomes on one item and slightly worse results on two. My own group outperformed the control on five items, were slightly better on three items and worse off on two. This is to be expected because I did not repeat these demonstrations exactly as before. The evidence suggests that the interactive model-based instruction was more successful on this topic than the lecture approach followed by Alfred. According to Richards et al. (1992) it is not necessary for students to create the models in order to understand them. The ability to use, interpret and compare a model with reality is where the learning takes place. Our outcomes suggest that this is valid. In our demonstrations I always provided a practical/vector model of force and the students then assessed it. This was done for each scenario. We made many links between experience from the demonstration and the model we used. However, we did not use computer simulation as suggested by Richards et al.. This means that with care and forethought one could devise a clear demonstration and engage the students with model interpretation and ramification.

Our third time saver was using computer-aided simulations. We did this because we thought the procedure to collect data for a paradigm or deployment experiment was too time consuming or awkward. For example, we studied projectile motion using frame by frame analysis of a video tape. While this procedure is easy to do, it does require a lot of time to create the video and collect the data especially when the AV equipment is limited. To overcome this we made a 1:1 copy of the frames on an overhead transparency and then copied it to paper. We then measured about 80% of the data and left the remaining 20% as an exercise for the students. This freed up considerable time for model construction and analysis. Also, this activity worked so well that we could have made this into a homework assignment. In this type of simulation where the data are presented the laboratory facilities are unnecessary. Our motivation here was to discover the explanatory models at work and not to learn the experimental technique. We had plenty of practice in experimenting and felt that not doing this as an actual experiment was not detrimental. Furthermore the models of motion had already been experimentally developed. The projectile laboratory was meant to deploy these models and not to create new ones. We decided that experiments were best left to creating models and not deploying them.

Again I needed to assess the effectiveness of this idea. On three FCI items related to projectiles and three related to free-fall in the vertical direction only Peter's groups consistently showed better levels of conceptual change than Alfred's. My groups were at least on par or better than Alfred's. My students did better than the control group in the projectile questions. They remained on par for the free-fall questions. I think my students' performance on the free-fall questions was good, considering Alfred treated free-fall as a special topic and I only remarked that it was just another example of uniform linear acceleration. Alfred's groups did improve in their performance over the term. However, his gains were only about half of Peter's. Again Richards et al. predicted that reasoning skill could be enhanced through the simulation. We carried his idea further, by having the students relate patterns in data for projectile motion to ones they discovered elsewhere. The act of data collection may have obscured this learning objective.

The second major problem we encountered in the delivery of this course was an inability to increase the students' responsibility for their own learning. Model-oriented, teacher led lectures dominated the classroom sessions. Students did not get a chance to lead the learning until in the laboratory sessions or problem solving periods. Subsequently they were not well prepared to lead these sessions.

The final problem encountered was the class size. During the laboratory sessions we had two instructors for every 24 students. In the class this dropped to one for approximately every 48 students. Many studies on modelling had been done in classes with fewer than 25 students. Also, Wells supported the idea that the student-centred approach needed to be followed always. As the class size goes up this becomes more difficult to do. We could not control this variable, and thus just had to accept this and work around it. Class size may have been a factor that intimidated some students into remaining silent. Their silence is sometimes viewed by instructors as a sign of understanding. Hence students who need help go unnoticed.

Effectiveness of methodology

After the question of applying the Wells approach to a mid sized college class, I wanted to know if attempting modelling would cause greater conceptual change than the traditional lecture. I analysed this question by breaking it into three smaller questions. First, did a traditional approach bring about a conceptual change? Second, did a model-oriented approach cause a conceptual change? Finally, which approach if either had the greatest degree of conceptual change? The FCI was my main instrument to find the answers to these questions. I used the limited MBT and Final Exam data to seek further (but not concrete) support for the answers.

I will start by trying to answer the question, "Did a traditional approach bring about a conceptual change?" A pretest-post-test comparison of the FCI means clearly shows that the control group did learn something. We see a significant gain in the control group's mean score as shown with the t-test on page 62. This is not surprising because the whole point behind any course is to produce a change in the student. However, it is on how much change we should focus. The control group saw a 13.7% growth in Newtonian beliefs and a mean post-test score of 39%. According to Hestenes (1997) [Seminar at University of Akron] this growth is lower than one would expect with a traditional approach. He claims that we should expect to see a 30% growth from a lecture recitation approach and an average posttest score of 50%. Alfred used a traditional approach, rarely challenging his student's belief systems. Instead he focussed upon the student's ability to answer textbook problems. This insured that his students were prepared to do the final examination, which was largely consisting of problems that emulated the ones found in the textbook. The final examination did not test to see if the student's beliefs had evolved, but instead to see if they could churn up the correct numerical answer. Thus a pass on the final may show students learned to solve textbook problems but not show their conceptual shift. His students retained their incorrect preconceptions but felt successful because they passed the course. I attribute this to the nature of the evaluation used in the course and the mode of instruction Alfred followed. It has been a tradition that the examinations for this course in this Institute have been centred on textbook-type problem solving. Alfred trained his students to do this. Thus when the final examination occurred around they can solve the problems no matter what conceptual understanding they had.

Regarding the MBT, Alfred's students scored an average grade of 22.36%. This too was much lower than the traditional MBT grades reported by non-modelling teachers (36%). This seems to imply that the non-modelling teacher was ineffective compared with other traditional non-modelling teachers. However, I do not believe that this data is sufficient proof for such a conclusion. I spoke with many students from Alfred's class as they left the test and heard several of them became tired of testing, quit trying and walked out. This threatens internal validity with physical and mental mortality. While Alfred's MBT results are abnormally low, I do not think that they in anyway reflect on his approach to teaching. Had the FCI and MBT test been spread out this may not have been a problem. Therefore, I have decided to disregard this data.

Peter, who tried a modified modelling format, also showed gains on the FCI. However, his mean score of 46% and gain of 27% still fell short of the expected results of a traditional lecturer. Statistically, this still was a significant gain in Newtonian knowledge. As the course progressed, Peter reverted to lecturing although he seemed to engage in multiple representations of problems and the laboratories did progress according to a modelling format. He admitted this in a post-course debriefing. Because both instructors failed to meet the standards of the traditional lecturer, I do not know whether to interpret these results as implying that Alfred's approach was substandard or if all of us were dealing with academically weaker than normal students. Keep in mind that the average high school pretest score was 30% with no formal background in "physics." Our average was lower and many of our students had already completed high school physics before coming to the Institute.

Peter's MBT performance was closer to that expected from a traditional approach. Remember the MBT is designed to measure problem solving skills. Peter did not stress the inane repetition of textbook problems and he still managed to have MBT results (31%) close to a lecture problem solving approach (36%). Furthermore, he did not complete all the material covered in this test (energy and momentum). Several questions on this test required knowledge in these areas.

As for myself, my group did about as well as Peter. My group's FCI post-test mean was

45% and the gain was 27%. I would think that my classes followed a similar format to Peter's although the presentation was not quite as well polished. Clearly, both Peter and I did cause higher levels of conceptual change but not nearly as much as we would have liked. When compared with other modelling teachers it appears that either Peter and I failed to grasp what needed to be done or effectiveness requires more practice (experience) than we had. In any event this experiment has not produced a negative outcome with respect to the academic achievements of our students. I did not attempt the MBT test this year due to time constraints and my skepticism with the control results.

As for the question of whether or not modelling produced more conceptual change than the traditional approach, the answer is yes. The ANOVA of Table 3 has shown all groups to be initially the same. Therefore, I needed to conduct two t-tests between the control and each treatment group. The t-test between the means of the 1997 treatment group and the control group, shown in Table 15, show that the 1997 treatment group had a significantly better conceptual change than the control group. Likewise from Table 22, we can see the post-test scores of the 1998 treatment were also significantly better than the 1997 control group. When I compared the Gains of 1997 treatment with the Gain of the control group, Table 17, again we saw a more dramatic and statistically significant improvement in the treatment group. Finally when I compared the Gains of the 1998 treatment group to the control group in Table 27 we can see that they has a significantly better improvement. Since all major factors were controlled, the only way to account for the difference was the departure from the traditional approach. Hake (1998) has shown that departures from traditional physics instruction including modelling approaches will result in higher gains and post-test averages on the FCI and MBT. My data supported this weakly. Hestenes says that gains and posttest scores on the FCI will improve with more reflective practice from the teacher. He (lecture series 6/23/97) often describes how Wells did not show great improvement at first but only after a few years of carefully teaching via modelling. This statement is my explanation for the results that I witnessed. Both Peter and I need more time to gain the expertise in delivering model-oriented physics courses. From my study I can say that it appears as if even novice modellers can see small but significantly better outcomes in conceptual changes. Extensive practice at this method by the instructor should lead to better results. Particular attention must be paid to leading Socratic discourse.

My final research question was, "how does the modelling method affect the college teacher?" The main impact is a radical departure in teaching methodology. No longer should the teacher just get up and preach what he or she knows. Both Peter and I have been exposed to new approaches during our teacher training such as inductive lecturing. Unfortunately once out of the Faculty of Education and into a real school we found the teaching culture to be less developed. Most of the senior instructors were "traditional lecturers" and passively dissuaded us from trying the new ideas we had learned. This was not a deliberate act on their part but it was always lurking in the background. Furthermore, our own experience was being lectured to, since as students our role models of teachers were our university professors. These professors were very traditional in their approach. As new teachers, being traditional was easier than trying these "risky" alternate ideas learned in the Faculty of Education.

Peter and I both had to recall the different approaches we were exposed to and try them out, despite the apparent conflict with tradition. Most of the modelling approach is a collection of ideas we saw as undergraduates. Nevertheless, with limited practice in these approaches trying them out at the institute was almost like learning them again for the first time. With no experienced teachers using such approaches we had no way of seeing if we were learning (applying) these ideas effectively. Learning these ideas had to take place outside the classroom. We routinely got together and discussed theories we had seen before and speculated on other new ideas. Applying these theories and ideas was just a continuation of the learning experience.

The single largest new idea we encountered was models and modelling. Both Peter and I use them and did model but we thought nothing of it. This is like walking. Most people do it without ever thinking about it. However, if the act is analysed carefully, one can understand getting from point A to point B is a remarkable act. Well, we use graphs to interpret the physical world. When we read a slope, let us say "10.2 metres per second" off a linear graph, we recognize the implications of that number. Also, we recognized that our students did not share the profound but simple message of that number. However, it was not too long ago that we would have brushed this sort of experience off as trivial saying that everyone must be able to understand it as we do. Perhaps our students picked up on our attitude but interpreted it as the basics are not important, i.e., do not afford them any time. What we learned about modelling is that it is the basic process underlying science. However, it is not trivial and should not be brushed aside. Modelling as described by many other researchers is something we have done in the past but just never acknowledged.

The last noticeable impact on the teacher was the increased demand for reflection. It was clear to me that both Peter and I were talking a lot more about the effectiveness and impact of what we were doing. We continually asked each other about how we gauged student understanding on a daily basis. We often asked each other if we thought the students really understood what was going on. Also, we would speculate on better ways of getting the students to see critical ideas by brain storming on experiments and analogies. We were working differently from our first teaching experiences. No longer were we focused on tasks such as creating notes or overheads but on the effectiveness of our efforts to lead students though. In our first year of teaching, we both spent huge amounts of time preparing lectures, examples, and evaluation instruments and spent virtually no time on assessing our effectiveness. We had a revolutionary change in focus on our daily activities. This is yet another example of dismissed undergraduate learning coming back to us.

Such deeper level reflection was not evident in Alfred. He tended to use old overheads and assignments. He never openly questioned if he was effective or could be more effective. This is not surprising because constructive self criticism is often not easy to do.

In short, modelling teachers must learn and understand the basics of student-centred theory, the role of modelling in science and mate these ideas in their everyday teaching practice. Then they must learn to monitor and assess their teaching habits with respect to student experience. This is perhaps nothing new, but is often overlooked. Perhaps years of unreflective teaching led Alfred to a comfort zone that he did not want to risk losing. Peter and I do not have that comfort zone. Thus, perhaps, we may learn to accept reflective teaching as the normal way of working.

The future.

Already, other model researchers think that the modelling approach may not be the key ingredient in student success. Hestenes recently suggested that it is the type of discourse that students engage in that makes the difference. However, he says that models should be the focus of the discourse. Mazur (1997) uses student discourse based on textbook reading assignments and conceptual questions in his Harvard classes. He too has seen large gains on the FCI. This suggests that the nature of classroom discourse may be the next logical line of future research.

If the classroom discourse issue is as critical as some have suggested, then how do we teach teachers to be effective leaders of Socratic discourse? This has not been addressed by my research or any of the articles that I have seen.

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Appendices

Appendix A: FCI Data for All Students Reported in this Study

Shaded cells show the correct response for the corresponding question.

FCI Pretest responses by question for the control group 1997.

Question	A	%	B	%	C	%	D	%	E	%	Blanks %
Q1	10	14.3	6	8.6	42	60.0	10	14.3	2	2.9	0.0
Q2	26	37.1	15	21.4	2	2.9	21	30.0	5	7.1	1.4
Q3	18	25.7	19	27.1	25	35.7	1	1.4	7	10.0	0.0
Q4	46	65.7	1	1.4	0	0.0	1	1.4	22	31.4	0.0
Q5	5	7.1	6	8.6	40	57.1	9	12.9	10	14.3	0.0
Q6	16	22.9	51	72.9	3	4.3	0	0.0	0	0.0	0.0
Q7	7	10.0	32	45.7	9	12.9	6	8.6	16	22.9	0.0
Q8	22	31.4	36	51.4	1	1.4	3	4.3	8	11.4	0.0
Q9	5	7.1	21	30.0	17	24.3	1	1.4	26	37.1	0.0
Q10	23	32.9	3	4.3	4	5.7	25	35.7	15	21.4	0.0
Q11	12	17.1	14	20.0	26	37.1	10	14.3	8	11.4	0.0
Q12	0	0.0	28	40.0	33	47.1	6	8.6	3	4.3	0.0
Q13	8	11.4	25	35.7	30	42.9	6	8.6	1	1.4	0.0
Q14	32	45.7	13	18.6	9	12.9	16	22.9	0	0.0	0.0
Q15	20	28.6	9	12.9	41	58.6	0	0.0	0	0.0	0.0
Q16	29	41.4	6	8.6	33	47.1	2	2.9	0	0.0	0.0
Q17	40	57.1	4	5.7	4	5.7	13	18.6	9	12.9	0.0
Q18	2	2.9	8	11.4	19	27.1	20	28.6	21	30.0	0.0
Q19	12	17.1	2	2.9	7	10.0	33	47.1	15	21.4	1.4
Q20	18	25.7	5	7.1	29	41.4	9	12.9	8	11.4	1.4
Q21	12	17.1	15	21.4	22	31.4	5	7.1	16	22.9	0.0
Q22	29	41.4	15	21.4	2	2.9	19	27.1	5	7.1	0.0
Q23	13	18.6	23	32.9	16	22.9	13	18.6	5	7.1	0.0
Q24	37	52.9	6	8.6	14	20.0	5	7.1	8	11.4	0.0
Q25	2	2.9	16	22.9	5	7.1	28	40.0	19	27.1	0.0
Q26	32	45.7	26	37.1	1	1.4	10	14.3	0	0.0	1.4
Q27	27	38.6	6	8.6	36	51.4	1	1.4	0	0.0	0.0
Q28	3	4.3	12	17.1	5	7.1	37	52.9	13	18.6	0.0
Q29	20	28.6	31	44.3	2	2.9	17	24.3	0	0.0	0.0
Q30	0	0.0	10	14.3	7	10.0	5	7.1	48	68.6	0.0

FCI Posttest responses by question for the control group 1997.

Question	A	%	B	%	C	%	D	%	E	%	Blanks %
Q1	4	5.7	2	2.9	60	85.7	4	5.7	0	0.0	0.0
Q2	34	48.6	18	25.7	6	8.6	10	14.3	2	2.9	0.0
Q3	24	34.3	5	7.1	25	35.7	2	2.9	14	20.0	0.0
Q4	30	42.9	2	2.9	9	12.9	6	8.6	23	32.9	0.0
Q5	5	7.1	6	8.6	23	32.9	14	20.0	22	31.4	0.0
Q6	12	17.1	50	71.4	7	10.0	1	1.4	0	0.0	0.0
Q7	6	8.6	45	64.3	6	8.6	4	5.7	9	12.9	0.0
Q8	8	11.4	48	68.6	2	2.9	5	7.1	5	7.1	2.9
Q9	4	5.7	20	28.6	17	24.3	5	7.1	24	34.3	0.0
Q10	37	52.9	4	5.7	1	1.4	15	21.4	13	18.6	0.0
Q11	4	5.7	5	7.1	44	62.9	15	21.4	2	2.9	0.0
Q12	0	0.0	51	72.9	16	22.9	2	2.9	1	1.4	0.0
Q13	9	12.9	14	20.0	36	51.4	11	15.7	0	0.0	0.0
Q14	29	41.4	12	17.1	9	12.9	20	28.6	0	0.0	0.0
Q15	17	24.3	6	8.6	46	65.7	1	1.4	0	0.0	0.0
Q16	46	65.7	5	7.1	17	24.3	1	1.4	0	0.0	1.4
Q17	40	57.1	9	12.9	1	1.4	17	24.3	3	4.3	0.0
Q18	2	2.9	7	10.0	10	14.3	26	37.1	25	35.7	0.0
Q19	8	11.4	2	2.9	7	10.0	34	48.6	19	27.1	0.0
Q20	15	21.4	4	5.7	29	41.4	16	22.9	6	8.6	0.0
Q21	6	8.6	14	20.0	29	41.4	4	5.7	17	24.3	0.0
Q22	27	38.6	19	27.1	4	5.7	20	28.6	0	0.0	0.0
Q23	11	15.7	28	40.0	11	15.7	15	21.4	4	5.7	1.4
Q24	45	64.3	3	4.3	15	21.4	0	0.0	6	8.6	1.4
Q25	2	2.9	16	22.9	9	12.9	27	38.6	15	21.4	1.4
Q26	35	50.0	17	24.3	4	5.7	6	8.6	7	10.0	1.4
Q27	18	25.7	5	7.1	40	57.1	4	5.7	2	2.9	1.4
Q28	5	7.1	1	1.4	7	10.0	33	47.1	21	30.0	4.3
Q29	5	7.1	48	68.6	3	4.3	10	14.3	1	1.4	4.3
Q30	0	0.0	8	11.4	11	15.7	3	4.3	45	64.3	4.3

FCI Pretest responses by question Treatment 1997

Question	A	%	B	%	C	%	D	%	E	%	Blanks %
Q1	5	7.4	2	2.9	38	55.9	12	17.6	11	16.2	0.0
Q2	19	27.9	13	19.1	5	7.4	24	35.3	5	7.4	2.9
Q3	18	26.5	20	29.4	19	27.9	4	5.9	7	10.3	0.0
Q4	47	69.1	2	2.9	0	0.0	0	0.0	19	27.9	0.0
Q5	4	5.9	7	10.3	39	57.4	6	8.8	11	16.2	1.5
Q6	20	29.4	39	57.4	7	10.3	1	1.5	1	1.5	0.0
Q7	15	22.1	29	42.6	10	14.7	5	7.4	9	13.2	0.0
Q8	22	32.4	23	33.8	2	2.9	10	14.7	11	16.2	0.0
Q9	3	4.4	20	29.4	13	19.1	6	8.8	26	38.2	0.0
Q10	20	29.4	3	4.4	6	8.8	30	44.1	9	13.2	0.0
Q11	7	10.3	29	42.6	21	30.9	4	5.9	6	8.8	1.5
Q12	1	1.5	24	35.3	36	52.9	4	5.9	3	4.4	0.0
Q13	9	13.2	28	41.2	28	41.2	2	2.9	1	1.5	0.0
Q14	37	54.4	9	13.2	6	8.8	16	23.5	0	0.0	0.0
Q15	13	19.1	9	13.2	40	58.8	5	7.4	1	1.5	0.0
Q16	24	35.3	2	2.9	40	58.8	2	2.9	0	0.0	0.0
Q17	34	50.0	6	8.8	5	7.4	10	14.7	13	19.1	0.0
Q18	3	4.4	1	1.5	24	35.3	20	29.4	20	29.4	0.0
Q19	13	19.1	4	5.9	7	10.3	25	36.8	19	27.9	0.0
Q20	22	32.4	3	4.4	21	30.9	11	16.2	11	16.2	0.0
Q21	7	10.3	20	29.4	15	22.1	9	13.2	17	25.0	0.0
Q22	19	27.9	21	30.9	3	4.4	23	33.8	2	2.9	0.0
Q23	10	14.7	17	25.0	22	32.4	16	23.5	3	4.4	0.0
Q24	42	61.8	2	2.9	13	19.1	4	5.9	7	10.3	0.0
Q25	2	2.9	12	17.6	7	10.3	26	38.2	21	30.9	0.0
Q26	21	30.9	30	44.1	5	7.4	11	16.2	1	1.5	0.0
Q27	25	36.8	13	19.1	28	41.2	1	1.5	1	1.5	0.0
Q28	1	1.5	10	14.7	6	8.8	35	51.5	15	22.1	1.5
Q29	15	22.1	34	50.0	4	5.9	10	14.7	4	5.9	1.5
Q30	0	0.0	5	7.4	5	7.4	4	5.9	52	76.5	2.9

FCI Posttest responses by question Treatment 1997

Question	A	%	B	%	C	%	D	%	E	%	Blanks %
Q1	2	2.9	6	8.8	52	76.5	8	11.8	0	0.0	0.0
Q2	37	54.4	10	14.7	1	1.5	19	27.9	1	1.5	0.0
Q3	13	19.1	16	23.5	38	55.9	1	1.5	0	0.0	0.0
Q4	47	69.1	0	0.0	0	0.0	0	0.0	20	29.4	1.5
Q5	2	2.9	12	17.6	10	14.7	27	39.7	17	25.0	0.0
Q6	3	4.4	60	88.2	5	7.4	0	0.0	0	0.0	0.0
Q7	6	8.8	54	79.4	2	2.9	0	0.0	6	8.8	0.0
Q8	6	8.8	56	82.4	0	0.0	3	4.4	3	4.4	0.0
Q9	3	4.4	20	29.4	16	23.5	5	7.4	24	35.3	0.0
Q10	48	70.6	2	2.9	3	4.4	10	14.7	5	7.4	0.0
Q11	3	4.4	3	4.4	29	42.6	26	38.2	7	10.3	0.0
Q12	1	1.5	51	75.0	12	17.6	4	5.9	0	0.0	0.0
Q13	7	10.3	16	23.5	22	32.4	21	30.9	2	2.9	0.0
Q14	13	19.1	21	30.9	10	14.7	24	35.3	0	0.0	0.0
Q15	17	25.0	3	4.4	46	67.6	2	2.9	0	0.0	0.0
Q16	46	67.6	1	1.5	17	25.0	2	2.9	2	2.9	0.0
Q17	36	52.9	18	26.5	2	2.9	4	5.9	8	11.8	0.0
Q18	2	2.9	21	30.9	7	10.3	20	29.4	18	26.5	0.0
Q19	12	17.6	4	5.9	5	7.4	21	30.9	26	38.2	0.0
Q20	16	23.5	4	5.9	16	23.5	26	38.2	6	8.8	0.0
Q21	3	4.4	11	16.2	40	58.8	5	7.4	8	11.8	1.5
Q22	27	39.7	22	32.4	4	5.9	14	20.6	1	1.5	0.0
Q23	21	30.9	27	39.7	11	16.2	7	10.3	2	2.9	0.0
Q24	47	69.1	3	4.4	8	11.8	4	5.9	5	7.4	1.5
Q25	3	4.4	1	1.5	16	23.5	37	54.4	11	16.2	0.0
Q26	14	20.6	19	27.9	6	8.8	14	20.6	15	22.1	0.0
Q27	21	30.9	12	17.6	30	44.1	4	5.9	1	1.5	0.0
Q28	0	0.0	4	5.9	5	7.4	26	38.2	33	48.5	0.0
Q29	1	1.5	49	72.1	1	1.5	14	20.6	1	1.5	2.9
Q30	2	2.9	5	7.4	11	16.2	2	2.9	46	67.6	2.9

Fall 1998 Treatment

FCI pretest responses by question

Question	A	%	B	%	C	%	D	%	E	%	Blanks %
Q1	7	13.2	3	5.7	30	56.6	10	18.9	3	5.7	0.0
Q2	13	24.5	8	15.1	4	7.5	24	45.3	4	7.5	0.0
Q3	16	30.2	15	28.3	17	32.1	1	1.9	3	5.7	1.9
Q4	36	67.9	1	1.9	1	1.9	1	1.9	14	26.4	0.0
Q5	9	17.0	2	3.8	22	41.5	10	18.9	10	18.9	0.0
Q6	9	17.0	42	79.2	2	3.8	0	0.0	0	0.0	0.0
Q7	8	15.1	24	45.3	9	17.0	7	13.2	5	9.4	0.0
Q8	17	32.1	15	28.3	1	1.9	6	11.3	14	26.4	0.0
Q9	1	1.9	19	35.8	13	24.5	2	3.8	18	34.0	0.0
Q10	13	24.5	6	11.3	8	15.1	24	45.3	2	3.8	0.0
Q11	5	9.4	18	34.0	18	34.0	7	13.2	5	9.4	0.0
Q12	0	0.0	22	41.5	25	47.2	4	7.5	2	3.8	0.0
Q13	12	22.6	15	28.3	22	41.5	2	3.8	2	3.8	0.0
Q14	27	50.9	9	17.0	6	11.3	11	20.8	0	0.0	0.0
Q15	8	15.1	4	7.5	38	71.7	3	5.7	0	0.0	0.0
Q16	20	37.7	6	11.3	23	43.4	3	5.7	1	1.9	0.0
Q17	30	56.6	5	9.4	0	0.0	8	15.1	10	18.9	0.0
Q18	3	5.7	6	11.3	17	32.1	18	34.0	9	17.0	0.0
Q19	15	28.3	2	3.8	9	17.0	18	34.0	9	17.0	0.0
Q20	16	30.2	5	9.4	17	32.1	5	9.4	9	17.0	1.9
Q21	6	11.3	13	24.5	13	24.5	5	9.4	15	28.3	1.9
Q22	14	26.4	19	35.8	1	1.9	16	30.2	2	3.8	1.9
Q23	8	15.1	13	24.5	14	26.4	12	22.6	5	9.4	1.9
Q24	25	47.2	3	5.7	12	22.6	3	5.7	9	17.0	1.9
Q25	2	3.8	11	20.8	6	11.3	19	35.8	14	26.4	1.9
Q26	21	39.6	11	20.8	2	3.8	14	26.4	1	1.9	7.5
Q27	18	34.0	4	7.5	26	49.1	2	3.8	0	0.0	5.7
Q28	1	1.9	9	17.0	2	3.8	32	60.4	5	9.4	7.5
Q29	11	20.8	25	47.2	1	1.9	11	20.8	1	1.9	7.5
Q30	1	1.9	4	7.5	6	11.3	1	1.9	37	69.8	7.5

FCI posttest responses by question

Question	A	%	B	%	C	%	D	%	E	%	Blanks %
Q1	3	5.7	4	7.5	42	79.2	3	5.7	1	1.9	0.0
Q2	22	41.5	10	18.9	1	1.9	17	32.1	3	5.7	0.0
Q3	18	34.0	13	24.5	15	28.3	7	13.2	0	0.0	0.0
Q4	15	28.3	0	0.0	1	1.9	0	0.0	37	69.8	0.0
Q5	2	3.8	12	22.6	13	24.5	15	28.3	11	20.8	0.0
Q6	5	9.4	46	86.8	1	1.9	1	1.9	0	0.0	0.0
Q7	3	5.7	40	75.5	5	9.4	3	5.7	2	3.8	0.0
Q8	17	32.1	19	35.8	0	0.0	7	13.2	10	18.9	0.0
Q9	2	3.8	18	34.0	8	15.1	3	5.7	22	41.5	0.0
Q10	27	50.9	4	7.5	2	3.8	15	28.3	5	9.4	0.0
Q11	1	1.9	1	1.9	31	58.5	19	35.8	1	1.9	0.0
Q12	0	0.0	44	83.0	7	13.2	2	3.8	0	0.0	0.0
Q13	5	9.4	14	26.4	26	49.1	8	15.1	0	0.0	0.0
Q14	27	50.9	7	13.2	2	3.8	17	32.1	0	0.0	0.0
Q15	17	32.1	0	0.0	34	64.2	2	3.8	0	0.0	0.0
Q16	35	66.0	1	1.9	15	28.3	1	1.9	1	1.9	0.0
Q17	37	69.8	13	24.5	0	0.0	2	3.8	1	1.9	0.0
Q18	1	1.9	17	32.1	6	11.3	19	35.8	10	18.9	0.0
Q19	9	17.0	1	1.9	4	7.5	18	34.0	21	39.6	0.0
Q20	10	18.9	2	3.8	21	39.6	19	35.8	1	1.9	0.0
Q21	4	7.5	11	20.8	17	32.1	3	5.7	18	34.0	0.0
Q22	19	35.8	18	34.0	0	0.0	15	28.3	1	1.9	0.0
Q23	6	11.3	17	32.1	14	26.4	13	24.5	3	5.7	0.0
Q24	32	60.4	0	0.0	12	22.6	2	3.8	7	13.2	0.0
Q25	1	1.9	1	1.9	17	32.1	23	43.4	11	20.8	0.0
Q26	19	35.8	9	17.0	3	5.7	13	24.5	9	17.0	0.0
Q27	18	34.0	11	20.8	23	43.4	1	1.9	0	0.0	0.0
Q28	1	1.9	1	1.9	5	9.4	11	20.8	35	66.0	0.0
Q29	1	1.9	46	86.8	1	1.9	4	7.5	1	1.9	0.0
Q30	3	5.7	6	11.3	16	30.2	0	0.0	28	52.8	0.0

Appendix B: Force Concept Inventory

Force Concept Inventory

Please:

Do not write anything on this questionnaire.
Mark your answers on the ParSCORE computer sheet.
Make only one mark per item.
Do not skip any question.
Avoid guessing. Your answers should reflect what you personally think.

On the ParSCORE computer sheet:
Use a No. 2 pencil only, and follow marking instructions.
Fill in your ID number. This is the number given to you by your school or your teacher.
Mark "A" under "Test Form".
Fill in the "Exam No." given by your teacher.

Plan to finish this questionnaire in 30 minutes.

Thank you for your cooperation.

Form 081695R

1. Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. The time it takes the balls to reach the ground below will be:
   (A) about half as long for the heavier ball as for the lighter one.
   (B) about half as long for the lighter ball as for the heavier one.
   (C) about the same for both balls.
   (D) considerably less for the heavier ball, but not necessarily half as long.
   (E) considerably less for the lighter ball, but not necessarily half as long.

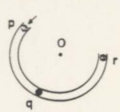
2. The two metal balls of the previous problem roll off a horizontal table with the same speed. In this situation:
   (A) both balls hit the floor at approximately the same horizontal distance from the base of the table.
   (B) the heavier ball hits the floor at about half the horizontal distance from the base of the table than does the lighter ball.
   (C) the lighter ball hits the floor at about half the horizontal distance from the base of the table than does the heavier ball.
   (D) the heavier ball hits the floor considerably closer to the base of the table than the lighter ball, but not necessarily at half the horizontal distance.
   (E) the lighter ball hits the floor considerably closer to the base of the table than the heavier ball, but not necessarily at half the horizontal distance.

3. A stone dropped from the roof of a single story building to the surface of the earth:
   (A) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
   (B) speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the earth.
   (C) speeds up because of an almost constant force of gravity acting upon it.
   (D) falls because of the natural tendency of all objects to rest on the surface of the earth.
   (E) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

4. A large truck collides head-on with a small compact car. During the collision:
   (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
   (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
   (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
   (D) the truck exerts a force on the car but the car does not exert a force on the truck.
   (E) the truck exerts the same amount of force on the car as the car exerts on the truck.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (5 and 6).

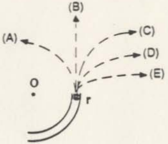
The accompanying figure shows a frictionless channel in the shape of a segment of a circle with center at "O". The channel has been anchored to a frictionless horizontal table top. You are looking down at the table. Forces exerted by the air are negligible. A ball is shot at high speed into the channel at "p" and exits at "r."



5. Consider the following distinct forces:
    1. A downward force of gravity.
    2. A force exerted by the channel pointing from q to O.
    3. A force in the direction of motion.
    4. A force pointing from O to q.

   Which of the above forces is (are) acting on the ball when it is within the frictionless channel at position "q"?

   (A) 1 only.
   (B) 1 and 2.
   (C) 1 and 3.
   (D) 1, 2, and 3.
   (E) 1, 3, and 4.

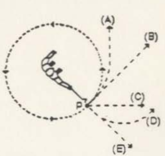


6. Which path in the figure at right would the ball most closely follow after it exits the channel at "r" and moves across the frictionless table top?

7. A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure.

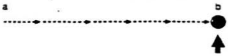
   At the point P indicated in the figure, the string suddenly breaks near the ball.

   If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?

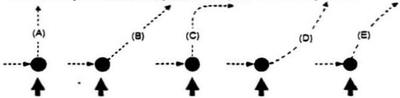


USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (8 through 11).

The figure depicts a hockey puck sliding with constant speed v_o in a straight line from point "a" to point "b" on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point "b," it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point "b," then the kick would have set the puck in horizontal motion with a speed v_k in the direction of the kick.



8. Which of the paths below would the puck most closely follow after receiving the kick?



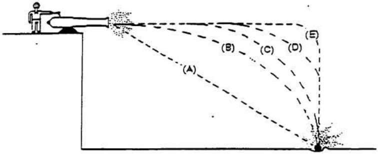
9. The speed of the puck just after it receives the kick is:
   (A) equal to the speed "v_o" it had before it received the kick.
   (B) equal to the speed "v_k" resulting from the kick and independent of the speed "v_o".
   (C) equal to the arithmetic sum of the speeds "v_o" and "v_k".
   (D) smaller than either of the speeds "v_o" or "v_k".
   (E) greater than either of the speeds "v_o" or "v_k", but less than the arithmetic sum of these two speeds.

10. Along the frictionless path you have chosen in question 8, the speed of the puck after receiving the kick:
   (A) is constant.
   (B) continuously increases.
   (C) continuously decreases.
   (D) increases for a while and decreases thereafter.
   (E) is constant for a while and decreases thereafter.

11. Along the frictionless path you have chosen in question 8, the main force(s) acting on the puck after receiving the kick is (are):
   (A) a downward force of gravity.
   (B) a downward force of gravity, and a horizontal force in the direction of motion.
   (C) a downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion.
   (D) a downward force of gravity and an upward force exerted by the surface.
   (E) none. (No forces act on the puck.)

3

12. A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?



13. A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are):

(A) a downward force of gravity along with a steadily decreasing upward force.

(B) a steadily decreasing upward force from the moment it leaves the boy's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the object gets closer to the earth.

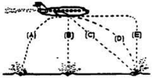
(C) an almost constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point; on the way down there is only a constant downward force of gravity.

(D) an almost constant downward force of gravity only.

(E) none of the above. The ball falls back to ground because of its natural tendency to rest on the surface of the earth.

14. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction.

As observed by a person standing on the ground and viewing the plane as in the figure at right, which path would the bowling ball most closely follow after leaving the airplane?



USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (15 and 16).

A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below.

15. While the car, still pushing the truck, is speeding up to get up to cruising speed:
    (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
    (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
    (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
    (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
    (E) neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

16. After the car reaches the constant cruising speed at which its driver wishes to push the truck:
    (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
    (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
    (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
    (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
    (E) neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

17. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure below. All frictional effects are negligible. In this situation, forces on the elevator are such that:

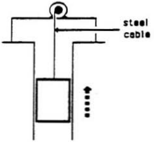
(A) the upward force by the cable is greater than the downward force of gravity.

(B) the upward force by the cable is equal to the downward force of gravity.

(C) the upward force by the cable is smaller than the downward force of gravity.

(D) the upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air.

(E) none of the above. (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable).



Elevator going up
at constant speed

18. The figure below shows a boy swinging on a rope, starting at a point higher than A. Consider the following distinct forces:

1. A downward force of gravity.
2. A force exerted by the rope pointing from A to O.
3. A force in the direction of the boy's motion.
4. A force pointing from O to A.

Which of the above forces is (are) acting on the boy when he is at position A?

(A) 1 only.

(B) 1 and 2.

(C) 1 and 3.

(D) 1, 2, and 3.

(E) 1, 3, and 4.

19. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.

Do the blocks ever have the same speed?

(A) No.

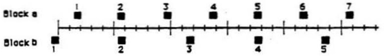
(B) Yes, at instant 2.

(C) Yes, at instant 5.

(D) Yes, at instants 2 and 5.

(E) Yes, at some time during the interval 3 to 4.

20. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



The accelerations of the blocks are related as follows:

(A) The acceleration of "a" is greater than the acceleration of " b".

(B) The acceleration of "a" equals the acceleration of "b". Both accelerations are greater than zero.

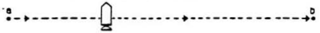
(C) The acceleration of "b" is greater than the acceleration of "a".

(D) The acceleration of "a" equals the acceleration of "b". Both accelerations are zero.

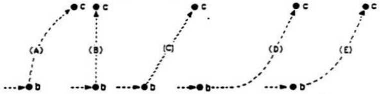
(E) Not enough information is given to answer the question.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (21 through 24).

A rocket drifts sideways in outer space from point "a" to point "b" as shown below. The rocket is subject to no outside forces. Starting at position "b", the rocket's engine is turned on and produces a constant thrust (force on the rocket) at right angles to the line "ab". The constant thrust is maintained until the rocket reaches a point "c" in space.

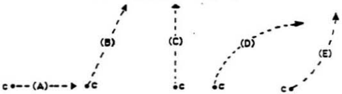


21. Which of the paths below best represents the path of the rocket between points "b" and "c"?



22. As the rocket moves from position "b" to position "c" its speed is:
   (A) constant.
   (B) continuously increasing.
   (C) continuously decreasing.
   (D) increasing for a while and constant thereafter.
   (E) constant for a while and decreasing thereafter.

23. At point "c" the rocket's engine is turned off and the thrust immediately drops to zero. Which of the paths below will the rocket follow beyond point "c"?



24. Beyond position "c" the speed of the rocket is:
   (A) constant.
   (B) continuously increasing.
   (C) continuously decreasing.
   (D) increasing for a while and constant thereafter.
   (E) constant for a while and decreasing thereafter.

25. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed "v_o".

The constant horizontal force applied by the woman:

(A) has the same magnitude as the weight of the box.

(B) is greater than the weight of the box.

(C) has the same magnitude as the total force which resists the motion of the box.

(D) is greater than the total force which resists the motion of the box.

(E) is greater than either the weight of the box or the total force which resists its motion.

26. If the woman in the previous question doubles the constant horizontal force that she exerts on the box to push it on the same horizontal floor, the box then moves:

(A) with a constant speed that is double the speed "v_o" in the previous question.

(B) with a constant speed that is greater than the speed "v_o" in the previous question, but not necessarily twice as great.

(C) for a while with a speed that is constant and greater than the speed "v_o" in the previous question, then with a speed that increases thereafter.

(D) for a while with an increasing speed, then with a constant speed thereafter.

(E) with a continuously increasing speed.

27. If the woman in question 25 suddenly stops applying a horizontal force to the block, then the block will:

(A) immediately come to a stop.

(B) continue moving at a constant speed for a while and then slow to a stop.

(C) immediately start slowing to a stop.

(D) continue at a constant speed.

(E) increase its speed for a while and then start slowing to a stop.

28. In the figure at right, student "a" has a mass of 95 kg and student "b" has a mass of 77 kg. They sit in identical office chairs facing each other.

Student "a" places his bare feet on the knees of student "b", as shown. Student "a" then suddenly pushes outward with his feet, causing both chairs to move.

During the push and while the students are still touching one another:

(A) neither student exerts a force on the other.

(B) student "a" exerts a force on student "b", but "b" does not exert any force on "a".

(C) each student exerts a force on the other, but "b" exerts the larger force.

(D) each student exerts a force on the other, but "a" exerts the larger force.

(E) each student exerts the same amount of force on the other.

29. An empty office chair is at rest on a floor. Consider the following forces:

1. A downward force of gravity.
2. An upward force exerted by the floor.
3. A net downward force exerted by the air.

Which of the forces is (are) acting on the office chair?

(A) 1 only.

(B) 1 and 2.

(C) 2 and 3.

(D) 1, 2, and 3.

(E) none of the forces. (Since the chair is at rest there are no forces acting upon it.)

30. Despite a very strong wind, a tennis player manages to hit a tennis ball with her racquet so that the ball passes over the net and lands in her opponent's court.
Consider the following forces:

1. A downward force of gravity.
2. A force by the "hit".
3. A force exerted by the air.

Which of the above forces is (are) acting on the tennis ball after it has left contact with the racquet and before it touches the ground?

(A) 1 only.

(B) 1 and 2.

(C) 1 and 3.

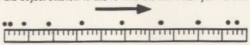
(D) 2 and 3.

(E) 1, 2, and 3.

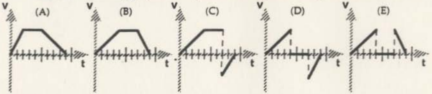
Appendix C: Mechanics Baseline Test

Mechanics Baseline Test

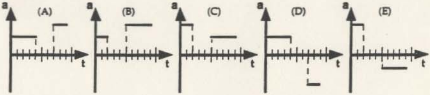
Refer to the diagram below when answering the first two questions. This diagram represents a multiflash photograph of an object moving along a horizontal surface. The positions as indicated in the diagram are separated by equal time intervals. The first flash occurred just as the object started to move and the last flash just as it came to rest.



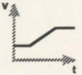
1. Which of the following graphs best represents the object's velocity as a function of time?

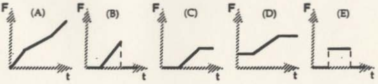


2. Which of the following graphs best represents the object's acceleration as a function of time?



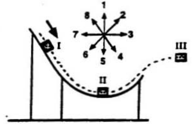
3. The velocity of an object as a function of time is shown in the graph at the right. Which graph below best represents the net force *vs* time relationship for this object?





Refer to the diagram on the right when answering the next three questions.

The diagram depicts a block sliding along a frictionless ramp. The eight numbered arrows in the diagram represent directions to be referred to when answering the questions.



4. The direction of the acceleration of the block, when in position I, is best represented by which of the arrows in the diagram?

   (A) 1 (B) 2 (C) 4 (D) 5
   (E) None of the arrows; the acceleration is zero.

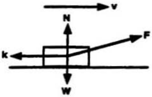
5. The direction of the acceleration of the block, when in position II, is best represented by which of the arrows in the diagram?

   (A) 1 (B) 3 (C) 5 (D) 7
   (E) None of the arrows; the acceleration is zero.

6. The direction of the acceleration of the block (after leaving the ramp) at position III, is best represented by which of the arrows in the diagram?

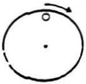
   (A) 2 (B) 3 (C) 5 (D) 6
   (E) None of the arrows; the acceleration is zero.

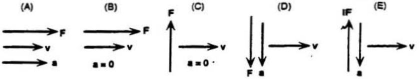
7. A person pulls a block across a rough horizontal surface at a constant speed by applying a force F. The arrows in the diagram correctly indicate the directions, but not necessarily the magnitudes of the various forces on the block. Which of the following relations among the force magnitudes W, k, N and F must be true?



   (A) $F = k$ and $N = W$ (B) $F = k$ and $N > W$
   (C) $F > k$ and $N < W$ (D) $F > k$ and $N = W$
   (E) None of the above choices

8. A small metal cylinder rests on a circular turntable, rotating at a constant speed as illustrated in the diagram at the right. Which of the following sets of vectors best describes the velocity, acceleration, and net force acting on the cylinder at the point indicated in the diagram?

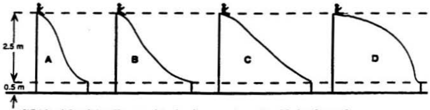




9. Suppose that the metal cylinder in the last problem has a mass of 0.10 kg and that the coefficient of static friction between the surface and the cylinder is 0.12. If the cylinder is 0.20 m from the center of the turntable, what is the maximum speed that the cylinder can move along its circular path without slipping off the turntable?

(A) $0 < V \leq 0.5$ m/s
(B) $0.5 < v \leq 1.0$ m/s
(C) $1.0 < v \leq 1.5$ m/s
(D) $1.5 < v \leq 2.0$ m/s
(E) $2.0 < v \leq 2.5$ m/s

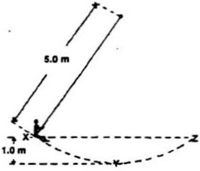
10. A young girl wishes to select one of the frictionless playground slides illustrated below to give her the greatest possible speed when she reaches the bottom of the slide.



Which of the slides illustrated in the diagram above should she choose?

(A) A (B) B (C) C (D) D
(E) It doesn't matter; her speed would be the same for each.

Refer to the diagram below when answering the next two questions.



X and Z mark the highest and Y the lowest positions of a 50.0 kg boy swinging as illustrated in the diagram to the right.

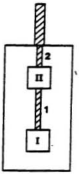
11. What is the boy's speed at point Y?

(A) 2.5 m/s (B) 7.5 m/s
(C) 10. m/s (D) 12.5 m/s
(E) None of the above.

12. What is the tension in the rope at point Y?

(A) 250 N (B) 525 N
(C) 7×10^2 N (D) 1.1×10^3 N
(E) None of the above.

Refer to the diagram below when answering the next two questions.



Blocks I and II, each with a mass of 1.0 kg, are hung from the ceiling of an elevator by ropes 1 and 2.

13. What is the force exerted by rope 1 on block I when the elevator is traveling upward at a constant speed of 2.0 m/s?

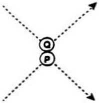
(A) 2 N (B) 10 N (C) 12 N
(D) 20 N (E) 22 N

14. What is the force exerted by rope 1 on block II when the elevator is stationary?

(A) 2 N (B) 10 N (C) 12 N
(D) 20 N (E) 22 N

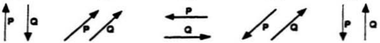
Refer to the following diagram when answering the next two questions.

The diagram to the right depicts the paths of two colliding steel balls, P and Q.



15. Which set of arrows best represents the direction of the change in momentum of each ball?

(A) (B) (C) (D) (E)



16. Which arrow best represents the direction of the impulse applied to ball Q by ball P during the collision?

(A) (B) (C) (D) (E)

17. A car has a maximum acceleration of 3.0 m/s^2. What would its maximum acceleration be while towing a second car twice its mass?

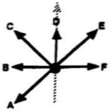
(A) 2.5 m/s^2 (B) 2.0 m/s^2 (C) 1.5 m/s^2 (D) 1.0 m/s^2 (E) 0.5 m/s^2

18. A woman weighing 6.0×10^2 N is riding an elevator from the 1st to the 6th floor. As the elevator approaches the 6th floor, it decreases its upward speed from 8.0 m/s to 2.0 m/s in 3.0 s. What is the average force exerted by the elevator floor on the woman during this 3.0 s interval?

(A) 120 N (B) 480 N (C) 600 N (D) 720 N (E) 1200 N

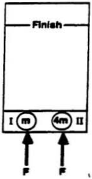
19. The diagram at right depicts a hockey puck moving across a horizontal, frictionless surface in the direction of the dashed arrow. A constant force F, shown in the diagram, is acting on the puck. For the puck to experience a net force in the direction of the dashed arrow, another force must be acting in which of the directions labeled A, B, C, D, E?

(A) A (B) B (C) C (D) D (E) E



Refer to the diagram below when answering the next three questions.

The diagram depicts two pucks on a frictionless table. Puck II is four times as massive as puck I. Starting from rest, the pucks are pushed across the table by two equal forces.

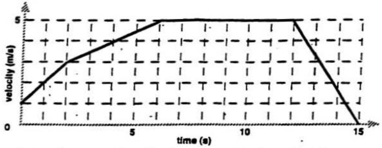


20. Which puck will have the greater kinetic energy upon reaching the finish line?
    (A) I (B) II
    (C) They both have the same amount.
    (D) Too little information to answer.

21. Which puck will reach the finish line first?
    (A) I (B) II
    (C) They will both reach the finish line at the same time.
    (D) Too little information to answer.

22. Which puck will have the greater momentum upon reaching the finish line?
    (A) I (B) II
    (C) They will both have the same momentum.
    (D) Too little information to answer.

Refer to the following graph of velocity *vs* time when answering the next three questions.



The graph represents the motion of an object moving in one dimension.

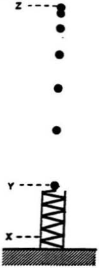
23. What was the object's average acceleration between t = 0 s and t = 6.0 s?
    (A) 3.0 m/s^2 (B) 1.5 m/s^2 (C) 0.83 m/s^2 (D) 0.67 m/s^2
    (E) None of the above.

24. How far did the object travel between t = 0 s and t = 6.0 s?
    (A) 20. m (B) 8.0 m (C) 6.0 m (D) 1.5 m
    (E) None of the above.

25. What was the average speed of the object for the first 6.0 s?
    (A) 3.3 m/s (B) 3.0 m/s (C) 1.8 m/s (D) 1.3 m/s
    (E) None of the above.

Refer to the diagram in the right margin to answer the following question.

The figure represents a multiflash photograph of a small ball being shot straight up by a spring. The spring, with the ball atop, was initially compressed to the point marked X and released. The ball left the spring at the point marked Y, and reaches its highest point at the point marked Z.



26. Assuming that air resistance is negligible:
   (A) The acceleration of the ball was greatest just before it reached point Y (still in contact with the spring).
   (B) The acceleration of the ball was decreasing on its way from point Y to point Z.
   (C) The acceleration of the ball was zero at point Z.
   (D) All of the above responses are correct.
   (E) The acceleration of the ball was the same for all points in its trajectory from points Y to Z.

Views About Sciences Survey

Form P12

This survey is designed by the Modeling Instruction research team at Arizona State University. It is intended to identify factors that affect people's understanding of physics, and to assist in the design of instructional material.

*Your participation is **voluntary**. The results will not affect your grade, even if you choose not to participate. All data are **confidential**. Your identity will not be disclosed to any party. Return of the survey materials will be considered your consent to participate.*

If you have any question about this survey, please call Dr. I. Halloun at (602) 965-8528.

Please:

Do not write anything on this questionnaire.
Mark your answers on the computer sheet.
Use a No. 2 pencil only, and follow marking instructions on the computer sheet.
Make only one mark per item.
Do not skip any question.
Avoid guessing. Your answers should reflect what you actually and honestly think.
Plan to finish the survey in 30 minutes.

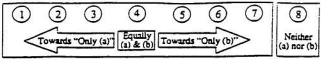
The example below illustrates the eight choices that you have for answering the following 31 questions. Please mark your answers to these questions in section III of the VASS Answer Sheet.

Example

Learning physics requires:
(a) a serious effort.
(b) a special talent.

What would each one of the eight choices mean?

① Only (a), Never (b):	Learning physics requires ***only a serious effort*** and no special talent ***at all***.
② Mostly (a), Rarely (b):	Learning physics requires ***far more a serious effort*** than a special talent.
③ More (a) Than (b):	Learning physics requires ***somewhat more a serious effort*** than a special talent.
④ Equally (a) & (b):	Learning physics ***equally*** requires ***both*** a serious effort and a special talent.
⑤ More (b) Than (a):	Learning physics requires ***somewhat more a special talent*** than a serious effort.
⑥ Mostly (b), Rarely (a):	Learning physics requires ***far more*** a ***special talent*** than a serious effort.
⑦ Only (b), Never (a):	Learning physics requires ***only*** a ***special talent*** and no serious effort ***at all***.
⑧ Neither (a) Nor (b):	Learning physics requires ***neither*** a ***special talent nor a serious effort***.



1. Learning physics requires:
   (a) a serious effort.
   (b) a special talent.

2. If I had a choice:
   (a) I would never take any physics course.
   (b) I would still take physics for my own benefit.

3. Reasoning skills that are taught in physics courses can be helpful to me:
   (a) in my everyday life.
   (b) if I were to become a scientist.

4. I study physics:
   (a) to satisfy course requirements.
   (b) to learn useful knowledge.

5. My score on physics exams is a measure of how well:
   (a) I understand the covered material.
   (b) I can do things the way they are done by the teacher or in some course materials.

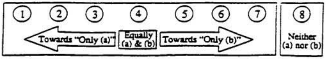
6. For me, doing well in physics courses depends on:
   (a) how much effort I put into studying.
   (b) how well the teacher explains things in class.

7. When I experience a difficulty while studying physics:
   (a) I immediately seek help, or give up trying.
   (b) I try hard to figure it out on my own.

8. When studying physics in a textbook or in course materials:
   (a) I find the important information and memorize it the way it is presented.
   (b) I organize the material in my own way so that I can understand it.

9. For me, the relationship of physics courses to everyday life is usually:
   (a) easy to recognize.
   (b) hard to recognize.

10. In physics, it is important for me to:
   (a) memorize technical terms and mathematical formulas.
   (b) learn ways to organize information and use it.



11. In physics, mathematical formulas:
    (a) express meaningful relationships among variables.
    (b) provide ways to get numerical answers to problems.

12. After I go through a physics text or course materials and feel that I understand them:
    (a) I can solve related problems on my own.
    (b) I have difficulty solving related problems.

13. The first thing I do when solving a physics problem is:
    (a) represent the situation with sketches and drawings.
    (b) search for formulas that relate givens to unknowns.

14. In order to solve a physics problem, I need to:
    (a) have seen the solution to a similar problem before.
    (b) know how to apply general problem solving techniques.

15. For me, solving a physics problem more than one way:
    (a) is a waste of time.
    (b) helps develop my reasoning skills.

16. After I have answered all questions in a homework physics problem:
    (a) I stop working on the problem.
    (b) I check my answers and the way I obtained them.

17. After the teacher solves a physics problem for which I got a wrong solution:
    (a) I discard my solution and learn the one presented by the teacher.
    (b) I try to figure out how the teacher's solution differs from mine.

18. How well I do on physics exams depends on how well I can:
    (a) recall material in the way it was presented in class.
    (b) solve problems that are somewhat different from ones I have seen before.

19. To me, physics is important as a source of:
    (a) factual information about the natural world.
    (b) ways of thinking about the natural world.

20. As they are currently used, Newton's laws of motion:
    (a) are the same throughout the universe.
    (b) change depending on where you are in the universe.

1	2	3	4	5	6	7	8
Towards "Only (a)"			Equally (a) & (b)	Towards "Only (b)"			Neither (a) nor (b)

21. The laws of physics are:
    (a) inherent in the nature of things and independent of how humans think.
    (b) invented by physicists to organize their knowledge about the natural world.

22. The laws of physics portray the real world:
    (a) exactly the way it is.
    (b) by approximation.

23. Physicists say that electrons and protons exist in an atom because:
    (a) they have seen these particles in their actual form with some instruments.
    (b) they have made observations that can be explained by such particles.

24. Where they are currently used, Newton's laws of motion:
    (a) will always be used as they are.
    (b) could eventually be replaced by other laws.

25. Physicists' current ideas about the particles making up the atom:
    (a) will always be maintained as they are.
    (b) could eventually be replaced by other ideas.

26. If we want to apply a method used for solving one physics problem to another problem, the objects involved in the two problems must be:
    (a) identical in all respects.
    (b) similar in some respects.

27. Different branches of physics, like mechanics and electricity:
    (a) are interrelated by common principles.
    (b) are separate and independent of each other.

28. Physicists use mathematics as:
    (a) a tool for analyzing and communicating their ideas.
    (b) a source of factual knowledge about the natural world.

29. Scientific findings about the natural world are:
    (a) dependent on current scientific knowledge.
    (b) accidental, depending on scientists' luck.

30. Knowledge in chemistry is:
    (a) related to knowledge in physics.
    (b) independent of knowledge in physics.

31. I answered all the questions in this survey:
    (a) to the best of my ability.
    (b) without thinking seriously about them.

Appendix E: Scientific Modelling Knowledge Survey

Scientific Modelling Knowledge Survey

All the responses to this survey will be kept confidential. Some information such as experience, education level, etc., may be used to classify your responses. Name and contact information are for my own personal sorting system and will be kept confidential.

Name: ____________________

Work phone: ____________________

E-mail: ____________________

School: ____________________

Education background: (list degrees and certification)

____

Physics background:(number of courses) ______________________________

Total years of teaching experience: ______________________________

Type of experience:(secondary/post-secondary, principally science, math, social studies, etc.)

____

____

Years of teaching physics: ______________________________

Typical class size in physics: ______________________________

General Instructions

Read each statement and then select one of the following responses, i.e., do you agree with, disagree with or are unsure about the statement. **In the space following the statement please defend your choice.** All answers should be on this paper. Please make additional copies for fellow instructors.

Completed surveys should be returned along with with the consent form by mail. If you are interested in the modelling workshops leave a message at my home number.

1. All models are creations of the human intellect.

   a. Agree

   b. Disagree

   c. Unsure

2. All models are representations. Some, like drawings on paper, are purely visual, others made of materials like plastic, wood, polystyrene, metal, etc. can be seen and felt.

   a. Agree

   b. Disagree

   c. Unsure

3. Any representation that one makes of an object, a structure or a process is called a model.

   a. Agree

   b. Disagree

   c. Unsure

4. Models exist in nature.

   a. Agree

   b. Disagree

   c. Unsure

____

____

____

5. All models are mental images (i.e., models exist only in the human mind).

   a. Agree

   b. Disagree

   c. Unsure

____

____

____

6. Models are aids that are used to obtain knowledge of nature.

   a. Agree

   b. Disagree

   c. Unsure

____

____

____

7. A model always provides a complete description of the object, structure, or process in nature that it models (represents).

a. Agree

b. Disagree

c. Unsure

8. This statement relates to the origin of models: a model is formulated using facts obtained through experiments and/or observation.

a. Agree

b. Disagree

c. Unsure

9. The terms model and theory are synonymous.

a. Agree

b. Disagree

c. Unsure

10. The only function of models in science is in teaching.

a. Agree

b. Disagree

c. Unsure

11. Models are of a temporary nature. Scientists use a model for a time, but as a consequence of the increase of scientific knowledge the model becomes obsolete or useless and is either adapted or replaced by another model.

a. Agree

b. Disagree

c. Unsure

12. A scientist always has more knowledge of an object, process, or structure than is represented by the model itself.

a. Agree

b. Disagree

c. Unsure

13. An important function of any model is to describe something (an object or a structure or process) in nature.

a. Agree

b. Disagree

c. Unsure

14. Models play an important role in the explanation of phenomena.

a. Agree

b. Disagree

c. Unsure

15. Models can be used to predict phenomena structures or process that had not been observed before.

a. Agree

b. Disagree

c. Unsure

Optics statements

16. Light rays occur in nature.

    a. Agree

    b. Disagree

    c. Unsure

17. Light beams occur in nature.

    a. Agree

    b. Disagree

    c. Unsure

18. Light is an electromagnetic wave.

    a. Agree

    b. Disagree

    c. Unsure

19. Light is the propagation of particles.

a. Agree

b. Disagree

c. Unsure

20. Light is either a wave phenomenon or a particle phenomenon.

a. Agree

b. Disagree

c. Unsure

21. Light possesses certain properties of transverse waves.

a. Agree

b. Disagree

c. Unsure

22. Light possesses certain properties of moving particles.

a. Agree

b. Disagree

c. Unsure

---

23. The wave and particle model are not applied simultaneously to explain a particular optical phenomenon.

a. Agree

b. Disagree

c. Unsure

Please answer remaining questions in the spaces provided. You may include extra loose leaf if necessary.

24. A number of optical phenomena are listed below. Write the name(s) of a model or models, which can be used to explain or describe each phenomenon.

a. Photoelectric effect ____________________

b. Interference ____________________

c. Diffraction ____________________

d. Polarization ____________________

e. Image formation by lens ____________________

f. Image formation by mirrors. ____________________

25. Define the term model in your own words.

26. Name three models that are used in physics (exclude the two mentioned in item 23 of the questionnaire).

27. Explain how a model can be used in physics.