A Case Study of Non-Traditional Students Re-Entry into College Physics and Engineering

by

Stewart Gordon Langton
B.Sc., University of Victoria, 1982
M.Sc., University of Victoria, 1995

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ABSTRACT

Two groups of students in introductory physics courses of an Access Program for engineering technologies were the subjects of this study. Students with a wide range of academic histories and abilities were enrolled in the program; many of the students were re-entry and academically unprepared for post-secondary education. Five years of historical data were evaluated to use as a benchmark for revised instruction. Data were gathered to describe the pre-course academic state of the students and their academic progress during two physics courses. Additional information was used to search for factors that might constrain academic success and as feedback for the instructional methods. The data were interpreted to regulate constructivist design features for the physics courses.

The Engineering Technology Access Program was introduced to meet the demand from non-traditional students for admission to two-year engineering technology programs, but who did not meet normal academic requirements. The duration of the Access Program was two terms for electronic and computer engineering students and three terms for civil and mechanical engineering students. The sequence of mathematics and physics courses was different for the two groups. The Civil/Mechanical students enrolled in their first mathematics course before undertaking their first physics course. The first mathematics and physics courses for the Electronics students were concurrent. Academic success in the two groups was affected by this difference. Over a five-year period the success rate of students graduating with a technology diploma was approximately twenty-five percent.

Results from this study indicate that it was possible to reduce the very high attrition in the combined Access/Technology Programs. While the success rate for the Electronics students increased to 38% the rate for the Civil/Mechanical students increased dramatically to 77%. It is likely that several factors, related to the extra term in the Access Program for the Civil/Mechanical students, contributed to this high retention rate. Additional time, with less academic pressure in the first term of the Access Program, provided the Civil/Mechanical students with the opportunity to develop academic skills and maturity resulting in improved self-concept and academic identity. These students may have been better equipped to take advantage of the alternate instructional setting of the revised physics courses.

Results from a wide range of studies in Physics Education Research provide ideas and opportunities to improve instruction and students conceptual understanding in introductory physics courses. Most studies focus on traditional students and curriculum. The development and implementation of alternate curriculum and instruction may improve outcomes for different groups of students, particularly for students in disciplines indirectly related to the sciences.

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CHAPTER 1
INTRODUCTION

The demand for graduates in science and engineering has accelerated throughout the twentieth century in pace with technological development. In 1950 fewer than 10% of high school students undertook physics courses, and those students were typically high academic achievers with good mathematical skills. In the last fifty years the proportion of high school students who continue on to postsecondary education has increased; at the same time, many more students require introductory physics as program requirements. However, most introductory physics courses are structured for students with good results in prerequisite mathematics and science courses. Many students who enroll in introductory physics courses may not have the basic skills, particularly in mathematics, that are considered necessary for conceptual understanding and problem solving; these courses appear to serve as a filter for higher level physics courses with the apparent aim of preparing students to become professional scientists. In reality, very few students who enroll in introductory physics courses take advanced physics courses or become professional physicists. A study of non-science majors found that "information is embedded in a massive amount of material primarily appropriate to science majors. ... [Science instructors,] despite the best of intentions and professional competence, are psychologically oriented toward producing specialists like themselves" (Calandra, 1972, p. 36).

This study investigated two introductory physics courses and the achievement of students taking these courses who were enrolled in a one-year Access program at a community college. Students completing this program met prerequisite requirements for entry to a two-year engineering technology program in electronic, computer, civil, or mechanical engineering technologies. Most of the students were non-traditional compared to typical students enrolled in engineering technology programs and many were re-entry students, having been away from formal educational environments for significant periods of time.

Historically, students who enter science and engineering programs are selected by admission standards based on their success in prerequisite mathematics and science courses. Most of these traditional students have previously shown that they learn well within the traditional system of physics education and continue to do well in college and university (House, 2000). But for the majority of non-traditional students, many of whom may be taking their first physics course, the traditional system of physics education does not work well. These students may be taking a physics course as a program requirement, may not have mathematics or science knowledge comparable to a student majoring in physics, and may have had limited success in the physics component of previous science courses. The Access program is typical of most other science programs in that the physics course instructors have graduate degrees in physics. Beichner, Saul, Allain, Deardoff, and Abbott (2000) referred to the process of education whereby "those few who manage to thrive within the current system are thus academically successful and often go on to careers in academia where they continue the tradition" (p. 3). Similarly, McDermott (2001) suggested that:

> The gap between course goals and student achievement reflects a corresponding gap between the instructor and the students. In teaching introductory physics, many faculty proceed from where they are now or where they think they were as students. They frequently view students as younger versions of themselves. This approach is not well suited to a typical introductory physics course since fewer than 5% of the students will major in physics. For most it is a terminal course in the discipline. (p. 1130)

McDermott's concerns about the misinterpretation of students' abilities, interests, and degree goals can be applied to many of the students in this study. These non-traditional students lacked current and substantial mathematics or science prerequisite knowledge and skills that have been found to be important variables for student success (Champagne & Klopfer, 1982). Most physics instructors consider these skills and knowledge as basic and necessary prerequisites for an introductory physics course. The success rate for students in this program were, historically, between 25% and 50%. The curricula and instructional methods used in the physics courses, up to the time of this study, are best described as traditional.

Purpose of the Study

The purpose of this three-year study was to determine the factors that influenced academic success for the re-entry, non-traditional students in the Access program of engineering technologies. The first year was an evaluation of the physics courses in the Access program that resulted in a revised curriculum for the courses. Data were collected during the subsequent year when the courses were offered. These data were then used for a case study of the program, which was then extended in the third year to a research and development project where the results were used for further curriculum development applied to this group of students, as well as more generalized results for students in science and engineering disciplines whose major was not physics.

Context

Over the last 100 years there has been a significant amount of research into physics education. Much of this research was informal and undertaken by faculty members of physics departments. More recently, educational research relevant to physics education has come mostly from studies of students in K-12 schools. A smaller amount has come from recent studies of introductory level physics courses at colleges and universities where the emphasis is on improving conceptual understanding by students in traditional introductory physics courses. While much of this research has continued to be undertaken by science faculty within science departments, there has been an awareness of the need to undertake physics education research as part of "a serious program to apply to our teaching the same scientific standards that we apply to physics research" (Hestenes, 1998, p. 465). However, the success of many individual innovations in physics education has begun to influence how many introductory physics courses are taught and influence the design of textbooks. But most innovations have been localized to a specific group of researchers and instructors (Jenkins, 2001). Even in the case of national and international secondary school programs, such as the Physical Science Study Committee (PSSC) and Harvard Physics Program (HPP) programs of the fifties and sixties, there was inadequate momentum for fundamental philosophical or systemic change in physics education. The increased focus on improvements in instruction and student understanding, as well as systemic changes in post-secondary education in the 21st century, may result in permanent changes to introductory physics courses.

While there has been continuous expansion of the postsecondary college and technical school system in Canada for over fifty years, there has been very little research into how physics should be integrated into program structures. Many colleges and technology schools offer physics courses for either university transfer or as a requirement for non-degree, pre-engineering or engineering technology programs. University-transfer physics courses are structured to match and articulate to university courses. The pre-engineering and technology physics courses are perceived as a way to provide "mastery of the fundamental scientific principles and a command of the basic knowledge underlying a branch of engineering" (Hughes & Matthew, 1993, p. 120). There is significant evidence that in most physics courses students are often acquiring very little fundamental conceptual knowledge and necessary procedural knowledge (Coleman, Holcomb, & Rigden, 1998; Driver, 1998; Ehrlich, 2002; McDermott, 2001; Halloun, 1998b; Thorton & Sokoloff, 1998).

This study was undertaken by the researcher who was also the instructor for the two consecutive physics courses in two parallel but different programs: one class of electronic engineering students (Electronic and Computer Engineering Access programs), and a combined class of civil and mechanical engineering students (Civil Access and Mechanical Engineering Technology Access programs). All students were enrolled in the same physics courses in two consecutive three-month terms. The objective of the program, for the physics courses, was to present two introductory courses that would prepare students to a level comparable with the physics prerequisite for the engineering technology programs: Physics 12. The students were concurrently registered in mathematics courses. The program structures were different for the two groups. The electronics students were enrolled in the Access program for two terms with mathematics and physics courses required in both terms. The civil and mechanical students were enrolled in the Access program for three terms with mathematics required in all three terms and the two physics courses in terms two and three. Thus, the civil and mechanical students received mathematics instruction for one term before entering the physics courses, whereas the electronics students received mathematics instruction concurrently with the physics courses. This variation in programs was considered the most important aspect to be investigated as a factor for student success in the physics courses.

The physics courses presented particular difficulties in developing structure, curriculum, and methodologies. The courses were adopted from an existing university transfer introductory physics course and adapted for differences in program, schedule, and duration. No formal evaluation of the courses had been undertaken to determine how well they were matching the needs of the program or the students, in spite of the students' low success rate (between 25% and 50%),. Thus, no data were available to describe those students or for evaluating the relationship between the curriculum and the ability of the students to complete the course. The Access program was presented as a one-year program that would prepare students for the two-year technology program with minimal prerequisite requirements. More generally, this policy of community colleges has been evaluated by Jones (1979).

> With an open-door policy and the influx of non-traditionally oriented college students, the community colleges face one of the most critical issues in education today – educating the academically unprepared student. (p. 2)

When these students enter an engineering technology program, they face even greater difficulties since the technology programs are often a challenge for traditional, well-prepared students.

The role of mathematics and physics courses in these programs was more complex than is usual for an equivalent introductory physics course. Students were required to pass all courses to remain in the program; many students dropped out because they were unable to meet this requirement. There was a consensus among instructors, based on a large quantity of anecdotal data, of a strong correlation between a student's achievement in mathematics and physics. Also, a student who did not achieve reasonable results in both mathematics and physics was unlikely to have a positive outcome for the three years of study in the combined Access and Technology Programs. In traditional introductory physics courses, the prerequisite academic requirements in mathematics and physics normally result in students with adequate academic and learning skills. The non-traditional students enrolled in this program may have been away from formal education for many years, and the nominal academic prerequisites for this program resulted in many students being admitted to the program who lacked not only basic science and mathematics skills but also the learning skills necessary for success in a formal academic environment. It had been recognized several years prior to this study that learning skills were a critical educational element for many of the students in the Access program, and a learning skills course had been included in the program. In contrast, there were usually a few students who had recently graduated from high school recently and who did not have specific academic prerequisites (most often high school physics) and hence did not meet the requirements for direct entry to the two-year technology program. These students may have had excellent academic backgrounds. As a consequence, the distribution of students ranged from those with limited academic or learning skills to those will both high academic ability, skills, and knowledge but with limited knowledge of physics. The students' initial knowledge state was very difficult to test and evaluate so as to differentiate between a student without specific knowledge who ranked high in probability of success and another student with an equivalent initial knowledge state but with a low probability of success. This range in student characteristics also influenced how the course was structured and presented, which was in a manner not typical of most introductory physics courses and that does not appear to have been studied elsewhere. It was possible to find research results for non-traditional students in areas other than postsecondary science or engineering and other studies for traditional science and engineering students, but the literature on non-traditional engineering students was very sparse.

Problem Focus

The Access program was offered as a way whereby students who had not completed a high school program required for entry to engineering technologies could upgrade and become eligible for entry to the two-year technology program. Academic results from previous years indicated that the majority of students in the Access program were not fulfilling this goal. The physics courses in the program had not been developed to accommodate the type of students in the program; and, as a result, it was common for students to leave the program due to failure in physics and/or mathematics courses.

This research study was structured to (1) identify the types of students who were admitted to the program (year 1), (2) identify factors that determined academic success (year 2), and (3) evaluate the physics courses in the context of physics education research to develop strategies useful in improving students' academic success rates (year 3).

This study addressed the following questions:

1. In the first year:
    a. What were the historical academic progression and success rates for students in the Access program in the previous 5 years?
    b. What strategies and methodologies from PER could be used to redesign the curriculum for the physics courses?
2. In the second year:
    a. How did entering students' initial educational state affect their academic achievement in the two physics courses over a six-month period?
    b. How did entering students' initial mathematics knowledge affect their academic achievement in two physics courses over a six-month period?
    c. What other qualitative factors (learning style, attitudes related to physics, and general attitudes related to the educational environment) were related to achievement in physics?
3. In the third year:

a. Can the relationship between students' attributes and achievement in physics be used as design principles to restructure the two physics courses?
b. Can the results from the study of the re-entry students in the Access program be used for curriculum development in other introductory physics courses?

Significance of the Study

The traditional approach to teaching introductory physics courses is characterized by selecting a textbook and teaching to the topics in that textbook. Most textbooks and faculty members have an approach that is successful for the small proportion of students in physics degree programs. Although the success rate of the non-traditional students in the Access program, the central focus of this study, had been very poor, there had not been any prior analysis or evaluation of the students or the physics courses.

This Access program was apparently unique in attempting to prepare non-traditional students for a program in engineering technology. It may not be practical to enroll an under-prepared student into an engineering program and, in a relatively short period of time (less than one year) expect that student to achieve results similar to a student who is well prepared from prior academic experiences. Consequently, the results from other research may not have been sufficiently encouraging to warrant publication.

Limitations of the Study

The results from this study are descriptive of the current state of the physics courses in this Access program. The results may allow recommendations to be made to increase the students' success rate within the program. However, some recommendations may be in conflict with admission policies, promotional policies, curriculum guidelines, or non-educational factors and constraints.

Because a wide range of students enroll in the Access program, it may be difficult to extrapolate the results from the descriptions of the students in this study to students in future years. Limitations on the use of statistics are necessary since the data are unlikely to be representative of any typical population distribution. Although the data are largely quantitative, great caution should be exercised in using the results for other groups, instructors, or for the same physics courses in future years.

In the year following the collection of data for this study (year 3), as a consequence of funding restrictions, the Access program was reduced to a maximum of six months for all students. It is thus not possible to undertake further studies to compare results relating to differences in mathematics courses between the two groups (civil and mechanical students whose program duration was nine months compared to electronics students whose program was six months).

The dual role of the investigator as instructor and researcher must be considered in the evaluation of validity of results. However, this may be mitigated by the program's unique nature and the cautions on generalization of results. The writing and grading of tests and examinations were a potential source of bias since instructors in this program were not required to have tests or examinations reviewed. To minimize this potential effect a test bank of questions with multiple choice answers from an introductory physics textbook, Physics (Cutnell & Johnson, 2001), were used for tests and final examinations. The same test bank had been used in previous years and an informal evaluation of tests and final examinations for Physics 150 and 151, by another member of the Physics Department, indicated no apparent differences in difficulty compared to other years. An important consideration when interpreting the results of this study is that an objective of the instructional program was to reduce early attrition, particularly in the transition from Physics 150 to Physics 151. When comparing the results of this study to results from the historical data it is important to recognize that some students in the year of this study were promoted from Physics 150 to Physics 151 when in previous years similar students may have failed Physics 150 and dropped from the program. This policy may not have been as readily adopted by an alternate instructor with no interest in the research program.

The results from this study have been used to make recommendations for changes in the curriculum for the physics courses in the Access program. However, constraints on the program, many external to this study, limit the value of those recommendations. Many students have difficulties in their personal lives, particularly related to finances, that take priority over their educational goals. Institutional limitations, in the physics department and at the college level, constrain changes to curriculum, instructional methodology and course structure. Proposed changes to curriculum are often difficult to implement and may not significantly improve results, particularly attrition, that are determined by factors outside the classroom.

CHAPTER 2
LITERATURE REVIEW

Introduction

In 1903 Robert Millikan criticized the degeneration of physics laboratory work into "servile following of instructions" (p. 3). In 1956 the American Association of Physics Teachers was concerned over the overwhelming amount of material in introductory courses and the lack of coherence with the historical and philosophical context of the discipline of physics (Arons, 1993). The state of physics education at the start of the 21st century does not seem to be significantly different than at the beginning of the 20th century. Reddish (1996) described the characteristics of the traditional model of introductory university physics:

- It is content oriented.
- It has 3-4 hours of lecture and may have 1 hour of problem solving recitation per week.
- If there is a laboratory, it will be 2-3 hours and 'cookbook' in nature; that is, students will go through a prescribed series of steps in order to demonstrate the truth of something taught in lecture or read in the book.
- The instructor is active during the class session while the students are passive during the class period (at least during lectures, and often during recitation).
- The instructor expects the student to undergo active learning activities outside the class session, in reading, problem solving, etc. (Part 2, p. 2).

In spite of an increasing acceptance that traditional instructional techniques for introductory physics courses are not working well for a large number of students, the methods of physics instruction remained, until quite recently, unchanged since the 1950s (Cooper, 1993). While change has been slow, recent developments in PER appear to be having a positive effect and the rate of change may be increasing (Carolan, personal communication, 2006). Some change may be restricted since many introductory physics courses serve other college or university departments by providing physics courses for students studying areas other than physics and with external requirements outside the control of the physics departments.

> Such a course is intended to introduce students to the rich domain of physics, with an understanding of its nature and practice, to expose the students to

> models of expertise in the field, and to provide students with cognitive frameworks that will help them advance from novice patterns of thinking and problem solving to more expert patterns. The last of these goals demands the development of both conceptual and procedural competence in the domain (Cooper, pp. 9-10).

These goals are often implicitly accepted but difficult to detect in the curriculum and instructional practices in many introductory physics courses. Both curriculum and instructional methods are closely related to the learning styles of the instructors (Elby, 1999).

Almost all college and university physics instructors have extensive backgrounds in the learning and practice of physics. They are often experts in their physics research domain and community, and they have acquired their expertise in traditional educational environments. Physics instructors usually have a clear and logical understanding of the material taught in their courses, select textbooks that reflect their understanding, and attempt to transfer the knowledge in a clear and concise manner. These instructors represent the small proportion of people who have prospered in a system of direct information transfer. However, there is increasing evidence that, for conceptual understanding, the transfer of information model is not working for the majority of physics students (Hestenes, 1998a). It has been suggested that, notwithstanding a widely held view that education is an art rather than a science, scientific research methods should be applied to physics education research (PER) (McDermott, 2001; Redish & Steinberg, 1999). This belief has led to many instructional innovations that have been justified from measurements of student outcomes using quantitative data analysis. Although concerns about the breadth of coverage at the expense of depth of understanding have been expressed for over fifty years, there is, at present in North America, no widespread support for change to the curricula of university physics courses. In many cases, the curriculum is very similar to that offered in physics courses at the beginning of the 20th century, with the addition of a limited amount of 20th century modern physics. Questions about what to teach and philosophies of instruction arise more often from researchers in Europe, where there appears to be a broader view for curriculum development. Most PER can be related to curriculum development, and a wide range of theories and applications originating from different research communities appears to influence these efforts. Although curriculum development is often characterized by physics departments as topic reorganization, a broader view includes all aspects, explicit and hidden, that make up the educational environment of a classroom. A useful starting point for curriculum development for a physics course is looking at the discipline of physics and the relationships between the practice of physics and what is taught in postsecondary physics courses.

The Nature of Physics

The list of philosophies relevant to physics education is extensive, and there may be as many possibilities for describing the nature of science as there are scientists (Wildy & Wallace, 1995). There are, however, ideas of fundamental concepts and processes that create the framework for scientific investigation. The scientific process with its iterations of model building, data acquisition, and interpretation provide a good reference for physics education research. This is particularly true if the goal is to change the focus of a physics course from information transfer to include more components of science as practiced by physicists.

One scientific process is the building of models to represent the physical world (Ingham & Gilbert, 1992); and these models have been constructed, modified, refined, and confirmed over the last four or five hundred years. The majority of these models in physics have a mathematical basis. Many, particularly in modern physics, are completely mathematical and may not have a parallel physical model. Random and chaotic processes represent a significant proportion of present physics research and involve many processes. Most current physics courses and instructional approaches do not reflect the fundamental nature of physics.

Physics Curriculum and Instruction

A major component of all introductory physics courses is mechanics. Osborne (1990) suggested "physics education should recognize that Newtonian physics has its uses but also has its limits, just as physics itself has" (p. 191). How students integrate information is not considered. It is a premise of constructivist learning theory that knowledge is developed from an existing framework into which new ideas are evaluated and modified, rejected, or integrated. Existing ideas take priority and the replacement of an existing concept requires significant justification and realignment. New ideas must be subjected to independent testing and confirmation. These ideas seem very similar to the requirements for scientific acceptance yet, although the commitment of physicists to this process is almost universal, they demonstrate limited transfer to their educational practice. The scientific process is experimental, adaptive, and often uncertain. Physics education is most often presented by instructors and perceived by students as deterministic. At the completion of an introductory physics course, many students think that scientific knowledge is composed of facts, formulae, and certainty that have been presented in a few hours of lecture. Many of these ideas were developed over decades by giants of the discipline.

> Historians have not failed to observe that the great intellectual struggles of the past provide valuable insights into the conceptual difficulties of students. Accordingly, they advocate a strong dose of history for the physics curriculum … but the curriculum leaves little room for the history of science. (Halloun & Hestenes, 1985b, p.1056)

The present curriculum represents at least five hundred years of scientific output that omits all but the final product and is presented in a linear, factual, and incontrovertible manner so that much of the context of the development and application may be lost.

> Deeper solidification of the students' understanding, which is almost invariably needed, is cultivated not by insistent hammering of the initial encounter but by continual spiraling back to earlier ideas, invoking these ideas in repeatedly extended contexts and using them in new juxtapositions. (Arons, 1972, p. 30)

This process of learning does not seem much different from that of the historical scientific process. "The arduousness of learning mechanics is expressed in the effort required as students shift their thinking from one paradigm to another. Paradigm shifts are not accomplished easily, neither in the scientific enterprise nor in the minds of students" (Champagne, Klopfer, & Anderson, 1980, p. 1077).

Introductory science courses are often taught using descriptions of accepted outcomes, while ignoring the process of development and acceptance by the scientific community.

> [Students] picked up some technical knowledge together with probably fallacious notions about the scientific method, most know little about the history, philosophy, and sociology of science, or about how and why it has revolutionized thought and life. They have no clear idea of what questions science can and cannot answer, why its answers are always partial and dubitable, why its triumphant advance may make the humanities all the more important. They have a legitimate excuse in that introductory courses in science are usually taught as technical courses, a basis for more advanced work, not as humanistic studies for non-specialists, or

> even as introductions to the fundamental question – the nature of scientific inquiry. (Muller, H.J. quoted in Arons, 1973, p. 769)

The reasons most introductory physics courses are not taught in a historical context are related to the choices that have been made in curriculum development. Lederman (2001) suggests that schools and education have fallen behind when compared to changes in technology and science. In the last fifty years there has been an unprecedented increase in technological development. A basic education in science and engineering may now be at a level that in the past would have been equivalent to an expert's knowledge. Notwithstanding comments about students learning how to learn or undertaking authentic scientific practice or other statements relating to the engagement of students as scientists, many physics instructors believe that the role of physics courses is to give students a basic understanding of the facts and concepts of the discipline. They have decided that it is necessary for students to be prepared with factual information and specific, often mathematical, abilities for advancement to higher-level courses. This model for teaching physics is the one that has been successful for those students who have become the community of scientists and physics instructors.

From early in the 20th century, behaviorists had a strong influence on the way that physics was taught (Cooper, 1993; Jenkins, 2001). Ideas were presented as facts, to be memorized or learned in preparation for using science and technology in the workplace. While understanding was an important feature, there was a stronger emphasis on knowing the basics, since these bits of information provided the foundation on which complex understandings were built. A significant change occurred around the 1950s when, due to greater demand for technologically proficient workers and a shortage of trained scientists, there were efforts to increase the general scientific training of the population. At the same time there was an increasing interest by physicists in physics education, which led to several programs like the Physical Science Study Committee (PSSC) curriculum that stressed understanding the structure of physics and scientific inquiry rather than content knowledge. There was a consensus that the PSSC program would change the presentation of physics from "a collection of unrelated definitions and formulas with a presentation of physics as a unified and evolving subject" (Haber-Schaim, 1998, p. 294). In a review of the PSSC program, French (1986) related the change that occurred as a consequence of the program:

> What physics was taught [before PSSC] emphasized rote learning and superficial description. ... The PSSC course would seek to present physics as an integrated

> intellectual activity, not as a set of mechanical rules for solving problems and manipulating nature. The course would be designed to reflect a spirit of inquiry. (p. 30)

There was also recognition that "in the interest of achieving depth of treatment, substantial areas of traditional material would be omitted" (p. 30). The goal was to get students to think and act like professional scientists rather than to acquire the body of traditional knowledge. The program did not result in the desired change in physics instruction. In recent years the process of curriculum and textbook development has become less inclusive of practicing physicists than at the time of PSSC. French (1986) provided some evidence of why the PSSC movement faltered:

> It can be argued that the course, although exciting to the scientifically inclined students, was too difficult, and perhaps not suitable, for the rest. The Harvard Project Physics course, developed a few years later, was designed to address this problem; it was well received, but did not significantly alter the picture (p. 32). Perhaps without thinking about it, the makers of PSSC Physics were speaking to their own kind. The problem of reaching the average student remains unsolved, and even among the academically talented, scientific literacy is the exception (p. 34).

The problem of teaching physics so that the majority of students begin to think in a scientific way is not unique to physics. In a review of mathematics instruction, Romberg and Carpenter (1986) noted that the textbook was consistently seen as the authority on knowledge and that mathematics and science were seldom taught as scientific inquiry – "all subjects were presented as what experts had found to be true" (p. 25).

Why is the emphasis in physics education on the classical topics of physics rather than the process of scientific inquiry? Regardless of the philosophy of instruction, there is often an accepted premise that an introductory course should provide exposure to and application of all the major topics of physics. There is also a perceived necessity to make explanations with sufficient detail, particularly mathematical, so that they are consistent with accepted theory. Lindenfeld (2002) termed this the "tyranny of the prerequisite" (p. 12). But, "there is [also] a common observation among physics instructors that the most strenuous efforts to improve instruction hardly seem to have any effect on general student performance" (Halloun & Hestenes, 1985a, p. 1048) and that most physics students do not gain any significant conceptual or procedural knowledge of physics (McDermott, 1993). To the end of the 20th century this paradox did not seem to have created any consensus among physics instructors for fundamental change to curriculum and instruction. In the first decade of the 21st century there appear to be signs of a growing recognition that successful initiatives from small groups and isolated individuals are gaining recognition and acceptance by the wider community of physics instructors and departments.

Constructivism

Since the late 1970s there has been a trend toward a constructivist philosophy, particularly in K-10 science courses, less so in high school physics courses, and to a limited extent in postsecondary physics courses. There has also been continued public and institutional awareness that scientific literacy is an important outcome of education (Alters, 1997; Harvard College, 2004). The philosophy and methodology of constructivism provide an alternate model for educating the average physics student.

The philosophy of constructivism is based on the premise that one gains knowledge and understanding by relating a new idea to the set of existing ideas or knowledge framework. This prior knowledge may not be fully developed or totally accurate. Appleton (1993), Appleton and Asoko (1996), and Yerrick, Pedersen, and Arnason (1998) provided broad definitions of constructivism relating to education through social interactions. Tobin, Briscoe, and Holman (1990) stated "learning is an interpretive process, involving constructions of individuals and social collaboration" (p. 411). Eflin, Glennan, and Reisch (1999) discussed the realist vs. social constructionist philosophies where "social constructionism replaces nature as an arbiter of scientific beliefs with scientists" (pp. 109-110). Yore (2001) adapted an earlier model of Henriques (1997) that describes four versions of constructivism that can be used as guides for science instruction: information processing, interactive-constructivism, social constructivism, and radical constructivism. While it may be possible to apply any of these to postsecondary physics, the information processing and interactive-constructivist models are most relevant to introductory physics courses where the ideas presented from classical and modern physics and the mathematics associated with the theoretical descriptions are accepted foundations of knowledge in the discipline. If scientific literacy is a desired outcome, then students need exposure to the actual scientific process, either in a modern context of current research or by understanding the historical context from which the accepted body of knowledge of classical physics and the fundamentals of modern physics have been derived. In a study of the views of scientists (Yore, Hand, & Florence, 2004), there was a consistent description that approximated the modern evaluativist epistemic view of the interactive-constructivist model. This appears to conflict with the view of science or of scientists, as presented in most introductory physics courses, where the usual goal is the transfer of basic knowledge.

The role of constructivism may be more pragmatic than philosophical. Millar (1989) suggested the constructivist philosophy is self-evident and that the value in constructivism is its application to developing curriculum or methodology. If the purpose of education is to gain understanding and develop the ability to solve complex problems, then building a conceptual network is essential. Historically, physics education has been based on the transmission of information. It was assumed that the process of developing skills and understanding would automatically follow. In K-12 science education, the broader view has been considered.

> Since the 1980's, the emphasis in science education has been gradually shifting toward a greater concern with an overall understanding of science and its role in society. From this perspective, the purposes of science education have been proposed as being: learning science, that is, understanding scientific conceptual knowledge; learning about science, that is understanding what the conduct of science involves; and doing science, that is, taking part in activities that contribute to the development of skills with which to obtain reliable scientific knowledge. (Justi & Gilbert, 1998, pp. 163)

This increased concern for broader understanding in science may be in response to the increasing complexity of the scientific process with its "complex entanglements of scientific claims, markets, ethics, transnational politics, sophisticated technologies, problems in need of resolution" (Flower, 2000, p. 36). Flower continued "to argue that our notions of science literacy are tied to a mythical view of science" (p. 36). The present educational system, particularly for physics, appears to support this mythical view; and the inertia of the system, based more on an information-processing model, may have limited change. But the number of new and innovative projects counters this view. The website for the Physics Sciences Resource Centre (PSRC) (available online at http://www.psrc-online.org/) provides a wide variety of resources for improving instruction. The increased influence of PER and the adoption of alternate curriculum and instruction may be overcoming the traditional inertia of physics education.

In K-12 science programs, there is a possibility of changing the philosophy of science education from information processing to one where social interpretation is emphasized (Jenkins, 2001). There is no indication of any suggestion from within the scientific communities that a major change in the philosophy of postsecondary physics education is necessary. But the majority of students who enroll in introductory physics courses are in programs where there is recognition that "the task of the physics teacher today is to figure out how to help a much larger fraction of the population understand how the world works, how to think logically, and how to evaluate science" (Redish, 1996, Part 1, p. 2). One possibility is to expand the curriculum to include more interdisciplinary components and interpretations, which would increase the degree of complexity. If the current curriculum, perceived as basic by most instructors, is not achieving the goal of literacy, then it does not seem possible that these alternatives would be any better. A major barrier to improving literacy is that many students come to science courses with a set of ideas that are inconsistent with the ideas of science. These conceptions and misconceptions must be addressed as part of the decisions made in curriculum development.

Preconceptions and Misconceptions

The idea of preconceptions and misconceptions is an important component of constructivism. Learners come with previous experiences organized into a schema that is consistent within each students' conceptual framework (Appleton, 1993; Halloun & Hestenes, 1985b). Their conceptual framework may be in conflict with accepted scientific explanations but they will interpret, or misinterpret, scientific explanations with respect to their personal schema. Halloun and Hestenes (1985a) referred to the initial knowledge state, before any formal physics instruction, as a "common sense knowledge state" (p. 1043). In mechanics this knowledge state is most commonly quite different from a Newtonian perspective and may be very stable and particularly resistant to change from conventional physics instruction (Halloun & Hestenes, 1985a, 1987). Thus, a pretest for conceptual understanding of Newtonian concepts can be an accurate predictor of a student's prior knowledge since "the student's ability to process information in the course depends mainly on his initial knowledge state and hardly improves throughout the [traditional] course" (Halloun & Hestenes, 1985a, p. 1048). When revising instruction to replace traditional instruction it is thus important to be aware of the students' conceptual knowledge state at the start of a course and include design parameters to address gaps in their conceptual understanding.

Prior knowledge may contain many forms of naïve conceptions and non-scientific explanations. Clement (1993) emphasized the importance of differentiating between preconceptions and misconceptions, and Palmer (1999) stated "students develop their own ideas and beliefs about natural phenomena even before they have formally been taught science" (p. 639). Students may have prior knowledge of physical phenomena that makes sense to them and that they use preferentially although these may conflict with formal physics concepts. The Laws of Newton are "inconsistent with the way in which many of our students make sense of their experiences of the world" (Redish & Steinberg, 1999, p. 24). "Many decisions students make about the behavior of physical systems seem to be driven more by prior knowledge and beliefs than by interpretations and application of formal physics principles, that is, by using personal mental models rather than those of the physics community" (Goldberg & Bendell, 1995, p. 978). Halloun (1996) referred to these as folk models in comparison to scientific models and believes that the inconsistencies between the folk and scientific models must be addressed so that students can internally construct models that are better aligned with accepted scientific explanations.

Misconceptions have also been described as phenomenological primitives (p-prims) (diSessa, 1993) or undifferentiated proto-conceptions (McDermott, Shaffer, & The Physics Education Group at the University of Washington, 2002). Clement (1982) defined a conceptual primitive as "a mental construct, the understanding of which is a foundation for many higher-order concepts" and noted that "it is easy to underestimate the learning difficulties that these 'root concepts' present to the student" (p. 66). Many students perceive common sense thinking as independent of formal scientific thinking (Palmer, 1999), so these root concepts may not be contextualized into a student's framework. Brown (1992) and Clement (1993) used initial conceptions as a foundation for expanded learning and proposed anchoring conceptions and bridging analogies based on existing experience. Students can use analogies to integrate new knowledge for which they have no direct experience. Clement (1993) discussed the "'Prior Knowledge Paradox' [where] in order for difficult conceptual material to make sense to the student, it is important to connect somehow with the student's existing knowledge; but the student's existing intuition in the area is in conflict with the theory being taught" (p. 1252). Millar (1989) suggested "a valuable insight [from the constructivist model] is that concept learning is understood as a reconstruction of meaning rather than simply the accretion of new ideas" (p. 588). Reconstruction must, therefore, include acknowledgement by students of the conflict between their existing ideas and the accepted scientific concept.

Champagne, Klopfer, and Anderson (1980) illustrated this reconstruction with the example of different concepts of Newtonian and Aristotelian mechanics:

> In Newton's abstract, idealized, and frictionless world, the behavior of objects is vastly different from their behavior in the Aristotelian world, and the central concept is the acceleration of objects, not their velocity. The Newtonian paradigm appears esoteric and unfamiliar to the uninitiated student in comparison with the comfortable and intuitive Aristotelian paradigm. (p. 1077)

However, "Learning science … is seen to involve more than the individual making sense of his or her personal experience but also of being initiated into the 'ways of seeing' which have been established and found to be fruitful by the scientific community" (Driver, 1998, p. 482). Some caution should be exercised in using Newtonian and Aristotelian models as references for students' internal conceptual models. Hake (1987) referred to students' non-Newtonian concepts as "pre-Aristotelian, Aristotelian, medieval, or simply muddled" (p. 880). Halloun and Hestenes (1985b) suggested most students' belief system is much closer to the medieval impetus system than to the elaborate and logically consistent Aristotelian system. Halloun and Hestenes (1985b) discussed the common sense conceptions of students:

> [Common sense] beliefs which are incompatible with established scientific theory are quickly labeled as 'misconceptions' and dismissed by most scientists. But students are not so easily disabused of [common sense] beliefs because their own beliefs are grounded in their own personal experience. [Common sense] misconceptions are not arbitrary or trivial mistakes. … If the evaluation of common sense was so difficult for the intellectual giants from Aristotle to Galileo, we should not be surprised to find that is a problem for ordinary students today. (p. 1056)

This implies that it is inadequate to rely on the authority of the instructor and the students' confidence in the instructor's status as a representative of the scientific community. Students' perceptions are obstacles to learning that must be considered and addressed.

Conceptual Change and Assessment

Students should be aware of their preconceptions and be shown the inconsistencies; then alternate, scientific ideas can be presented that are acceptable to the student. One way to accomplish this process is by using a predict-observe-explain cycle. If students are confronted with a situation that has an obvious (i.e., common sense) outcome, they will normally predict that outcome unless they suspect some trick. If the outcome is not as expected and there is no trick, then the events may create a cognitive dissonance for the students; and they may be ready to propose or accept a new explanation beyond that of the common sense explanation. Included in this process is the aim of making students aware that there are alternate ways of thinking (Millar, 1989). These ideas are useful for misconceptions that are easily overcome in the course of instruction. Other problems are more intractable and constrain learning of more complex concepts and may be resistant to change (Schoenfeld, 1988; McDermott, 1993). At higher academic levels, a student may have multiple references to an idea – some scientifically consistent and others inconsistent – for which there are no common sense outcomes. These may be theoretical, often mathematical, representations for which there are no physical models. However, Halloun and Hestenes (1985b) found it is possible, after long discussions, for students to overcome even obstinate beliefs if they realize the inconsistency of their thinking. To further compound the difficulty, it has been found that "it is often impossible to separate difficulties with concepts from difficulties with reasoning … [and that] growth in reasoning ability does not usually result from traditional instruction. Scientific reasoning skills must be explicitly cultivated" (McDermott, 1993, p. 296). But if each student has a unique framework into which new ideas must be integrated, the task of traditional large-group instruction appears to be ineffective. Millar (1989) suggested:

> i) Many teachers are now persuaded of the value of knowing about the prior ideas their pupils are likely to have about a given science topic, or having the tools to elicit these for themselves, but are much less sure about how (or even whether) they can act on this knowledge when teaching a class of 25 or more learners.
>
> ii) There is a need to reconcile the constructivist emphasis on 'taking learners' ideas seriously' with the fact that science is, at any particular time, almost entirely a body of consensually agreed knowledge.
>
> iii) It would be more productive to model understanding as a collection of discrete 'knowledge fragments' than as a 'framework' of ideas and propositions. (p. 588)

It is the second and third ideas where instruction and learning may diverge. The transmitted knowledge fragments may be independent of that received and interpreted by the students in the context of their own knowledge framework. McDermott (2001) suggested:

> [S]tudents must go step-by-step through the reasoning needed to overcome conceptual hurdles and build a consistent framework. … Guided by the questions and exercises, they conduct open-ended explorations, perform simple experiments, discuss their findings, compare their interpretations, and collaborate in constructing qualitative models that can help them account for observations and make predictions. Great stress is placed on explanations of reasoning. … The instructor does not lecture but poses questions that motivate students to think critically about the material. (p. 1129)

She suggested that alternatives to the traditional lecture-recitation-laboratory instruction must be investigated:

> Hearing lectures, reading textbooks, solving quantitative problems, seeing demonstrations, and doing experiments often have surprisingly little effect on students learning. We have found that an effective instructional approach is to challenge students with qualitative questions that cannot be answered through memorization, to help them learn how to respond to such questions, and to insist that they do the necessary reasoning by not supplying them with answers. (p. 1133)

But this alternate approach is often inconsistent with what university students expect in a course, and the change in instructional philosophy cannot be undertaken without concurrent change in expectations of students and how they are evaluated. Ehrlich (2002) and Golberg and McDermott (1986) described common situations where a student perfectly reproduces assigned problems but is unable to answer even simple questions about problem-solving assumptions, information, and procedures. This superficial reproduction of knowledge represents the major source of the students' mark and consequent grade. If conceptual understanding and the production of knowledge rather than knowledge reproduction is the goal of physics courses, then conceptual testing must be the major component of assessment and evaluation. However, many physics instructors continue to believe that results from traditional instruction are much better than the PER results indicate. If tests include only numerical problems without probing for conceptual understanding, it is likely that students' mathematical skills will mask misconceptions of physics concepts. If the intent of evaluation is more than to test students' abilities to solve standard physics problems, then examinations must include more conceptual questions (Halloun & Hestenes, 1985b, 1987).

While many physics instructors are confident that their students are learning the material, extensive data from the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992) and the Mechanics Baseline Test (MBLT) (Hestenes & Wells, 1992) indicate that the majority of students who complete an introductory physics course do not have basic conceptual understanding of mechanics topics. Students may appear to have conceptual understanding since they may "dress up [his or her] misconceptions in scientific jargon, giving the false impression that he [or she] has learned something about science" (Halloun & Hestenes, 1985a, p. 1048). "[S]tudents often carry out of traditional physics courses loose bundles of vague and undifferentiated concepts about physical objects and their properties" (Halloun, 1998a, p. 239). McDermott (2001) suggested that conceptual understanding is also concealed by the grading practice of awarding marks for partial solutions. Students achieve acceptable grades by accumulating enough marks for incorrect solutions or for numerical solutions using memorized algorithms. Within constructivism, the term 'authentic assessment' describes evaluation that covers a broad range of attributes including reflection on instruction and learning outcomes. Formative rather than summative evaluation and the incorporation of assessment into the learning environment result in a continuous feedback system for students. Lajoie and Lesgold (1992) referred to dynamic assessment integrated into learning experiences through portfolios, projects, compositions, and performances. In most physics courses, problem solving is a major component that involves process as well as factual information; but authentic assessment stresses the overall process more than may be the case in traditional testing. Many forms of informal assessment by both instructor and student can be incorporated to maximize the engagement and progress of students.

Improving the Instructional Environment

The change from traditional instruction to constructivism or any alternate instructional philosophy and methodology has significant challenges. McDermott acknowledged "the challenge of securing the mental engagement of students in a typical calculus-based or algebra based course is much greater [than in a physics course for preservice elementary teachers]" (2001, p. 1130). The process of engaging students may require instructional time devoted to the difficult task of promoting a set of student beliefs that are more closely aligned with the scientific beliefs of most instructors. Elby (1999) reported some of the beliefs of students that may conflict with the perceptions of instructors and that influence how students learn physics. When told that a deep understanding is important, the student might not understand what that means and often perceive learning physics to be a significantly different activity from trying to do well in the course. There is no correlation between the habits of students and their grades – all students "play the game" (p. S52). Another large set of students believed that a deep understanding can lead to good grades but that a more rote understanding can also lead to good grades. Many students did not view acquiring a deep understanding of physics as a necessary condition for doing well on tests and spent a disproportionate time focusing on formulas and problem-solving algorithms. Consequently, many college and high school physics students enter the classroom with the deeply entrenched view, supported by years of experience, that rote learning will be rewarded.

Halloun (1996) described some of the beliefs that may explain the reasons behind some common methods for solving physics problems that students use and that instructors recognize as descriptive of novice techniques: a) trial and error, b) backward from a numerical answer provided in a textbook, and c) invoking a solution presented in class to a problem that they wrongly assume to be familiar to the one on which they are working. Similar difficulties in mathematics instruction are discussed by Schoenfeld (1988) as a set of beliefs that students hold for geometry problem solving. It is likely that these apply equally to physics instruction due to the dependence of physics on mathematics as well as similarities between problem solving in physics and in geometry.

> Belief 1: The processes of formal mathematics (e.g., 'proof') have little or nothing to do with discovery or invention. Corollary: Students fail to use information from formal mathematics when they are in 'problem solving' mode.
>
> Belief 2: Students who understand the subject matter can solve assigned mathematical problems in five minutes or less. Corollary: Students stop working on a problem after just a few minutes because, if they have not solved it, they do not understand the material, (and therefore will not solve it).
>
> Belief 3: Only geniuses are capable of discovering, creating, or really understanding mathematics. Corollary: Mathematics is studied passively, with students accepting what is passed down 'from above' without the expectation that they can make sense of it for themselves. (p. 151).

The equivalent in physics for Belief 1 is that students rarely consider concepts when solving problems. A typical technique for problem solving is to find a similar, solved problem in a textbook and use that as a model for an assigned problem. Belief 2 is directly applicable to physics. Students in most physics courses are rarely given problems that include more than a single concept, with the numerical values for all required variables, a single unknown, and no extraneous information. Students can use a problem-solving algorithm for solutions: extract the information from the problem statement, find the correct formula, and solve for the single unknown variable. Ill-structured problems that reflect real problems are difficult for students as a consequence of their limited experience with this type of problem. Students often perceive open-ended problems as unfair. Belief 3 is reinforced in traditional physics programs by the high attrition in undergraduate programs and the focus on advanced mathematics in many upper level courses. Since many students hold these beliefs, their attitude toward physics can make the ideas of constructivism difficult to apply in a university level course where students may have a very pragmatic approach to success in an introductory physics course.

In a study of a senior high school physics teacher who had limited success in attempting to apply constructivist methodology in a physics course, Wildy and Wallace (1995) recommended that constructivism be applied more generally to meet the needs of each particular situation. "We entered the research setting with a particular frame of reference and discovered the frame of reference neither fitted the situation nor had the relevance for the players" (p. 151). In that situation it meant considering a broader definition of constructivism than is generally presented in the research literature.

> It [constructivist literature] is inadequate because it presents a singular view of good teaching and learning. Teachers and students do not construct knowledge in a vacuum. The way they teach and learn as well as the choices about what to teach and learn are integrally connected to the social and cultural contexts of schooling (p. 154).

But there are still many physics classrooms where the only form of instruction is the one-way presentation of factual material by the instructor to the students. There are also many classrooms where the instructor is attempting to adapt constructivism to maximize student learning in the context of the academic and social environment of that classroom.

Introductory Physics Course Curriculum

The majority of physics courses at all levels are taught with lectures, demonstrations, problem-solving and confirmatory laboratory exercises based on a curriculum that is largely unchanged since at least the 1950s when "the curriculum in physics was generally considered to consist of a course syllabus, a text, a collection of standard problems, and a set of prescribed laboratory experiments" (McDermott, 1991, p. 302). In the context of science literacy, Bencze (2000) collapsed the outcomes for science courses into two domains: "Conceptual understanding (learning 'science') and procedural understanding (learning 'about science' and 'to do science')" (p. 732). Procedural outcomes comprise non-specific activities that may be directly or indirectly included in a physics course: laboratory tasks, activities such as problem solving, and philosophical discussions relating to the nature of science. In traditional physics courses the dominant focus during a course and particularly for examinations is students' knowledge of facts and algorithms and their use in problem solving (Halloun, 1998b). Although the traditional physics curriculum stresses "physics as an intellectually challenging scientific enterprise" (Haussler & Hoffman, 2000, p. 697), this is not consistent with the interests of students taking physics courses. McDermott (1993) suggested, while most instructors "are eager to transmit both their knowledge and enthusiasm" (p. 295), the instructional process where the presentation of fully developed concepts eliminates the engagement of students "in the abstraction and generalization. Very little inductive thinking is involved" (p. 295).

Traditional methods of instruction also reduce opportunities for students to openly engage in intellectually challenging activities (Bamber and Tett, 2000). In most physics classes the method of presentation is one-way transmission and the application of the knowledge is a presentation of problem solutions. The objective is to provide students with intellectual sophistication: generally in application of mathematics to physics, and specifically in conceptual understanding and problem solving. But students may misinterpret the instructor's goal in the context of their own goals. Instructors are not unaware of the difficulty in overcoming this misinterpretation:

> Faculty in introductory [physics] courses work hard at preparing lectures in which they give lucid explanations, show demonstrations, and illustrate problem-solving procedures. They expect that, in the process of learning how to solve standard problems, students are developing important concepts in simple situations. There is ample evidence from research, however, that students do not make nearly as much progress toward these basic goals as they are capable of doing. (McDermott, 2001, p. 1129)

This view is consistent with Halloun's:

> In the last two decades, research in physics education has constantly been showing that conventional physics instruction by lecture and demonstration has

> no noticeable impact on secondary school pupils and college students … [They] complete these courses still holding fast to their beliefs, thus misconstruing the scientific message in these courses, whether in relation to the conceptual structure of scientific theory or in its relevance and applicability in the real world. (1998b, p. 313)

Halloun and Hestenes (1987) suggested the pedagogy needed to improve conceptual understanding requires considerable skill of instruction that is independent of – but complementary to – the instructor's subject mastery. The presentation of problems in a class illustrates a typical component of instruction that can be used with different results. Problems are used to illustrate the application of a concept. Alternately, the focus can shift from the development of problem-solving skills to the use of problems as elucidation of concepts and in overcoming misconceptions. But the use of problems to overcome conceptual difficulties is not a trivial process.

Brown (1992) questioned the use of problem examples as a methodology of instruction. Little research has been done concerning the best use of examples in attempts to remediate misconceptions or the effectiveness of a traditional teaching-by-example technique. Students may have cognitive strategies that constrain their ability to relate specific problems to underlying concepts as "they desperately seek to avoid reasoning and explanation by manipulating a formula in a memorized, but never understood, procedure" (Arons, 1972, p. 32). Relating concepts to problems is a common problem for students in mathematics and physics.

Akatufba and Wallace (1999) studied a group of high school students to determine the mathematical processes that students used in solving physics problems involving proportions. Results indicated that:

> [Students] employed mathematical proportional reasoning patterns and algorithms which they could not explain. Students also had difficulties translating physics tasks into mathematical statements, symbols, and relations. Students could not perform mathematical operations not directly obvious from physics tasks, and some had difficulty with division. Students did not have adequate understanding of the mathematical processes involved in proportional reasoning. (p. 31)

Beichner (1996) related students' difficulties in understanding the meaning of area under a curved graph and how a lack of understanding can be masked by use of a formula to solve a problem. A shift from problem solutions – where students can use algorithmic mechanisms – to problem formulation – where students must understand both conceptual ideas from physics and applications of concurrent mathematics topics – may result in improvement in both conceptual understanding and problem-solving ability. Halloun & Hestenes (1987) proposed a method of instruction appropriate to the conceptual sophistication of the students. A didactical (perceptive) approach is appropriate for more advanced courses where the audience shares the preconceptions of the lecturer. But a dialectical (evaluative) approach, where the students need to examine their own preconceptions in comparison to that of the accepted scientific community as presented by the lecturer, is preferred. Regardless of the specific instructional method, there is a widespread commitment to increasing the amount of active learning, shifting the focus from the instructor to the students.

Active Learning

The term 'active learning' includes components that increase student understanding and encompass the ideas of knowledge construction (Driver, 1998). Goldberg and Bendall (1995) described the building of a knowledge foundation as:

> "[t]he process of developing a deeper understanding of a concept in terms of new connections between that concept and related concepts, images, experiences, etc. [and that] opportunities must be provided for students to actively construct new knowledge that is meaningful, robust and valid". (p. 979)

They suggested that the process of knowledge construction is often invisible to the student and that the instructional environment must make this process visible to the student. Felder (1995, 1996) undertook a longitudinal study of engineering student performance that is particularly relevant to this study. His objective was to demonstrate that repeated use of active learning instructional techniques in engineering courses would have significant positive effects on students' performance and retention. Felder's techniques included:

1. Introduction of topics by presentation of related problems,
2. Allowing students to work on problems for which they may not have all the necessary tools,
3. Providing a balance of concrete and conceptual information,
4. Providing a balance between visual and verbal information,
5. Always including numerical examples with algebraic derivations,
6. The use of physical analogues for magnitude of quantities,
7. Using experimental data to determine a relationship inductively,

8. Allowing time for reflective activity and for active student participation,
9. Encouraging cooperative work, and
10. Emphasizing the sequential and global relationships of concepts.

These techniques provide an active learning environment to encourage the inclusion of as many different types of students and to present different learning situations.

Felder's study indicated that while different instructional methods may result in active engagement of the students and be more effective than the traditional instructor-centred lecturing, there is a caution that:

> While [professors] are learning to implement active and co-operative methods they will make mistakes and may for a time be less effective than they were using the old methods. They may also have to confront and overcome substantial student opposition and resistance, which can be a most unpleasant experience, especially for teachers who are good lecturers and may have been popular with students for many years. (Felder,1995, p. 366)

In a class where alternate methods are introduced, there may be students who perceive the new instruction as detrimental to their academic progress. Hake (1998) suggested that "motivational problems can be especially severe for students in IE [interactive-engagement] courses who dislike any departure from the traditional methods to which they have become accustomed and under which their grades, if not their understanding, may have flourished" (p. 66). One consideration in modifying the classroom environment should be to convince students of the benefits of an alternate approach.

An effective strategy in overcoming misconceptions is to create a situation where students are confronted with evidence of the inconsistencies in their ideas. This conceptual conflict can then be resolved. Driver (1998) described this as "sense making" over which the student has some control. McDermott (1993) and Clement (1993) suggested many students, unlike scientists, will tolerate inconsistencies. It is necessary for students to acquire an intellectual commitment to resolve an inconsistency. "Those who learn successfully from lectures, text-books and problem-solving do so because they constantly question their own comprehension, confront their difficulties and persist in trying to resolve them" (McDermott, 1993, p. 297). These students may have a feeling of ownership of their learning, which leads to an improved attitude and greater understanding (Arion, Crosby, & Murphy, 2000). Redish, Saul, and Steinberg (1998) defined stages of student learning as either binary or constructivist. In the binary stage, students want to be told the correct answer. In the constructivist stage, which may not occur until graduate school, a student "takes charge of building his or her own understanding … carry[ing] out their own evaluation of an approach, equation, or result, and understand[ing] both the conditions of validity and the relation to fundamental physical principles" (p. 213). "Elby pairs" (Elby, 2001) may provide an opportunity to present students with related but inconsistent situations where the students can resolve the inconsistency without being directly confronted with misconceptions. Students may be more likely to acknowledge and overcome misconceptions. A rarely stated goal of physics education is developing and encouraging the intellectual commitment of a student to be the same as that of a scientist, represented by the majority of instructors in both secondary and postsecondary physics courses. However, the process of developing this commitment in students may be constrained by factors in the course structure and curriculum as well as in systemic elements of the educational system. It is not possible to add a new element to the curriculum without eliminating some other component and allowing time for students to develop new skills and attitudes. There must also be flexibility in the curriculum and by the instructors to adapt to an alternate way of teaching physics.

Beichner (1994) noted "students should be given (1) the opportunity to consider their own ideas and then (2) encouragement to help them modify those ideas when necessary" (p. 755). This may at times require new ideas or concepts that may not have yet been taught and students must accept without justification. In a study of case-study experiments, a course where projects were the major component, Arion, Crosby, and Murphy (2000) found that "[s]tudents were much more receptive to learning new material 'out-of-phase' when it was relevant to their projects" (p. 376). Situations may occur where the student requires a leap of faith of the relevance to their project, which may provide time for a concrete coherent knowledge framework to develop. This may also help to overcome the problem of physics instruction that Halloun (1998b) described as episodic and incoherent with the consequence that students' knowledge is often "weakly structured and fragmented" (p. 314). Arons (1981, 1983) and McDermott, Shaffer, and Somers (1994) emphasized students must be allowed repeated opportunities to practice the use of concepts in different contexts.

> If we are serious about cultivating some measure of the kind of understanding, … we must give students time to learn. … This means we must cut down on 'coverage.' It is futile and fatuous to drown students in a stream of names and jargon, to throw at them in one quarter or one semester all of physics from

> Galilean kinematics to the uncertainty principle, not to speak of adding meteorology and geology on the side. (Arons, 1973, p. 774)

Goldberg and Bendall (1995) conceded that the instructional strategies needed for active learning use up much more time compared to direct transmission of information. At the time of the PSSC program development, it was recognized that it was necessary to make "hard decisions on what to include and what to leave out" (Haber-Schaim, 1998, p. 295).

In most current textbooks, there are sufficient resources for a student to obtain a good breadth of understanding. However, it is not clear how a typical student can attend three or four hours of lectures and two or three hours of laboratory work per week, read 1200 pages of instructional text in forty chapters, and work 50, 100 or more problems that most textbooks include at the end of each chapter. There may be several thousand problems in an introductory physics textbook. It would be rare for any student to undertake all of the problems; but in many one-term courses, students could be assigned as many as 200 problems. At the same time, many physics students will be undertaking four or five other courses, equally challenging. The fact that some students do achieve excellent understanding in such an environment has been used as the rationale for its maintenance. In the U.S. national standards for secondary school physics curriculum, there is no evidence that time to cover the suggested curriculum was a consideration. Although "inquiry, cooperative learning, and historical perspectives are mentioned everywhere, … the content 'suggested' in these documents is so extensive that there is no time to learn anything in depth" (Haber-Schaim, 1998, p. 295). Even though the problem of an excessive content coverage routinely surfaces, there is no widespread support to drastically reduce the number of topics in introductory courses. Many instructors continue to support the existing curriculum and the need to cover a wide range of topics as part of a survey course in physics.

In the most recent edition of *Fundamentals of Physics* (Halliday, Resnick, & Walker, 2005), a typical calculus-based introductory text, the goal for the text and, by inference, the course is stated in the preface to the text:

> The principle goal of *Fundamentals of Physics* … [is] to provide instructors with a tool by which they can teach students how to effectively read scientific material, identify fundamental concepts, reason through scientific questions, and solve quantitative problems. This process is not easy for either students or instructors. Indeed, the course associated with this book may be one of the most demanding

> of all the courses taken by a student. However, it can also be one of the most rewarding, because it reveals the world's fundamental clockwork from which all scientific and engineering applications spring. (p. xvii)

The authors list major changes to the content of the new edition; one being that "several thousand of the end-of-chapter problems have been rewritten to streamline both the presentation and the answer" (p. xvii). It may be difficult to equate streamlining with several thousand questions. Different versions of the textbook are described:

> To accommodate the individual needs of instructors and students, the seventh edition of *Fundamentals of Physics* is available in a number of different versions. The regular edition consists of Chapters 1 through 37. … The Extended Edition contains six additional chapters (p. xix).

It is clear that the messages of 'less is more' or 'an inch thick and a mile wide' either represent a minority view or textbook writers and publishers are ignoring the message. In a review of a higher-level thermodynamics textbook, Somer (2001) described the "stereotypical physicist's book – long on logical rigor and mathematical sophistication, short on clarity and physical intuition" (p. 1602). This attention to rigor and detail in textbooks is also apparent in the philosophy of most college and university physics instructors who accept that any university-level physics courses should have the appropriate amount of mathematical detail necessary to support the physical models.

Alternate textbooks that largely eliminate mathematics are available. Two that are widely used are *Conceptual Physics* (Hewitt, 1997), which covers traditional mechanics topics conceptually, while *Physics by Inquiry* (McDermott & The Physics Education Group at the University of Washington, 1996) and *Tutorials in Physics* (McDermott, Shaffer, & The Physics Education Group at the University of Washington, 2002) support tutorial-based instruction for preservice elementary teachers. While these and other textbooks that focus on conceptual understanding are available, the majority of courses continue to use traditional textbooks. Most research studies focus on difficulties in improving conceptual understanding of the traditional topics using alternate instructional methods.

Instructional Approaches

Research results are clear in showing that the traditional lecture-recitation-laboratory structure for introductory physics course is not effective for most students. Swartz (1996) suggested we should either abandon any attempts to reach students who do not respond to instruction or try one of the many new methods in a continuous stream of innovative instructional techniques that claim to solve the problems of teaching physics. He comments on two alternate instructional approaches. The first is that most methods are organized and supported by an individual or a small group rather than by most faculty members or students. If the instigator leaves, then the system will disintegrate due to demands on time and lack of effort from the remaining faculty members. The second is that all education experiments succeed.

> Students may do better for awhile, but is it because of the intrinsic nature of the method or because the students work harder or longer on fewer topics? Was the teacher more enthusiastic and perhaps more caring? … Are the graduates more competent some years later, and how do we test? (p. 390)

Swartz's editorial does not provide good support for the idea of applying scientific methodology to curriculum development. This may be due in part to the complexity of the classroom and more importantly to limited resources for testing, particularly testing for conceptual understanding. The primary method for testing conceptual understanding is one of the Force Concept Inventory (FCI), Mechanics Baseline Test (MBLT), or Force and Motion Concept Inventory (FMCE). These tests have been used for studies involving large numbers of courses and students on the narrow question of short-term conceptual understanding in mechanics. If Swartz's comments are correct, then any alternate to traditional lecture-recitation-laboratory instruction may have positive results for the outcomes tested. A difficulty for a physics department or instructor who has decided to undertake curriculum change is to choose an appropriate approach from the many innovative methods available. In any proposed method there will be some components that are suitable and some components that do not appear appropriate for a class or course different from the original setting.

A common goal of physics education is to teach problem-solving skills and use those skills in real-world applications (Arion, Crosby, & Murphy, 2000; Goldberg & Bendall, 1995; Heller & Hollabaugh, 1992; Hughes & Matthew, 1993; Lechner, 1996; Reif, 1981). The focus is on understanding concepts rather than memorization of facts and reducing student reliance on algorithmic methods of solutions. Yet "many students in introductory physics courses consider problem solving to be independent of physics concepts and principles being taught … or they believe that specific patterns of mathematical solutions are the physics to be learned" (Heller, Keith, & Anderson, 1992, p. 627). Romberg and Carpenter (1986) found that most teachers follow the textbook very closely and that both course syllabi and textbooks are inflexible and standardized to the point of predictability. While many textbooks provide emphasis on concepts, the typical introductory physics textbook covers the complete range of classical physics topics and some topics from modern physics in over 40 chapters. “Textbooks neither convey the excitement and vagaries of science-in-the-making nor invite inquiry. Textbooks are not where the action is, representing instead the outcomes of the actions that were” (Flower, 2000). It is, therefore, necessary for physics instruction to move from a curriculum based on textbook organization to one where students are the focus of instruction.

Many proposed instructional methodologies provide for an environment with greater involvement and engagement of students. Cummings, Marx, Thorton, and Kuhl (1999), in a study of Studio Physics, an instructional format with integration of lectures and laboratory sessions and a high level of instructor-student interaction, noted that while student engagement may be a necessary condition for successful instruction, it is not sufficient.

The Physics Education Group at the University of Washington has over many years developed and implemented a curriculum of introductory physics for preservice elementary teachers that provides an environment for high levels of student engagement and mechanisms to improve conceptual understanding (McDermott, 2003). Redish (1996) referred to McDermott’s Wheel as a feedback mechanism for developing a model of learning, curriculum development, instruction, and research that results in a helical improvement cycle. Ehrlich (2002) speculated “the classroom is a chaotic system. … In a chaotic system, small and subtle changes in the initial conditions – in this case the nature of the instructor’s comments or the state of mind of the students or instructor – lead to large differences in the state of the system” (p. 24). In educational research assessment is an integral part of the system and can greatly influence the system and limit the validity of results. While this limitation in physics education is acknowledged, there are very few measuring instruments available to determine the effectiveness of either traditional or alternate instructional methods (Saul, 1995). Saul suggested the evaluation process must be developed for the explicit and hidden curriculum and goals of each course, which can also affect outcomes due to student attitudes. Students who excel in the present system may not readily adapt to differences in teaching methods and evaluation. Ehrlich (2002) expressed this sentiment in the context of problem solving: “we need to place greater emphasis on deep conceptual understanding without compromising our students' problem-solving skills" (p. 25). This may be accomplished by using some of the criteria for building an interactive-constructivist instructional model:

1. Students' content knowledge and depth of understanding of physics topics taught should be the central focus.
2. Fewer, big ideas should be used in a connected whole rather than attempting coverage of a large number of isolated ideas.
3. Strategies to access and utilize information on student ideas should be used in planning instruction.
4. Strategies to challenge student ideas should be used in an environment where students reflect on and integrate those ideas into their thinking.
5. Strategies should be used that routinely and continuously incorporate students' personal experience as a context for learning physics.
6. Authentic assessment should empower learning and inform instruction.

Redish (1996) summarized these same ideas. The course should be student oriented and focus on what the students are actually doing in the class. Laboratories should be of the discovery type where students are guided to observe the phenomena and build fundamental ideas for themselves via observation. The course may include explicit training of critical thinking and reasoning. Students are expected to be intellectually active during the class.

Many alternate instructional methods developed by PER groups have the goal of improving conceptual understanding and use the MBLT, FCI, or FMCE as the basis for evaluating the method's effectiveness, compared to traditional lecturing. The following examples illustrate a few of the many alternate methodologies and represent the more widely known and promoted, most with available instructional material. They have been developed over a number of years by PER groups for their introductory physics programs. Most alternate methods are developed for a specific set of students, e.g., elementary preservice teachers, pre-medicine, introductory calculus-based physics, etc. There may be limitations on the transferability of the method to courses with different students than in the original study. It is unlikely that a specific method can be adapted without change to a setting different from that in which it was designed, tested, modified, and perfected. Many methods require resources beyond that available in traditional university or college settings.

Modeling Instruction Program

The Modeling Instruction Program (MIP) teaching methodology was designed at the University of Arizona for preservice and inservice high school physics teachers (Hestenes, 1998). Its instructional objective is to engage students by using scientific models presented in a variety of formats to explain, predict, and control physical phenomena. A small set of models is used as the program's core content for topics from classical mechanics. The program depends on informed teaching, planning, and guidance and relies on a significant familiarity with PER research results on misconceptions. Workshops prepare teachers to use the instructional method. A long-term goal of the program is to create a community of expert teachers to provide resources for other physics teachers. Improvement in students' conceptual understanding is measured using the FCI, also developed at the University of Arizona (Hestenes, Wells, & Swackhamer, 1992). Although the MIP has focused on high school students and teachers, its use in post-secondary physics courses should expand as a consequence of the improved conceptual understanding of students where modeling instruction is used.

Workshop Physics

Working Physics (WP) was developed at Dickinson College (Laws, 1991) to replace traditional lecture/laboratory/tutorial instruction with guided inquiry workshops using computers and specifically designed equipment to allow students to develop their own understanding of experimental and theoretical aspects of classical topics. Although the program was designed for a calculus-based course, it can be adapted for algebra-based courses. The equipment and instructor resources to implement Workshop Physics are likely beyond that available in most physics departments. However, the specific laboratory exercises and activities could be used in a traditional laboratory setting.

Peer Tutoring

Mazur (1997) used a technique for lectures whereby Harvard University students are given the opportunity to discuss a question from the instructor with a small group of other students. A recursive process – including voting on an answer to a conceptual question, more discussion, and repeat voting – is used to encourage students to participate in critical thinking. The results from this easy-to-implement process indicated improvement in students' conceptual understanding, which is likely due to increased levels of student engagement in a traditional lecture setting.

Socratic Dialog-Inducing

Hake (1992b) described replacement of traditional lectures with laboratory exercises similar to that used at the University of Washington by Arons and later McDermott with preservice elementary teachers. The Socratic Dialog-Inducing (innovations) (SDI) laboratory exercises were developed for use in algebra-based introductory physics courses with students who are not physics majors.

> The primary goal of SDI labs is to help students attain a good understanding of the basic concepts of Newtonian mechanics through creative engagement with simple mechanics experiments involving a body at rest or in motion as indicated in the lab manual. You will often be asked to predict the outcome of an experiment before you perform it. It is more important for you to understand the material you work on rather than to 'cover' all the prescribed sections. You must take responsibility for your own learning. If you find yourself somewhat ahead of your lab partners, why not try to explain some physics to them (explainers often learn more than listeners). (p. 4)

While dialogue between students was a secondary goal of SDI, it was an important component of this method that can be easily transferred to both laboratory and tutorial situations for any course.

Studio Physics

Studio Physics has been used to describe several different course structures at several universities including Curtin University of Technology (Studio Instructional Model) and Massachusetts Institute of Technology (MIT) (TEAL: Technology Enhancing Active Learning) but was based on ideas from Rensselaer Polytechnique (Integrated Laboratory 'Studio Approach'). The goal of these approaches was to maximize engagement of students in educational tasks. Group work was a required component, and lecture time was reduced or eliminated. Information technology resources available to students and computer-based problems and exercises are part of the curriculum. At MIT dedicated rooms with student workstations anchor an environment rich in information technology hardware and software to maximize the effect but was likely beyond the available resources of most introductory courses. At Curtin University of Technology a cost analysis indicated that the breakeven point for class size was 30-35 students when Studio Physics was compared to traditional instruction with lectures, tutorials, and laboratories. The educational outcomes are more difficult to evaluate because there are many issues when changing from a traditional educational environment, such as differences in student backgrounds, computer systems development, and faculty development problems. The last issue, faculty development, was perceived as the most difficult to overcome.

Other Methodologies

A multitude of other methodologies have been presented for which the titles often provide a description of the methodology. RealTime Physics, Tools for Scientific Thinking, and Interactive Lecture Demonstrations (Thornton & Sokoloff, 1990, 1997) used microcomputer-based kinematics and dynamics equipment incorporated into the traditional curriculum. Computer graphics displays were used to reinforce concepts from mechanics in demonstrations in lectures and for laboratory exercises. Other methodologies included Active Learning at the University of Iowa (Meltzer, 2002), Student-Centred Activities for Large Enrollment University Physics (SCALE-UP) at North Carolina State University, Constructing Physics Understanding (CPU) at San Diego University, Minds-on-Physics ASK-IT at Massachusetts, Minnesota Model for Large Introductory Courses at Minnesota. Activity-Based Thinking Problems at University of Maine (Redish, 1996) focus on mathematical concepts within physics problems.

VanHeuvelen (1991a) suggested the objectives of physics instruction are to help students (1) construct qualitative representations of physical processes, (2) reason about the processes, (3) construct mathematical representations, and (4) solve problems quantitatively. All of these objectives are aimed at having the students learn to think like physicists. Expert physicists typically look for “relationships and similarities between diverse pieces of information. Students, at the end of their conventional study, have little structure to their knowledge. Their understanding consists of random facts and equations that have little conceptual meaning“ (p. 894). A comparison of expert physicists with novice students (Reif, 1981) indicated, while significant time and effort is spent by experts on formulation of a problem and in careful evaluation of the final results, students typically neglect both of these activities and focus their attention mainly on constructing a solution from formulae. Historically, physics has been taught by expository lectures, which include a well-defined presentation where specific problems demonstrate the use of definitions, laws, and principles. Laboratory exercises often have the objective of confirming the principles and laws. This method is perceived as being an efficient way to transmit information: the expert instructor knows the concepts and techniques, and the students should learn by emulating the expert. A wide range of research studies has indicated that, although the transmission of knowledge is efficient, the reception of the knowledge is negligible. Students typically are exposed to instruction in a topic, usually one chapter of a text, for about one week; and permanent acquisition of knowledge is unlikely without multiple exposures over a long period of time. In response to this method of instruction, where "the emphasis of instruction is on mathematical formalism to an excessive extent" (Reif, 1981, p. 313), many students successfully adopt algorithmic methods for problem solving and "come to believe that qualitative or verbal descriptions are to be shunned as scientifically inappropriate of illegitimate" (p. 313).

VanHeuvelen (1991b) also suggested physics instruction must include active participation by the students using qualitative representations for qualitative reasoning about physical processes that can then be used to confront preconceptions and misconceptions and finally learning to use the concepts to solve problems. A method for implementing these ideas in a traditional lecture format is Active Learning Problem Sheets (ALPS) (VanHeuvelen, 1996). Students participate by interacting in groups and solving problems that involve skills and concepts with both qualitative and quantitative components. The instructor acts as facilitator and tutor in the learning process. While the ALPS kit can be used as independent exercises, the Overview, Case Study Physics (VanHeuvelen, 1991b) is a method for teaching introductory physics by integrating the above ideas into a one-year course. Small conceptual knowledge blocks are introduced in the first semester, the overview, using qualitative (non-mathematical) representations. In the second semester, multiple knowledge blocks from the first semester are used for case studies of complex problems. Students receive repeated exposure to the concepts over the entire year. While working on the case studies, students develop more sophisticated problem-solving skills than in a traditional introductory physics course where their exposure to problems is normally restricted to applications of a single concept (van Aalst, 2000). Results from the application of this method indicate students use expert techniques, such as sketches, free-body diagrams, and principles of conservation of energy, at much higher rates than students taught with conventional lectures. This method appears to be particularly suitable for students without previous experience in physics courses who traditionally have very low success rates in introductory physics courses.

This sample of alternate instructional methods has a general theme of increasing student engagement using traditional curriculum topics and does not address the issue of students' interest in physics. Although the reasons are unclear, there appears to be greater interest in a redefinition of physics education from the United Kingdom, where new curricula have been developed with a much broader view of what should be included.

The Nature of Physics and the Nature of Physics Teaching

Suggested student outcomes for physics courses include changing their understanding of physical phenomena, attitude toward scientific knowledge, and ability to undertake problems in new circumstances. All of these attributes are required and practiced in scientific inquiry – yet most undergraduate physics courses reinforce the idea that physics is applied mathematics where accepted relationships are presented or, in higher level courses, derived from basic principles using mathematical techniques. The success of most students is tested with assignments and examinations that document their ability to reproduce the results for identical or similar problems to those presented in class. A typical physics classroom environment bears no relationship to how physics is practiced by the faculty members teaching these courses or by practicing physicists outside the university environment. The PER movement continues to provide research results that reinforce the argument for reform of physics education – yet widespread change in how undergraduate physics is taught has been slow. Since almost all university faculty members teaching physics courses are involved in physics research, understanding the nature of physics and related research enterprise can provide insight into the difficulties in implementing a reformed physics education curriculum.

Physics inquiry consists of a variety of conceptual foci and research approaches. Descriptions for these scientific methods are difficult since there are multiple situations and ways that science is practiced. However, the way that 'the scientific method' is presented to students bears little relationship to how science is practiced. McComas (1996) provided a summary of "the most widespread and enduring misconceptions held by students regarding the enterprise of science" (p. 10). These include perceptions of both certainty and uncertainty in the process and results of science. While physics is about trying to describe physical phenomena of the world, physics instruction is about transmitting accepted descriptions. Inquiry and scientific processes are largely eliminated from the educational process in favour of applying mathematics to physical situations in most physics courses. This may be a consequence of the extensive use of mathematics in most areas of physics research.

There appears to be a discrepancy between some physics education reform ideas and how physics is practiced. It appears that the main concern of physics education is to provide students with the mathematical tools and to provide examples of the uses of mathematics in physical situations so students will be capable of undertaking advanced research. There is a progression in mathematical complexity from introductory courses – where algebraic solutions are presented for a wide variety of topics – to advanced undergraduate courses – where derivations of mathematical solutions for specific topics are the basis for most courses. In all cases, mathematics is normally a required prerequisite for physics courses. This focus on mathematics may be justifiable at higher levels; but in high school courses and introductory university courses where students will not take further physics courses, there does not seem to be a justification for the emphasis on mathematics and limited emphasis on process or attitude.

Models are the basis of all physics. The degree to which those models reflect reality usually depends on the availability of data to support the model. Undergraduate physics focuses on a set of models that have been accepted and refined over hundreds of years. Most are conceptually simple, well accepted, and unlikely to change. It is an informal rule of physics, credited to Einstein, that results should be as simple as possible but not too simple. The model development process includes this simplification but what is presented to students is the end result. In current research, the models are often very complex and much too abstract to successfully present to undergraduate students.

Most students taking introductory physics courses do not have the necessary mathematics to evaluate problems using complex mathematics. Furthermore, many students in introductory courses may not have an understanding of basic physics concepts. Most research projects require an understanding of mathematics and physics, and the ideas and implementation occur over a long period of time. Most university courses are completed in three or four months and students do not have the resources or time to undertake a project similar to that of a research project. Thus, simple situations with simple equations are presented to match the prior knowledge and ability of students and the time limitations of most courses. Although textbooks try to present problems that are related to real situations, they are not real physics research situations. This may reinforce the opinions of students who assume that the curriculum is irrelevant because they cannot relate any of the material to their own lives.

The widespread acceptance of the traditional curriculum for undergraduate physics indicates an assumption that the curriculum is appropriate and justified. Creating a teaching environment similar to a research environment is not perceived as important until later in graduate studies, where students who have acquired the basic knowledge necessary for advanced research are given the opportunity to work in authentic research settings. Unfortunately, most introductory students' physics education ends before this authentic opportunity is available.

Although most students taking introductory physics courses do not graduate with physics degrees, another factor influencing physics education relates to opportunities available to students who complete an undergraduate physics degree. The Canadian Association of Physicists recently reported that approximately 50% of the students who graduate with a B.Sc. in physics continue and obtain either a M.Sc. or Ph.D. This confirmation data, rather than the very high attrition rates, appear to justify the undergraduate program's emphasis on preparation for graduate research. Furthermore, the remaining physics degree graduates usually have good employment prospects. There is a wide range of jobs for physics graduates with many jobs not requiring specific knowledge related to the curriculum of their undergraduate physics courses. A focus on theoretical and mathematical topics rather than concepts and applications is not perceived as detrimental to the opportunities for graduates. Thus, the existing curriculum appears to be successful in preparing students for either graduate studies or careers; and concerns about service courses are not assigned high priority. Also funding is often used to explain limited adoption of alternate instruction. While costs of supporting the traditional curriculum are often much less than for a curriculum with increased student participation there has been a focus from PER on innovations for large enrollment classes. It is also possible to adapt programs to reduce or eliminate additional costs.

The North American PER community has been slow to address the issue of the traditional curriculum for introductory courses. For at least 50 years there have been pockets of innovation and instruction demonstrating that regular physics students' achievement has improved. But any meaningful model for reform of introductory courses requires broader definitions of physics education for students undertaking a single introductory physics course. Science education in K-10 has provided some momentum to concentrate on inquiry rather than teacher-directed instruction. For many students in introductory courses, physics is included as a required course in non-science programs so that students will graduate from university with some understanding of physics and scientific inquiry. A sentiment where physics contributes to a liberal arts education is not apparent in the physics education communities or curriculum of physics courses in most colleges and universities. External conditions, particularly declining enrolments, may result in changes for physics courses dealing with non-physics majors. A curriculum that is more representative of authentic physics research might be more interesting to many students, but the demand on resources and financial constraints might impede implementation.

Curriculum Development: A New Philosophy for Physics Courses

In 1976, at a seminar on science education at Visegrad, Hungary, Jon Ogborn spoke on the theme "What should we teach? How should we teach it?" (Ogborn, 1978, p. 11). While there has been some change in how we teach, there does not appear to have been any change in what we teach. A summary of Ogborn's paper illustrates an alternate philosophy: teaching physics as an example of the practice of physics. It is not clear why there has been resistance to this idea, particularly in North America (O'Neill & Polman, 2004). It is clear that physics instruction at all levels is focused on preparing students with knowledge necessary to undertake higher level physics courses. Alternate philosophies are perceived as diluting a curriculum that produces future physicists, in spite of the fact that most students in an introductory physics course do not continue to graduate school in physics and may never take another physics course after their experience. A few cases of implementing an alternate philosophy indicate the difficulties due to student resistance (Dykstra, 2001a, 2001b; Wildy & Wallace, 1995). In a study of non-traditional learners, Bamber and Tett (2000) discussed the relationship between faculty and learners:

> [There is a] need for a shared understanding between educators and students which ensures that the difficulties encountered by the latter are acknowledged and addressed. Extensive mechanisms may be needed to support achievement. Yet this must be done without undermining the criteria for assessment set by the university. This type of approach may present a challenge to an academic mindset more accustomed to entry protocols based on high school leaving qualifications, full-time students and conventional methods of assessment. (p. 60).

There is no indication that many faculty members in physics departments view their role in the educational process as providing these mechanisms. Regardless of specific reasons for why change is difficult, there are some ideas for changing the current curriculum from one that is topic based to one with a broader philosophy.

Ogborn (1978), in a review of the design process for the Nuffield Physics advanced level course, discussed at least five themes in choosing a new curriculum: (1) choosing topics, (2) strands and connecting the topics, (3) non-physics topics, (4) the hidden curriculum, and (5) attitudes. Choosing from the range of topics presented in most textbooks becomes the problem of finding reasons for selecting and eliminating topics. "Every one of them is valuable and important, which would take two or three times longer to teach than was available" (p. 11). He suggested that the curriculum should have a pattern that is connected by the use and re-use of ideas in every part. In his example, three topics were chosen: electromagnetic waves, the 2nd Law of Thermodynamics, and quantum physics. These topics were then connected through three strands: matter, process and change, and fields. This approach is different than the traditional curriculum – narrower in selection of topics yet deeper in the relationship between topics. The connection of topics is stressed and promotes an interconnected conceptual network of useful ideas. In a traditional physics curriculum with a traditional textbook, the rejection of topics would break the continuity of explanation. Davies (1997) suggested a major effort is needed to develop a new curriculum with a new set of principles:

> Forget tradition; forget content; forget core; forget university and other top-down needs; forget progression; forget examining boards; forget all those educational buzz words. (p. 419)
>
> A radical new physics curriculum … starts from physics itself, as it is and how it will be, and seeks ways of engaging young people profitably and enjoyably with physics in its (twenty-first century) manifestations. (p. 420)

But the change to a radical new curriculum requires a rationale and "an examination of the premises that dominated the formulation of the present courses" Osborne (1990, p. 190). Newtonian ideas dominate introductory physics courses but they are not the whole of physics, and the picture presented to students is an extremely one-sided view of our understanding of the natural world. A goal of the curriculum should be to relate physics to the real world in its scientific context as well as to the experiences of typical students.

> Responders to my suggestions may argue that physics is a hierarchical subject and that it is necessary to undergo a long apprenticeship in the fundamentals to appreciate the full depth of modern or contemporary physics. … It is absurd to have the physics education of 700 000 eleven to sixteen year olds determined by

> the 40 000 who continue to A-level or the 200 who continue to a degree (Osborne, 1990, p. 195)

These comments apply even more to typical introductory physics courses in North America where students enrolled in a non-calculus-based course must often take an alternate introductory physics course for prerequisite credit necessary to take advanced physics courses. In another review of the UK A-level Physics, Swinbank (1997) suggested "there has been a groundswell of feeling amongst those concerned that A-level physics is overdue for change and improvement" (p. 111). There is no evidence of a similar movement in Canada or the United States; in recent years, support or discussion of alternate curricula in the UK has disappeared in the research literature. At the present time there appears to be no support for alternatives to the traditional curriculum.

Summary

The literature for PER is extensive and reveals a wealth of information and results applicable to the development of curriculum and instruction for introductory physics courses. Most results indicate that, in many cases, neither conceptual understanding nor attitude toward physics changes for students as a consequence of taking an introductory physics course. The majority of PER in North America has focused on improving conceptual understanding in mechanics although there has recently been increased interest in other topics and at higher academic levels. The MBLT, FCI, and FMCE dominate the literature as measures of conceptual understanding; all three tests focus on mechanics, but some attention has addressed electricity and magnetism and astronomy. Studies or discussions of alternate curricula are apparent to a limited extent in North American PER literature. While the UK models for alternate curriculum provide examples for a physics curriculum that would be of greater relevance to more students, implementing such a curriculum in most colleges or universities would be difficult. No general models for curriculum design for postsecondary physics courses exist in PER. The curriculum design process is one of selecting ideas that can be used for the specific educational environment in the context of a rationale for offering the course.

CHAPTER 3

INSTRUCTIONAL SETTING AND RESEARCH METHODS

Introduction

This hybrid study involved a three-year research and development (R&D) project reflecting both fundamental aspects of scientific inquiry and technological design. The intention and focus evolved over each year of the study. Year 1 focused on the exploration of student attributes and instructional features of the physics courses in the Access Program. Data from implementation of a revised curriculum for the physics courses were collected in year 2, and these data were evaluated during year 3 and used to adapt and extend a curriculum development model.

Students in the Study

The students in this study were non-traditional in that about 25% of the students entered the program directly from high school. Others had undertaken a wide range of previous activities from long-term employment in industries where employment opportunities were declining or in situations with limited advancement opportunities. Very few students had any direct experience in science or engineering. Although there were requirements in mathematics and English for admission to the program, these prerequisites were not intended as academic prerequisites for mathematics or English courses. This admission policy, related to academic achievement, is an important factor in achievement and retention of students (Grimes, 1997). Although there were no specific prerequisites required for the physics courses, the course material and curriculum were based on mathematical competency at about a grade 9 level. Many students did not have functional prerequisite knowledge in mathematics.

The general academic skills of the students varied widely but can be roughly divided into three groups. The first group of students, perhaps two or three students in each class, or 5% of the total students, had high academic success in high school and prerequisite credit in mathematics and physics. These students normally attended university or entered the Technology Program direct from high school. A second group of students entered the Access Program directly from high school and most often lacked specific prerequisite courses (often physics) for the Technology Program. Included in this group were some students who had completed high school as well as some postsecondary courses. This group represented about 25% of the total number of

Access Program students; they tended to have relatively good overall academic skills and may have had acceptable mathematics skills. They tended to do well in the program and, although there are no data available, were the students who completed the Access Program and graduated from the two-year Technology Program. The third group was composed of the remaining 70% of students with widely varying academic and mathematical skills.

Thus, the students in the Access physics classes had a wide range of abilities and background. The majority of students was re-entry and under-prepared. In a study of college students, Dunn and Stevenson (1997) concluded:

> non-traditional and poor-achieving students are particularly vulnerable to academic failure despite the availability of conventional college tutoring and advisement. Adults returning to college after many years away from traditional learning may also have adjustment problems. (p. 334)

Previous experience in the program indicated that many of the weaker students were unaware of and unprepared for the academic nature of the program. Part of this discrepancy may have been related to their high school experiences, particularly in science courses. Data from studies of introductory chemistry courses (Kogut, 1993; Mitchell, 1989,1991) indicated that there is disagreement between high school and college instructors on what attributes and skills students should have. Also, "[the] assumption is often made by college professors that incoming freshman students think logically" (McKinnon & Renner, 1971, p. 1047). Thus, many of the students in this study may never have been taught or had lost the skills necessary for academic success at the introductory college level. The purpose of the Access Program was to prepare students for entry to the Technology Program. The transition of students from their entry state to the equivalent of Mathematics 11 and Physics 11 was an important factor in curriculum design for the physics courses of this study and in the academic success of the students.

Instructional Environment

For the purposes of the second year of this study, evaluating the students in the Access Program, there was an important subdivision into two specialty groups: those in Civil and Mechanical Access and a second group in Electronics Access. The civil/mechanical students were enrolled in a three-term (nine months) program while the electronics students were in a two-term (six-months) program. There were initially 26 civil/mechanical students, all of who participated in this study. There were initially 26 electronics students of whom 24 participated in this study. All students were required to take two introductory physics courses. Until the second year of this study, all of the students were in a three-term program with the physics courses in the first two terms. The program for the electronics students was reduced to two terms in the second year of this study. At the same time, the program for civil/mechanical students was changed so that the two physics courses were taken in terms two and three while mathematics was taken in all three terms. Thus, the civil/mechanical students were taking their first physics course after completing one term of mathematics while the electronics students took their first mathematics and physics courses concurrently. There was a widespread belief among the physics instructors that lack of mathematics ability was an important factor in determining the probability of student success. This situation provided the opportunity for an evaluation of the physics courses on the basis of different mathematical prerequisites.

The physics curriculum had been revised for the second year of this study. The original curriculum had been used for five years and had been based on a university transfer introductory physics course. The topics were the traditional ones from mechanics, thermal energy, and optics and waves. In the past, the courses had been taught with traditional lectures, tutorials, and laboratory sessions and with assessment based on tests and examinations typically using end-of-chapter problems. A defined set of laboratory experiments had been used, with the usual difficulty of poor connection between lecture topics and experiments. The laboratory component included formal writing of results similar to the requirements of university physics courses. There was a locally prepared textbook for the courses that had in prior years caused difficulties for instructors and students and was, therefore, judged to be unsuitable for the courses. However, no alternate textbook had been found other than an older book (Preston & Betts, 1978), also locally prepared, that had not been used for at least 10 years. This older book was revived, with reservations discussed below. The classes were taught in a single room. The instructor was responsible for all contact hours of the courses, with no other assistance. There were 7 hours of scheduled classes per week. The classroom was open to students at other times, unless it was occupied for other courses.

In developing the new curriculum, the wide distribution of the students' academic abilities was the most important factor to be accommodated. The existing curriculum did not differentiate between types of students (civil/mechanical or electronics). Weaker students had the opportunity to develop skills necessary for success while the better students addressed alternate tasks. The new curriculum included activities that were intended to minimize lectures. Lectures were proposed for organizational and motivational purposes and for summarizing conceptual and theoretical topics. The majority of time was allocated for students to work in groups on workbook and laboratory exercises with the intention of increasing the students' time on tasks most likely to improve their skills. The classroom, also used for laboratory work, was furnished with benches accommodating 3 students. In most cases the groups were formed and developed from social connections, with some relationship between academic status and peer grouping. There were no constraints on students forming or changing group membership although students were required to be a member of a group. However, a different environment was observed in the Civil/Mechanical class compared to the Electronics class. A greater amount of peer tutoring occurred in the Civil/Mechanical class with more interaction between better prepared students and students experiencing difficulties. In contrast there appeared to be a stronger relationship between academic status and group membership in the Electronics class with less willingness to participate in peer tutoring outside their own group. These differences may have been related to the Civil/Mechanical students previous term of work and to a different socio-educational environment in the Civil/Mechanical Program or may have been associated with the particular group of students in the year of this study.

Assessment of work was intended for formative evaluation only although the summative evaluation necessary for grading required that the test results were recorded with the option of using those marks for a final grade. The primary source for the final grade was a final examination that included conceptual and analytical problems as well as tests of laboratory skills. Many ideas from PER were included in the course design. Instructional methods from Peer Tutoring (Mazur, 1997) and Socratic Dialog (Hake, 1992a,b) were used extensively.

The textbook and sources for problem sets were problematic. These physics courses and the students enrolled in the courses presented a unique situation. Most textbooks were judged to be either too high or too low in academic level. Local instructors had developed the textbook selected for similar courses offered during the 1970s and included a short theoretical explanation of a topic with an extensive problem set for each section. The problem sets included a wide range of concepts and algorithms from physics and mathematics. The use of this textbook was resisted by the academic administrator (who had developed the subsequent textbook) with the comment 'that [the old] textbook includes too much mathematics … this is not a mathematics course.' The use of this older textbook resulted in some difficulties. The original authors retained the copyright and would not allow the textbook to be re-written. The textbook had been typed on a traditional typewriter, and the original version was not available. Student copies were made from an existing copy of the textbook. Although this book appeared to be the best available, it had been written for a physics course where the academic level of the students was higher, due to entry requirements at the time, than of the students enrolled in the Access Programs of this study.

Class time, 7 hours per week, was largely devoted to active engagement of the students. Each course was broken down into weekly sections with a schedule of required work. This was characterized as a structured open environment with the class time organized to allow students to undertake any of the course components at any time. However, when implementing the revised instruction this flexibility was reduced by having all students undertake the laboratory exercises at the same time. This occurred when it was realized that the preliminary explanation for the laboratory exercises was seen by the students as a signal to undertake the laboratory exercise. The consequence of all students undertaking the laboratory exercises at the same time may have been beneficial since peer tutoring was more probable when all students were engaged in the same activity. Progress of each student was monitored daily. The amount of material covered in the course and in the textbook was such that many students could not complete the assigned work using class time only. A description of a typical week of physics instruction is provided in Appendix 6. This environment was similar to that described by Beichner, et al. (1999)

> Students were responsible for reading material from the textbook and asking about difficulties when they arose. It was explained to them that the only occasions when content from the book would be directly addressed was when their questions about it were being discussed or at those times when the instructor had an alternate way of presenting a topic. (p. S17)

This minimization of lectures allowed for more individual or small group tutoring on specific difficulties.

The laboratory exercises used in these courses were selected from a variety of sources. Previously the students had been required to undertake a set of 10 laboratory experiments in each course. Many of these activities were structured investigations with the majority of time allocated to laboratory report writing. Most of these original exercises were included in the course, but the instructions were removed and the objectives rewritten. Approximately 20 exercises were used for each course, many of which were exploratory. The laboratory exercises were designed to be directly related to the topic under study. Students used a bound exercise book to record their results. The preparation of formal written reports was minimized for two reasons: 1) the objective of the laboratory exercises was investigative rather than confirmatory, and 2) the rationale for requiring formal laboratory reports in most physics courses is to prepare students for writing reports in higher level courses. There was a realization in the Technology Program that students who entered the Technology Program directly from high school were not able to prepare acceptable technical reports. As a consequence, one major focus of the Technology Program was to provide students with those skills. Therefore, Access Program students who proceeded to the Technology Program would not be at a disadvantage if they had not acquired formal report writing skills.

The classroom did not provide access to computer equipment or connections. No students used personal computers in the class. Computer access was available in the building, and students used them during and outside class time. A decision was made to require graphing to be done on graph paper for the first course, but graphing using an available computer-graphing program was required for the second course.

Some effort to formalize connections with other mathematics and English instructors was made in the curriculum design process. Over many years there had been discontent with both the order and the content of the mathematics curriculum and the need for specific mathematical skills essential to the physics curriculum. Discussions with Mathematics instructors were inconclusive. The mathematics curriculum topics were perceived by them as necessary and prerequisite and that reorganization to accommodate needs external to the Mathematics Department was not possible. The English Department was much more accommodating and receptive to the idea of coordinating their course with physics. An arrangement was made to have the students prepare two assignments involving writing that would be marked by the physics instructors for physics content and then passed on to be marked and graded for English content by the English instructor.

Data and Instruments

The data collection and analysis were designed to obtain information about the students and processes in the classroom and to identify differing views related to the curriculum of individual students and the instructor.

Historical data were available for five years of final grades in every course undertaken by previous students in the civil/mechanical and electronics Access Programs. These data were evaluated to show historical trends in academic success.

During year 2 of this study, data for personal and academic histories (Appendix 1) and data from inventories on learning style, attitude toward physics, prerequisite conceptual knowledge in physics, and a mathematics pretest (Appendix 2) were collected at the start of Physics 150. During the two terms of physics, data were collected from the results of tests and examinations in mathematics and physics. Qualitative data were also collected through student and instructor journals to evaluate the attitude and impressions during this study. Videotaping of classes or the use of an external observer, either of which might have provided an alternate interpretation of the classroom environment, were not practical.

The Gregorc Learning Styles Inventory (Gregorc, 1982) was used as a measure of learning style. The inventory defines two poles on each of two dimensions resulting in four outcomes: Concrete Sequential, Concrete Random, Abstract Sequential, and Abstract Random. The results of this inventory are difficult to use, although the dominant style for typical science and engineering students may be concrete sequential (Farragher, personal communication, 2000). Although there are no data to support the supposition, it is possible that in the environment of a physics class where most students and the instructor are likely to be Concrete Sequential a student who is Abstract Random may have some difficulty relating to the explanations and discussions. There were no previous data to assess the learning styles of Access Students and the wide range of students enrolled in program may have resulted in a distribution different from traditional science or engineering students.

Attitude toward physics was measured pre- and post-course using the Maryland Physics Expectation (MPEX) (Redish et al.,1998) survey. This instrument has been used to measure the attitudes of students in physics classes in six dimensions:

1. Independence – whether knowledge is uncertain or constructed
2. Coherence – whether knowledge elements are independent or part of a coherent system
3. Concepts – whether ideas in physics are based on concepts versus a collection of formulae
4. Reality Link – the relationship of physics to the students' lives

5. Math Link – whether mathematics models physical systems or is useful only for generating numerical answers
6. Effort – do students expect to think carefully about and evaluate information.

van Aalst and Key (2000) reported the results of a study in four types of introductory physics courses: (1) for students who had not previously taken a physics course (referred to as academic-bridging students), (2) for life sciences, (3) for honours physics, and (4) for engineers. The results from students were compared to the results from experienced physics teachers, referred to as experts. The results from this study indicate that overall there was a 5.8% decline (pretest and posttest) in the number of academic-bridging students who agreed with the experts after completion of a one-year physics course. For life science students, the overall decline was 0.7% while for engineers there was a 2.9% increase in the number of students. Results for the honours physics students were not presented due to the small sample size. Redish, Saul, and Steinberg (1998) reported similar results from four US universities. In both studies, the only group with increasing agreement was engineers, where maximum agreement was 60%. Most results indicated that fewer than 50% of the students were in agreement with the experts and demonstrated decreased agreement between starting and completing an introductory physics course.

The FCI and MBLT provide data on students' prerequisite conceptual knowledge. Due to time limitations it was decided to use only the FCI. It had been observed, in previous course offerings, that students had greater difficulty with dynamics concepts that with kinematics. Also, the Civil/Mechanical students' previous term's mathematics course included graphing that may have biased the pretest results since the MBLT included many questions using graphs. The final score for 30 multiple choice questions was collected (Appendix 2). The same inventory was administered to the students during the last week of Physics 151 and the results used to calculate their conceptual gain for comparison to a study of 6000 students in United States high schools, colleges and universities (Hake, 1998),

During the course, student journals were used to gather data on students' perceptions of the learning environment. In most cases, students expressed uncertainty about what to write so the instructor proposed a focus question. Most students chose this question and wrote in point form. Results from tests throughout the term, from final examinations, and students' final grades were recorded. The final examination was composed of conceptual problems, analytical problems, and a laboratory skills test. A record (complete/incomplete) was kept for each student for completion of problems and laboratory exercises.

Procedure

A research and development (R&D) model for vocational education and training (VET) in Australia provided the framework for this study (Smith, 1999). Smith cited the Organisation for Economic Co-operation and Development (OECD) Frascati Manual for a definition of R&D:

> Creative work undertaken on a systemic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this knowledge to devise new applications. (p. 5)

Smith interpreted R&D as the provision or application of new or revised knowledge for new or existing settings. The Australian study had five components: a literature review, a working symposium to identify key issues, quantitative data gathering, case studies to explore the identified factors in particular situations, and the discussion of preliminary findings by informed experts. This study utilized a similar approach for structuring the inquiry, but the unique nature of the Access Program created difficulties in evaluating the results as part of the body of research from PER.

In the context of education research and decision making, Smith described the "climate of opinion" (p. 6) for the use of research results. Likewise, R&D studies need to be opportunistic in both the specific foci and procedures. Smith suggested:

> Much research, particularly in universities, is conducted from the standpoint of a particular academic discipline; and R&D on VET employs many disciplinary perspectives. (p. 6)

The approach used influences the questions generated and techniques used to explore the resulting questions, the reporting style, and the perception of quality. The present state of PER is such that it is neither a discipline of science nor the education community. PER is composed of a small, well-defined group of physics educators who are mostly resident in physics departments who divide their research efforts between physics and physics instruction. Within university physics departments, the traditional curriculum dominates. PER has made some impact in changing attitudes of physics instructors, often by applying scientific methodologies to PER. Broader views for physics education reform are often founded on statements of physics education as art (Ogborn, 1978). The exploration, data collection, and interpretation for this study were initially planned so that the research outcomes bridged at least three communities: the students in the Access Program, the teaching faculty for the program, and researchers represented by PER.

This three-year case study involved three major components and focused on the physics courses in the Access Program. The evidence from this case study would be used to evaluate the effectiveness of a modified curriculum and to make proposals for the next stage in the curriculum development process using the ideas of a helical spiral of improvement. The three components of the study were defined by activities of years 1, 2, and 3.

Year 1

The first component of this study was to describe students in the Access Program and to develop a curriculum for the physics courses to better serve the needs of these students. The opportunistic aspects of the study surfaced in the fortuitous change to the Access Program so that the civil/mechanical students were enrolled in a mathematics course before their first of two physics courses, compared to the electronics students who undertook their first and second mathematics and physics courses concurrently. This opportunity provided a setting to explore the effect of mathematics achievement on achievement in physics. Historical data were collected and evaluated to provide a typical description of the students enrolled in the Access Program. These data provided more detail of the students' academic history and state than had previously been available and provided support to redesign the curriculum to address issues of high attrition. The original topics in the curriculum were retained but the focus of instruction was substantially changed to include elements of constructivism. The experience of the physics course instructors, as well as ideas from PER outlined in chapter 2, were used in the curriculum design process.

Year 2

The second component of this study occurred over two terms and two physics courses and consisted of a case study of the civil/mechanical and electronics cohorts where quantitative and qualitative data were collected. Pre-course data were collected on students' academic history to provide details for grouping the students. Pre-course tests for prerequisite mathematics knowledge and physics conceptual knowledge provided data to be used in evaluating improvement in conceptual understanding and academic progress in physics. Attitude toward physics was measured pre-course, mid-course, and post-course. These data, student journals, and a pre-course learning styles inventory provided qualitative data to explore relationships between student achievement and factors other than grades and scores. The evaluation of the revised curriculum was the underlying rationale for collecting and interpreting these data. Modifications to the instructional component of the curriculum were made before the second physics course as a consequence of data collected during the first physics course.

The personal data collection and mathematics pretest were administered during the first class of Physics 150. The multiple choice questions for the mathematics test were provided to each student who recorded their answers on a separate sheet. No time limit was imposed and all students completed the test. The learning styles and attitude surveys were administered during the third Physics 150 class. The instructions and word matrix for the Gregorc Learning Styles Inventory used by the students were copied from the original (Gregorc, 1982) and the students were given instructions for graphing and interpreting their own learning style. All students completed the inventory followed by discussion of individual and class results. Several of the words used in the matrix were unfamiliar to students (for example, aesthetic) and a dictionary definition was read to the whole class in each case. The MPEX attitude survey was copied from the authors' website (Redish, Saul, & Steinberg, 1998). The instructions preceded the statements on the handout. Students responded on the survey, to the right of each statement and no difficulties were encountered by students, all of whom completed the survey within 30 minutes. The FCI for conceptual knowledge were administered during the fifth Physics 150 class. The multiple choice questions were provided to each student as copied in Appendix 2 and a separate answer sheet was provided. Students were requested to provide an answer to each question although they were informed that no assistance would be provided for interpretation of the questions. A 90 minute time period was used for the students to complete the inventory. While the majority of student had finished within one hour several students continued to work until the end of the time period, although every student provided an answer to all of the questions. The question and answer sheets were collected and since the same inventory would be used as a posttest, there was no discussion of the results.

The FCI was administered for posttest data on the third day prior to the end of classes for Physics 151. The final examination for the course was scheduled for the following week. Students were informed before each of these pretests that although the results would be recorded they would not be used for assessment. The administration of the MPEX survey was repeated during the last week of classes for Physics 150 and again during the last week of classes for Physics 151.

Year 3

The final component of this study was the interpretation of the data and the curriculum for development of a general curriculum development framework. Consideration was given to using the results in future offerings of the same physics courses as well as the relevance to other physics courses in different settings, particularly other introductory physics courses although some of the results were applicable to higher level courses. The helical cycle of improvement (Redish, 1996) used by the Physics Education Group at the University of Washington resulted in improved methodology and resources for their physics courses. In that case and other similar physics programs for preservice education students, the helical process has been used to converge to an improved solution. Since this study was the first stage of the curriculum development cycle, and due to the historically high attrition in the Access Program, the utility of the results was an important factor in the interpretation of the results.

CHAPTER 4

DATA ANALYSIS AND INTERPRETATION

Introduction

Data were collected during the first two years of this three year study. In the first year, two tasks were undertaken: evaluation of the previous five years of data on former students as a (1) benchmark for the next cycle of the Access Program and (2) basis for changes to the two physics courses of the Access Program: Physics 150 and 151. During the second year, data were collected from the students in the two groups of the Access Program to (1) evaluate potential factors influencing their academic performance, (2) predict their academic success, and (3) evaluate the revised instruction for Physics 150 and 151 in the third year of the study.

Historical Data

College registration records include final grades for students who completed at least one course at the college. Access to these data required a listing of student identification numbers that were available for only 7 of the 12 Physics 150 classes offered in the previous five years. Final grades in all mathematics and physics courses were compiled for 130 students from these 7 classes. Four classes were for students in the Electronics Access Program (N = 67), and 3 classes were for students in the Civil/Mechanical Access Program (N = 63). While the initial enrolment in the 7 classes of Physics 150 was approximately 170 students, approximately 40 students did not complete Physics 150; as a consequence, grades for these students were not available. Approximately 290 students were initially enrolled in all 12 classes while the total number of students who completed Physics 150 was approximately 222. Thus, the available data represented 58% of the students who completed Physics 150 and 45% of the students who were initially registered in Physics 150. There were no apparent reasons to assume that these students were not a reasonable representation of students completing the physics requirements of the Access Program. Grades for this benchmarking sample of former Access students in four consecutive physics and mathematics courses, concurrent with the first two physics courses, were accessed and evaluated (Table 1). Students were graded using a 9-point scale that was compressed into four categories: A (A+, A, A-), B (B+, B, B-), C (C+, C, D), and F (F or Dropped). The data for students' final grades were analyzed to provide a representation of the academic progress of students in the Access Program and the Technology Program. Physics and mathematics courses shown were normally concurrent. Physics 3 and 4 and Mathematics 3 and 4 were courses in the first two terms of the Technology Program. The number of students for each set of courses does not represent the same initial cohort of students since some students repeated courses or obtained credit for prerequisite courses external to the Access Program.

Table 1: Number of students in each of 4 physics and concurrent mathematics courses.

Grade in Physics	Physics 150 / Math 1 (N = 129) (E 67; CM 62)	Physics 151 / Math 2 (N = 97) (E 49; CM 48)	Physics 3 / Math 3 (N = 52) (E 26; CM 26)	Physics 4 / Math 4 (N = 36) (E 20; CM 16)
A	27 (E 17; CM 10)	26 (E 16; CM 10)	19 (E 11; CM 8)	15 (E 9; CM 6)
B	47 (E 21; CM 26)	44 (E 21; CM 23)	24 (E 11; CM 13)	16 (E 7; CM 9)
C	21 (E 10; CM 11)	21 (E 10; CM 11)	6 (E 2; CM 4)	2 (E 1; CM 1)
F (Dropped)	34 (E 19; CM 15)	6 (E 2; CM 4)	3 (E 2; CM 1)	3 (E 3; CM 0)

Academic Progress

From the group of 129 students who completed Physics 150 in the benchmark sample, 33 (26%) completed the three-year, combined Access/Technology Program in three or more years while the remaining 96 students either failed or dropped from the program. Completion rates for the Electronics and Civil/Mechanical groups were 27% and 23%, respectively. For individual years, the completion rate ranged from a low of 21% for the Civil/Mechanical group to a maximum of 28% for both the Electronic and Civil/Mechanical groups. Completion data were compiled for each of the three grade groups: A, B, and C. Seventeen (64%) of the 27 students whose grade in Physics 150 was an A completed the Technology Program while only 24% of the B and C students completed the combined program. The academic success rate is also demonstrated for the individual grade groups: 34% (16 of 47) of B students and 10% (2 of 21) of C students. These data (Table 2) suggest a declining probability of success dependent on the students' grades in Physics 150. It was assumed that this grade was related to students' understanding of basic physics and related mathematics prior to their enrolment in the Access Program. The change in GPA per term was calculated from a linear fit to course grades for each group over four terms. These results were used to determine a threshold grade for Physics 150: the minimum grade necessary for likely success in a student's fourth physics course. A student with a grade in Physics 150 less than a B (4.2 out of 9) was unlikely to achieve a C in Physics 4, the minimum grade necessary for academic advancement. Note that this result is for the group of students who completed Physics 4; many students had previously failed or dropped from the program.

Table 2: Academic progress over four physics courses as a function of grade in Physics 150 for students who remained in the program.

Grade in Physics 150	Attrition: students/term (% / term)	Change in grade (GPA / term)
A	1.5 (7%)	-0.45
B	5.3 (15%)	-0.33
C	7.0 (12%)	-0.26

The historical data were explored for other trends in academic progress. The Access Program was designed to be completed in three terms over nine months. The historical data indicate that, while extending the time beyond three terms may have helped students to complete the Access Program, it did not result in successful completion of the combined Access/Technology Program. Of the 130 students in the historical data set, 68 (52%) completed the Access Program in nine months while only 16 (12%) completed the Access Program in more than nine months; another 46 (35%) did not complete the program. When these results are adjusted to include those students who dropped from the program before completion of Physics 150, the 68 students who completed the program in the normal nine months represent 40% of the students who were initially enrolled in the Access Program.

The enrolment data for the 46 students who did not complete the Access Program is of interest. Figure 1 illustrates the wide range in time that those students were enrolled in Physics 150 or Physics 151. While 19 (41%) of the students dropped from the program after completing either Physics 150 or Physics 150 and 151, the remaining 27 (59%) repeated one of the courses at least once and as many as seven times. Only one student in the group that completed the combined Access/Technology Program repeated a physics course (in that case, Physics 150). This compares to the 32 students out of 68 (47%) who completed the Access Program in the standard three terms and who continued to successful completion of the Technology Program. These data demonstrate that a student who is not successful in the physics courses of the Access Program is unlikely to benefit from repeating a course, possibly because of a mismatch between the student and the course. The Access Program completion data were broken down for the two groups: 18 of the 49 (37%) Electronics students completed the program while 14 of the 48 (29%) Civil/Mechanical students completed the program.

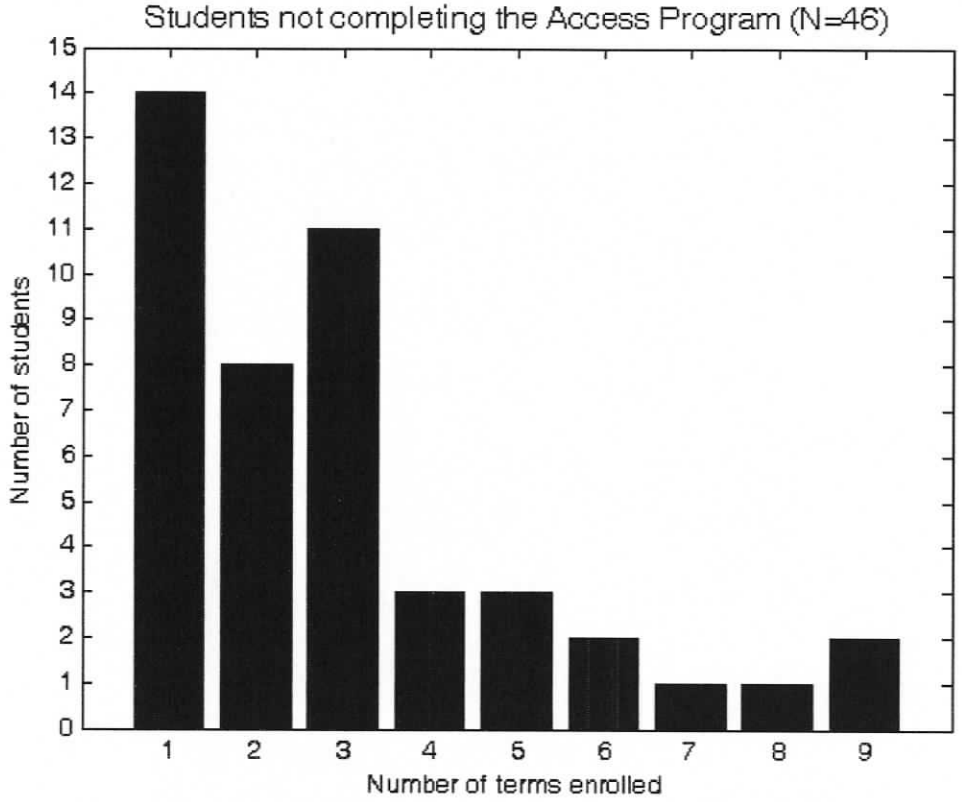

Figure 1: Number of terms of enrolment for students who did not complete the Access Program.

The grades of students in Physics 150 show different distributions for Electronics students compared to Civil/Mechanical students as a result of differing admission policies for the two programs. Demand for places in the Electronics Access Program resulted in those applicants preferentially admitted on the basis of prior academic grades. In most years, the number of places available in the Civil/Mechanical Access Program matched the number of applicants; and all students who applied were admitted. However, over the span of the four physics courses, the distribution of grades became increasingly similar. The results for Physics 150 (Table 1) show more students from the Electronics group with an A grade (25%) compared to Civil/Mechanical students with an A grade (16%). In the fourth physics course (Physics 4), 45% of Electronics program students achieved an A grade while 38% of Civil/Mechanical program students achieved an A grade. These data also show that the higher initial grades for the Electronics students did not significantly affect completion of the Access Program. While 20 of the initial 67 (30%) Electronics students completed the Program, 16 of the initial 62 (26%) Civil/Mechanical students completed the program. In both groups, the distribution of grades shows a trend toward higher percentages of A grades and lower percentages of C grades. Thus, the Access Program had been successful for students with good preparation for the program. However, the differences for the two groups suggest that effective instruction and early success may overcome initial academic differences.

Mathematics—Physics Relationships

The historical data were used to compare students' grades in their first two physics courses with their grades in corequisite mathematics courses. A strong relationship between mathematics and physics grades would allow mathematics grades to be used as a predictor of academic success in ultimate physics courses and in the combined Access/Technology Programs. The results shown in Table 3 confirmed the strong association between mathematics and physics grades that had been hypothesized from anecdotal information from previous course offerings. While no historical data were available to consider how entry-level mathematics knowledge and skills were associated with grades in mathematics and physics courses, these data did not invalidate the use of an entry mathematics test as a predictor for success in subsequent courses of the Access Program.

Table 3: Pearson's Product Moment Correlation for historical data of students' grades in physics and mathematics courses. Values for means are for a 3-point system (0 = Fail, 1 = C, 2 = B, 3 = A). All correlations significant at 0.01 (2-tailed).

	N	Physics Mean	Physics S.D.	Mathematics Mean	Mathematics S.D.	Pearson's Correlation r	% of Variance
Physics 150 / Mathematics 1	123	1.52	1.10	1.46	1.09	0.66	44%
Physics 151 / Mathematics 2	97	1.37	0.92	1.34	1.15	0.64	41%

Results of Historical Data

Results from the interpretation of historical data were used to formulate design principles for changes to the instruction of the two physics courses of the Access Program. These design principles were used to develop innovations intended to improve the program's success rate. Although the Access Program was developed to provide opportunities for non-traditional students, the data indicated that successful students were most often those with initial academic success and who may have been characterized as traditional students. Changes that would produce enhanced results for academically weaker students might provide those students the opportunity and time to develop knowledge and skills as a foundation for future studies, which was the central goal of the program and faculty. Furthermore, these results suggested that the practice of allowing students to repeat foundation courses was ill advised and generally non-productive. Such policies may have been misleading to students and faculty who believed a 'second-chance' could make up for effort or lack of first-time success.

It was hypothesized that most of the students who did poorly or repeated Physics 150 were non-traditional and that barriers to success were the traditional structure and focus of the existing curriculum and assumptions of prerequisite mathematics skills. Three design principles were identified as important: (1) integration of mathematics into the instruction of physics topics, (2) changes in the instructional environment from traditional lectures, and (3) postponement of the introduction of higher order concepts or processes until later in the two physics courses to give underprepared students more time and experiences from which they could develop the skills necessary for success in a formal, postsecondary, educational environment. Interpretation of the historical data suggested that those students who achieved success in the Access Program most often entered the program with strong academic backgrounds. These design principles were proposed to address the needs of the majority of those students who were unsuccessful, particularly those students with a low B or C grade in Physics 150 who later failed or dropped from the program.

Mathematics in the Access Program Curriculum

The mathematics curriculum included a wide variety of topics accepted as background necessary in Years 2 and 3 of the combined Access/Technology Programs. Many students in the Access Program were undertaking advanced topics in their mathematics courses that would not be applicable until much later in the Technology Program but were unable to relate more elementary topics of mathematics to the problems encountered in the immediate physics courses. This fundamental issue — to focus on 'access', not future and distant possibilities — resulted in two approaches: (1) postponement of the Civil/Mechanical first physics course until the second term when the students would have completed their first mathematics course and re-established basic numeracy, and (2) an increase in the amount of instructional time in both groups' physics classes that was dedicated to reinforcement of mathematics applications in the context of physics problems, which would increase relevance and decrease transfer difficulties. The goal of these approaches was to provide students with the time and experience to develop the mathematical skills necessary to undertake the type of problems encountered in introductory physics. It was not a goal to increase the general mathematical skills or knowledge of students with the assumption that improved understanding of mathematics would necessarily improve results in physics.

A common situation in previous Physics 150 classes had been students' lack of knowledge and skills in areas that had been assumed as prerequisite. These included basic knowledge of geometry for simple figures, algebraic skills with linear equations, and particularly the ability to recognize or differentiate variables in equations when symbols other than x, y, or z were used and, more particularly, when subscripts were used in kinematic equations. The curriculum for Physics 150 was similar to the majority of algebra-based introductory physics courses and introduced the kinematic equations within the first two weeks. Most faculty perceived these equations as applications of the type of equations students had worked with in their mathematics classes. Many students perceived the equations as new to their experience, beyond what they had previously studied in mathematics, and beyond their expectations for prerequisite knowledge. A basic goal of the traditional curriculum was training students in formal physics and mathematics in preparation for careers in physics. While students' lack of skills was recognized in other areas, especially general study skills, their mathematics background was considered as very important for academic success and as necessary for future academic success in the Technology Program. In spite of recognition that many students were not achieving success with the traditional curriculum and that the goal of the Access Program was not to prepare students for careers in physics, there had been no significant changes in the past to address these problems. The proposals in this research agenda for Physics 150/151 included a greater focus on integrating mathematics with the physics curriculum at a level more appropriate to the students enrolled in the Access Program concurrent with changes to the instructional environment better adapted to those students.

Instructional Setting for Physics 150 and 151

Results from PER reported in Chapter 2 included descriptions of alternate instructional environments that increased student engagement. The students in these studies were traditional high school, college, or university students with previous academic success. The Access students were not traditional students and while instructors were motivated to reduce the attrition rate in the program and were aware of results from PER attrition rates remained high. The use of interactive questioning and peer tutoring described by Mazur (1997) had been used to increase student engagement and address misconceptions. Although PER results showed that simply increasing student contact time was not necessarily successful in improving conceptual understanding, instructors perceived that an additional tutorial class each week would be beneficial for Access students and was implemented two years prior to this study. During these tutorial classes students were mostly engaged in problem solving. The FCI and MBLT were used as post-test measures of conceptual understanding but since pre-course data were not available the value for gain <g> could not be determined. During these years the curriculum and lecture, recitation, laboratory format for curriculum and instruction remained unchanged and assessment was largely summative through term tests, laboratory reports and final exams. Since major changes to the curriculum content and objectives were not possible during this study, and since minor changes in instruction prior to this study had not shown significant results, the only remaining option appeared to be major change to teaching and assessment approaches.

The threshold grade of a B in Physics 150 for success in the combined Access/Technology Programs suggested that a different format of instruction was required for students who had difficulty achieving this grade and in achieving levels of understanding and problem-solving ability necessary for long-term success. While increasing the duration of the program or increasing class time might have produced the desired results, these options were not available in this college context. The design principles for revision included reducing lectures, which would free instructional time for activities that reinforced basic skills. While traditional definitions of curriculum and instruction for physics courses do not normally include aspects of education other than physics topics, for this program it was necessary to include a broader range of issues that appeared to constrain academic success for many students. Although many students were judged to have poor entry-level knowledge and skills, the informal skills or scientific knowledge that students possess are not usually exploited. An environment different than traditional physics classes would allow students time and experiences to develop necessary understanding and skills of formal physics and mathematics by utilizing their informal knowledge. Class time could be used to stress the evaluation of existing understanding of physics by presenting topics and then allowing students the time and opportunity to develop internal bridges between their existing knowledge and the more formal representations of physics and engineering. It was believed that the proposed changes would likely have an equal benefit for all students or at least should not have any negative effects for any group.

Requirements from the administrators of the Access Program were that the topics of both Physics 150 and 151 be the same as in previous offerings (Appendix 3) and that the curriculum and instruction be the same for both Electronics and Civil/Mechanical students. Changes involved replacing traditional lectures with student-centered activities that included greater amounts of related mathematics and increased opportunities for students to develop problem-solving and general academic skills. Many students in the program had been away from formal education for many years, and few students had experience in typical postsecondary physics or mathematics courses. As a consequence, many students were not aware of or did not possess the skills or attitudes necessary for academic success in a traditional environment. An environment was required with explicit activities that modeled and reinforced academic behaviour and success. The primary component for instruction was a large number of problem sets that students would be required to complete within a specific time. Formal laboratory activities were replaced with exploratory laboratory activities, and traditional assessment and evaluation placed greater emphasis on formative evaluation.

Previously the two physics courses had been taught with three hours of lectures per week and two hours in a structured laboratory setting. Although some of the lecture time was used for problem solving, the majority of time was allocated to formal lectures on specific topics that were explored in later laboratory activities. In the two years prior to this study, one additional hour per week was scheduled for tutorials. This time, in several cases, was used by instructors for testing that had previously been undertaken during the lecture periods rather than for the intended purpose of tutoring. Thus, the additional tutorial time resulted in some increase in time for problem solving but also increased the time that the instructors were engaged in lecturing, which had been deemed to be least effective for the at-risk students. The assigned problems were selected from end-of-chapter problems from a traditional, algebra-based textbook (Cutnell & Johnson, 2001). Students were typically assigned 10 to 15 problems per week. For each course, student evaluation was based on four midterm tests, laboratory reports, and a three-hour final examination. For Physics 150, the laboratory reports were all informal, with descriptions of the process undertaken by the students rather than statements of formal objectives and outcomes of experiments. For Physics 151, the laboratory report requirements increased so that the final report was similar to that expected in the Technology Program. Short, typically 10-minute, quizzes were often used for formative assessment, although these grades were sometimes used in student evaluation. The assessment changes focused on each of these activities.

Lectures were replaced with a short (15 to 20 minute) introduction at the beginning of each new unit, which was principally a description of the physical process. This meant a significant reduction in the one-to-many (instructor to the class of students) verbal discourse, traditional physics demonstrations, and mathematical derivations. Parallel to these reductions were increases in one-to-few (instructor to individual or small groups of students) and peer discourse. A small number of end-of-chapter problems were replaced with a large number of problems, many at a basic level including more examples of similar problems but with differences in mathematics and symbology. Completion of problem sets was required each week. For assessment of these problem sets, completion instead of grades was recorded. One hundred percent completion was required, but some flexibility in completion time was allowed. Solutions to problems were available to students. Laboratory activities provided concrete examples of concepts under consideration, but students mainly worked with equipment and gained experience in measurement techniques. While not dissimilar in substance to previous laboratory activities, these activities were not constrained by 'cookbook' instructions — their focus was the process of science and engineering, rather than the output stressed in the laboratory reports required in previous physics courses. While students typically undertook 8 to 10 laboratory experiments per term, all with formal reports, it was proposed that as many as 20 laboratory activities per term were included with fewer formal reports. For Physics 150, there were no formal reports; for Physics 151, there would be two or three. During a typical instructional week, the majority of time would be unstructured and students could work individually or in groups to complete assigned work. The role of the instructor during this time was to provide individual, group or, in rare cases, whole class tutorial assistance.

More complex and integrated problems involving multiple concepts where students could work on developing problem-solving skills would conclude each topic. To reduce students' perceptions that each unit of work was independent, the integrated problems would include many different concepts, particularly from earlier units of work. These problems were introduced to illustrate the complex nature of most engineering and science problems. One difficulty in implementing these ideas was the lack of textual resources.

An extensive search for a textbook that would better accommodate the requirements of the students and the instructional setting resulted in no satisfactory outcome. A wide range of textbooks was available for traditional courses and students, but resources for underprepared students similar to those in the Access Program did not exist. The best choice for a textbook was a locally prepared text that had been used for similar courses several years earlier. This text provided suitable material to accompany the topics of the curriculum and a wide range of problems involving both physics and mathematics. The format and quality of the print in this textbook was below a minimum standard for readability. Requests to reproduce the textbook using computer word processing and printing were refused by the authors. In spite of the situation, this textbook was the only suitable resource found and was selected for the two courses. The use of the existing laboratory manual did not present as much difficulty. This manual included some of the experiments that were planned to be used, and other supplementary or alternative activities could be explained in a few minutes before each session. All laboratory activities were at a low level of scientific complexity. The traditional objective of laboratory activities for confirmatory evidence of theory taught in lectures was replaced with laboratory activities for practical application of scientific, mathematical, and engineering tools to explore and explain a simple concept.

Evaluation and Assessment

Evaluation and assessment are well defined and play an integral role in traditional physics courses. The primary purpose is most often summative: to provide test, assignment, and laboratory report marks for grading purposes. While many physics instructors recognize that formative evaluation is an important tool for student learning, the instructional need for marks and grading takes higher priority. Testing is traditionally perceived as a strong motivational tool. A common perception of instructors is that students who do not achieve good marks have not put in the necessary time and effort. While the intention of most instructors is to promote understanding, the perception by most students is that marks and grades are more important than understanding. For Access Program students — many of whom lacked appropriate learning skills — traditional evaluation by midterm testing did not provide time to develop necessary skills before they failed or dropped from the program. It was not unusual for students in Physics 150 to be tested within the first weeks of classes and achieve marks below 50%.

In many cases, those students' marks did not improve in subsequent weeks until they recognized that they could not pass the course or until they had completed the course but with a failing grade. An alternate method of evaluation and assessment was necessary — one integrated with more appropriate activities to give these students the opportunity to develop necessary skills concurrently with learning physics but without the disincentive of poor grades, which would eventually terminate their enrolment. Alternate evaluation where students would not be at a disadvantage due to initial lack of learning skills or knowledge could be used as a learning tool to replace testing for evaluation and assessment and to inform and empower learning, rather than for ranking of students into grade categories.

Formative evaluation was a major component of the revised instruction. It was important that students with unsatisfactory initial academic progress had the opportunity and time necessary to achieve satisfactory achievement. However, since the ultimate goal of the Access Program was to prepare students for entry into the Technology Program, it was important that by the end of Physics 151 students had skills, abilities, and attitudes comparable to the Technology Program students who entered directly from secondary school. These direct-entry students represented the majority of students in the Technology Program; and the curriculum, instruction, evaluation, and assessment of students in the Technology Program reflected the traditional educational attributes of many of those students. The high-failure and dropout rate early in the Access Program in previous years was a consequence of similar evaluation methods applied to students who were not traditional. Thus, the first half of Physics 150 would include the usual components of evaluation; but grades would be collected only for feedback on understanding and progress. While students were required, for administration reasons, to be assigned a grade at the end of each course, there was no perceived difficulty in altering the evaluation method for Physics 150 so that more students passed that course. Oversight for the Access Program was achieved through observation of students who completed the program and were admitted to the Technology Program. In the past, some Access students achieved better than average results in the Technology Program. Many of the students who successfully completed the combined Access/Technology Programs were traditional students who lacked prerequisite course requirements for direct entry to the Technology Program. For these students, the Access Program provided time to improve their skills and knowledge. For the majority of non-traditional students, the Access Program was not a bridge into the Technology Program. Increasing the number of students who completed the Access Program and enrolled in the Technology Program was not a goal of the proposed changes. The goal was to provide opportunity for more students to acquire attributes necessary for success in the Technology Program.

Results from a previous, unpublished study conducted by the instructional staff had shown that in the initial period of the Access Program unacceptable academic results were often a consequence of students not completing assigned work. A greater emphasis on compliance was included for Physics 150 that also overcame concerns that students would interpret self-paced differently than intended from the design parameters. The intent was to allow students more flexibility in completing work while discouraging procrastination. In the past, weaker students may have expended an equal or greater amount of time and effort than better-prepared students but were unable to overcome their initial academic deficit. The revised instruction would allow for early academic success with a realistic workload rather than academic success based on achievement of traditional course content. There was a perception from former instructors that many students perceived self-paced as an opportunity for less effort. Thus, a schedule for completion of the course allowed a maximum of two weeks to complete each week's work. However, students were required to complete the 12 weeks of term work in 12 weeks; so a student could never be more than one week behind the schedule. This required students with lower rates of progress to be working on multiple units. Students who were consistently behind would receive increased instructor attention with the objective of having them on schedule by the end of the term. Student progress would be monitored several times per week while frequent testing would be used to inform students of their progress relative to the schedule and expectations. Results from these tests would impress on students the importance of adhering to the schedule. Cumulative testing, where each test included problems from earlier units, would be included to encourage students to build networks of physics concepts that more closely approximated the complexity of engineering and science problems and to mediate weaknesses and misunderstandings. Increased class time for tutorials would allow students to work on areas of weakness with direct assistance from other students or the instructor.

In most traditional postsecondary physics courses, including these two courses in the past and in the Technology Program, academic achievement is the responsibility of the student. A new objective was to increase the level of scrutiny for students in Physics

150 who were at high risk of failure. By reducing early attrition of at-risk students, they would have the time to develop the skills and attitudes necessary for success in a traditional academic environment. While focused on students initially lacking experience and skills for academic success, this process would be used for all students; and it was expected that benefit would accrue to all students. The average decrease in grades over four physics courses, recognized from the historical data, showed that all students in the Access Program were encountering some obstacles to success. In developing the revised courses, it was acknowledged that for some students the obstacles could not be overcome in the time allocated for the Access Program. A process of triage, similar to that in medicine, could be used to segregate students into three categories: (1) those who, in the past, achieved success in the combined Access/Technology Programs, (2) those who had been away from formal education for many years and lacked many skills necessary for academic success, and (3) those with good work experience or lacking some academic skills. It was considered unfeasible to adapt the courses to the needs of the students in the second category. The third group would be the most likely to benefit from the proposed changes to the instruction of this study during the two terms of the Access Program. Since graduates of the Access Program would be in a traditional educational environment, it was proposed that there would be a progression toward traditional evaluation and assessment by the completion of Physics 151 in preparation for the Technology Program.

Year 2: Access Program

The students in this study were from two groups: Electronics students in their first term of the Access Program and Civil/Mechanical students in their second term of the program. At the start of Physics 150, the first physics course for both groups, 50 students participated in the study: 24 in Electronics and 26 in Civil/Mechanical. All students continued to participate throughout the first term of the program. Six students did not return for the second term: 2 in Electronics and 4 in Civil/Mechanical. The data were evaluated for the 44 students completing the Access Program and agreeing to participate (Human Research Ethics Committee approval can be found in Appendix 4): 22 in Electronics and 22 in Civil/Mechanical. Two female students were enrolled in Physics 150, one in each of the Civil/Mechanical and Electronics groups, although neither of these students completed the technology program. Both dropped after completion of the Access Program and did not enter the Engineering Technology Program.

Data were collected during the first week of Physics 150 on personal and academic histories, learning style, mathematics prerequisite knowledge, physics conceptual understanding, and attitude toward physics. Data were collected during Physics 150 and 151 from tests, examinations, and assignments as measures of academic achievement and progress. Student journals provided qualitative data on students' attitudes toward the physics courses and toward the Access Program. The FCI was administered to measure student conceptual understanding in mechanics, and the MPEX survey was administered to measure attitude toward physics. The FCI and MPEX were also administered at the conclusion of Physics 150.

Personal Data

Raw data for students' personal and academic histories is shown in Appendix 1. Students in the two programs ranged in age from 18 to 42 years with a mean age of 24.5 years. The mean age (22.5 years) for the Electronics students was slightly lower than the mean age (26.3 years) for the Civil/Mechanical students. The number of years since the students last participated in formal education varied from 1 to 14 years with a mean of 4.2 years. The mean for the Electronics students was 4.3 years and 6.1 years for the Civil/Mechanical students (Figure 2). These data show the non-traditional nature of many students in the Access Program. The lower ages and fewer years since last attendance in school for the Electronics students were consistent with enrolment in previous years. Greater numbers of applicants for the Electronics Access Program resulted in a selection process with preferential admission for those applicants judged by faculty to have a higher probability for success, i.e., more traditional students. In most years, the number of applicants for the Civil/Mechanical Access Program was close to the number of available seats; thus, all applicants were admitted. The Electronics Access Program was judged as more successful than the Civil/Mechanical Program on the basis of more students completing the combined Access/Technology Programs, with better average grades for students selected for the Electronics Access Electronics students than for Civil/Mechanical students. The positive match between the teaching style of the Electronics faculty and the learning styles of the students selected for the Electronics Access Program is the likely cause of these better results in grades and retention rates.

For this study, the number of students with recent educational experience (within two years) was 10 for the Electronics group (42%) and 8 for the Civil/Mechanical group (31%). The graphs for both age and years since last attending school show a wider distribution for the Civil/Mechanical group than for the Electronics group. Those students with long periods of time since their last attendance at school can be used for comparison of Electronics and Civil/Mechanical students. The graph for the Electronics students indicates that only 2 students had been away from school for more than 7 years, while 11 Civil/Mechanical students had been away from school for more than 7 years.

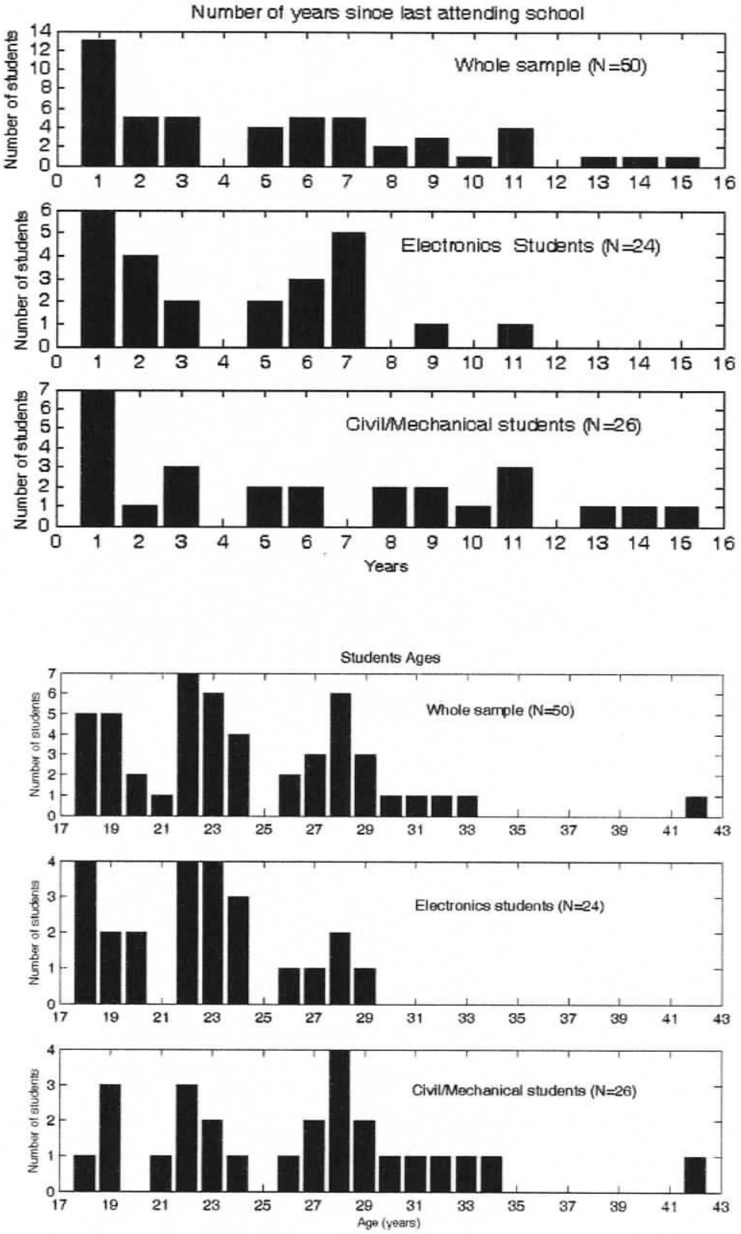

Figure 2: Graphs for personal data: Students' ages and number of years since attendance at school.

A factor affecting the physics courses that could not be inferred from these data was students' employment history. Experience from previous years indicated that many Civil/Mechanical students had worked in areas that were related to the curriculum of the Civil/Mechanical Technology Program and applied for admission due to their interest and experience in civil or mechanical engineering. This employment factor had been observed much less frequently for Electronics students. While no data or relationships had been formally documented, it was speculated that the differing admission processes resulted in the selection of Electronics students with good academic records while many Civil/Mechanical students applied for admission on the basis of their work experiences. Admission decisions with different criteria may have affected the ultimate success of students in the combined Access/Technology Program. A general categorization of students was made from these data: (1) those students who recently graduated from secondary school, (2) older students with work histories related to engineering, and (3) older students who previously had poor employment prospects or whose area of employment was significantly different from engineering. The last group of students had, in the past, a low probability of success in the Access Program.

Previous experience with students in the Access Program provided another factor related to age and probability of success. External commitments, particularly to jobs and families, that restricted the time students had available for their academic studies appeared to affect ultimate academic success. Students in the first group, as described above, were often better able to combine working and academic commitments. Students in the second group were more likely than students in the other two groups to have financial resources such that they did not have to work during the academic terms. Students in the third group were most likely to have work commitments in addition to their academic responsibilities. Thus, students in the third group were least academically prepared and were most likely to have external factors that often combined to limit their success in the program.

Precourse Entry-Level Mathematics Test

Precourse mathematics knowledge was measured by each student's grade on a 40-item test (Appendix 2). The test items were selected from a well-established textbook test bank. The test covered three levels of mathematics knowledge: Mathematics 8, 9, and 10 of the British Columbia school system. Typical problems in introductory physics courses require students to apply mathematics knowledge comparable to Mathematics 9. The majority of problems in introductory physics courses involve recognition, reorganization, graphing, and solving of linear equations. Thus, a threshold score for this mathematics test was set as 50% and included items up to solving simple linear equations, as well as items from arithmetic and geometry and problems using concepts up to Mathematics 9. Scores above 50% indicated increased proficiency in non-linear equations, trigonometry, and with more complex problems from Mathematics 10. Although the use of subscripts to differentiate between variables in physics is recognized as a major difficulty for students, problems using subscripts were not included in this mathematics test since the curriculum of Physics 150 and 151 included instructional units designed to address this issue.

The distributions for mathematics scores for the two groups are shown in Figure 3. The mean for the Electronics group was 29% compared to 55% for the Civil/Mechanical group. The minimum/maximum scores on this test were 11% and 77% for the Electronics students compared to 13% and 96% for the Civil/Mechanical students. Four (17%) of the Electronics students scored above the 50% threshold score, while 19 (73%) of the Civil/Mechanical students scored above the threshold. The historical data (Table 1) indicate that Electronics students were more likely to achieve A grades than the Civil/Mechanical students. The high scores for the Civil/Mechanical students on this test, as a consequence of completing their first mathematics course, provided the opportunity to compare success in the physics courses on the basis of the students' mathematics preparation. A further apparent advantage for the Civil/Mechanical students, not investigated, was the improved academic maturity due to the extra term enrolled at the College.

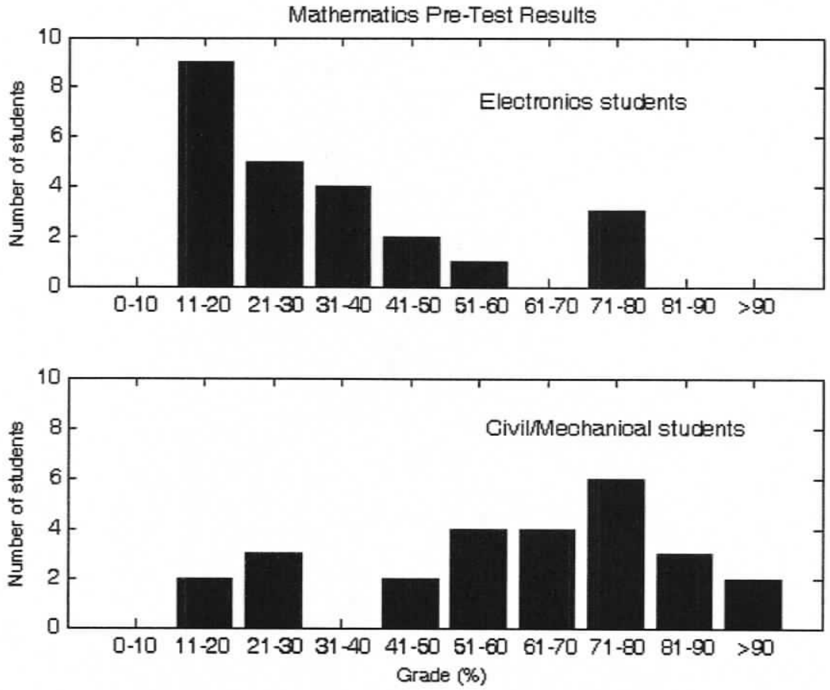

Figure 3. Precourse mathematics score for Electronics and Civil/Mechanical students

Force Concept Inventory

The Force Concept Inventory was used to measure students' conceptual understanding of mechanics, a central and difficult topic in most introductory physics courses. Figure 4 shows the distribution of scores for the two groups of students. Hestenes and Halloun (1985) suggested that a score of 60% represents the lower threshold for conceptual understanding of mechanics, while a score of 85% represents a mastery threshold in Newtonian mechanics. The precourse average score (pretest score) for the Electronics students was 48% while it was 60% for the Civil/Mechanical students. The pretest scores for both groups were much higher than most scores reported in the literature where typical pretest scores for high school students are in the range 20 to 45%, for college students 30 to 50%, and for university students 30 to 70% (Hake, 1998).

A graph of pre/post gain is shown in Figure 5. This graph uses the <g> score of normalized gain (Hake, 1998):

$$\langle g \rangle = \frac{posttest\ score\ -\ pretest\ score}{\max imum\ score\ -\ pretest\ score}$$

The calculation results in a fractional value for a student's gain compared to maximum possible gain. This statistic attempts to adjust for pretest-posttest gains for students with the highest scores. For example, students who achieved 10% on the pretest have the possibility of 90% gain on the posttest while students with 90% on the pretest could, at maximum, improve their score by 10% on the posttest. The pre/post gain <g> is thus a relative measure rather than absolute.

The average FCI <g> scores were 46% for the Electronics students and 69% for the Civil/Mechanical students. The average for all students was 57%. Epstein (2000) discussed the 70% barrier for <g> using the FCI results of Hake. Those data show a clear boundary at about 70% with very few groups of students achieving more than 70%. Several Access students in this study achieved pretest-posttest gains above 70%. No explanation for the 70% barrier has yet appeared (Epstein, 2000), and there may be different reasons for students with low or high pretest scores. Low-scoring students are unlikely to achieve 100% of the possible gain on their posttest. While it is recognized there are some areas of mechanics that prove difficult for all students, students with high pretest scores are unlikely to achieve 100% of the possible gain on their posttest. A more recent study (Coletta & Jeffrey, 2005) includes graphs of normalized gain <g> as a function of pre-instruction FCI score for individual students with outliers above 70%. This study also investigated the relationship between pre-instruction FCI score and gain <g>. For students at Loyola Marymount University, Southeastern Louisiana University and University of Minnesota students a linear fit to averaged data indicated that higher pre-instruction FCI score resulted in higher gains <g>. However, for Harvard University students the slope of the graph was zero; i.e. no relationship between pre-instruction FCI score and <g>. It should be noted that Eric Mazur was a principal instructor in the Harvard University study using methods of Peer Instruction (Mazur, 1997) and that the gains reported appear higher than the other three situations. Also of interest from the Colletta and Jeffrey study was their investigation of gain <g> as a function of the Lawson Classroom Test of Scientific Reasoning score (Lawson, 1978). Their results indicated a stronger relationship between gain <g> and Lawson's Test score than between <g> and pre-instruction FCI score.

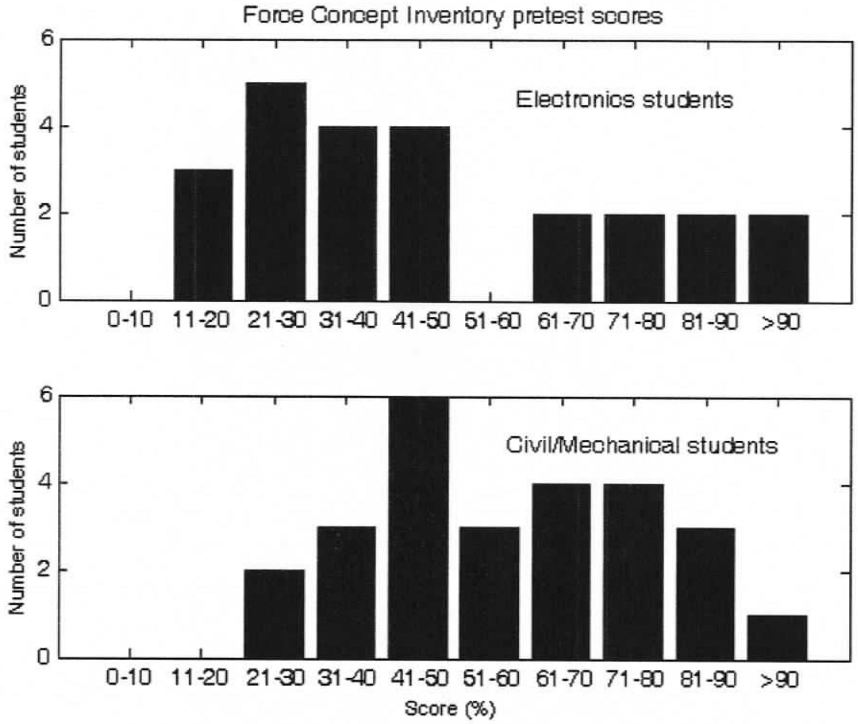

Figure 4: Precourse scores for Electronics and Civil/Mechanical students on FCI.

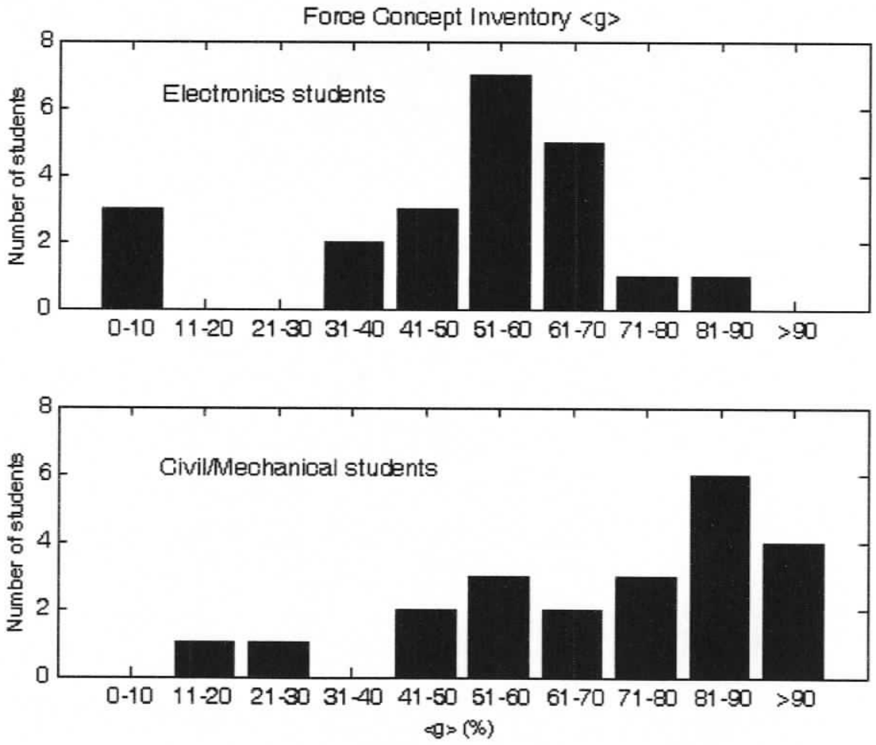

Figure 5 : Pretest-posttest gain <g> on FCI Electronics and Civil/Mechanical students

The high scores from both pretest and posttest applications of the FCI indicate that students who enrolled in the program had acquired conceptual understanding prior to enrolment in the program and beyond that reported in other studies. Thus, factors other than prior physics knowledge were more important in explaining the low success rates in the Access Program. The very good results for the 9 students in the Civil/Mechanical group who scored above 80% on the FCI may be a reflection of their previous work experience in jobs related to engineering.

MPEX

The MPEX (University of Maryland Physics Education Research Group, 2005) is a 34-item inventory (Appendix 2) to evaluate students' attitudes toward physics using a Likert scale for responses to statements about their perceptions of physics and how they think they work in their physics course. Students responded on a 5-point scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree. The authors of the survey have categorized the questions into six groups:

1. Independence: the degree to which students take responsibility for their own learning;
2. Coherence: how students view physics in term of interconnection of ideas;
3. Concepts: the students' perceptions of the need to understand concepts vs. memorizing facts;
4. Reality link: the students' perceptions of the relationship of ideas from the course vs. relevancy to real situations;
5. Mathematics: the students' awareness of mathematics as a tool for representation of physical relationships; and
6. Effort: a measure of students' perception of the effort required to use available information.

This categorization can be used to evaluate attitudes, beliefs, and expectations that may affect what students learn in an introductory physics course. Students who have attitudes and beliefs that are closely aligned with physicists may achieve better results than other students.

Pretest and posttest results for Physics 150 are summarized in Table 4. The lowest score is 1.0 and the highest 5.0. The results must be compared to the Experts column in Figure 5. In all categories, there was improved agreement between the students' and experts' responses from precourse to postcourse. However, the improvements were significant ($p \leq 0.01$) only for the categories of Independence and Effort for both groups and Concepts for the Electronics group. The high value for Reality Link (4.4 postcourse for both groups) is consistent with one study (Redish, Steinberg, & Saul, 1998) where 60 to 80% of the student responses were positive. In another study (Redish, 1997), student responses to the Mathematics category ranged from 40 to 70% positive responses, which may be consistent with the postcourse results from both groups (mean = 3.5). The precourse results for the Civil/Mechanical group (mean = 2.9) was lower than for the Electronics group and significantly lower than the Expert results. This result was counter to the expectation that the mathematics course prior to the Civil/Mechanical students' first physics course would have improved attitudes to mathematics. The two categories that indicated poor agreement with Experts were Coherence (how students view physics in term of interconnection of ideas) and Concepts (the students' perceptions of the need to understand concepts vs. memorizing facts). With the exception of the Electronics group for Concepts, both groups had similar results with little improvement between precourse and postcourse administration of the inventory. While the result for the Electronics group for Concepts improved, the postcourse result (3.0) was low compared to the Expert response (4.5).

Table 5: Results from the MPEX survey from a 5-point Likert scale.

	Electronics Precourse		Electronics Postcourse		Civil/Mechanical Precourse		Civil/Mechanical Postcourse		Experts
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
Independence	2.5	0.6	3.8	0.6	3.2	0.7	3.9	0.6	4.5
Coherence	1.8	0.4	2.2	0.4	3.8	0.5	4.4	0.5	4.5
Concepts	2.3	0.5	3.0	0.6	2.1	0.4	3.9	0.5	4.5
Reality Link	4.2	1.0	4.4	0.7	2.2	0.6	4.2	0.8	4.5
Mathematics	3.3	0.6	3.5	0.5	2.9	0.3	3.5	0.4	4.5
Effort	2.6	0.5	3.2	0.5	3.1	0.3	3.9	0.6	4.5

Improvements in Independence (the degree to which students take responsibility for their own learning) and Effort (a measure of students' perception of the effort required to use available information) were consistent with previous experience and attributed to increased academic maturity of students. Although anecdotal, former students in these programs often commented that their expectations of the necessary commitment in time and effort was much less than what was required for success in the program. Those students also commented that the actual time and their perception of the necessary time both increased as they progressed through the program.

Student Journals

Students were given the opportunity at specified dates during class time to comment on any topic related to their classes and the program. They were encouraged to reflect on the relationship between their personal circumstances, the value of the program, and how they had adapted to the demands of the courses and program requirements. The use of journals was unique for most of these students, and most had difficulty with the activity. The instructor frequently suggested a structured entry or suggested an idea for consideration that resulted in either positive or negative responses; very few neutral responses were recorded. The journals were started in the second month of Physics 150 with entries approximately every two weeks until the end of Physics 151. The Electronics group had nine journal entries while the Civil/Mechanical group had eight entries. All students participated in journal writing although many comments were very short, often a single word or short comment. Informal class discussions during the time reserved for journal writing resulted in additional information that was not directly recorded in the journals. Student comments were classified in categories of 1 = external factors, 2 = motivation, and 3 = structure of the course. Entries were assigned a value for either negative (-1) or positive (+1). These results for the two groups are shown in Table 6.

Table 6: Comments from student journals for each category of comment.

	Electronics		Civil/Mechanical	
	Number of Negative Comments	Number of Positive Comments	Number of Negative Comments	Number of Positive Comments
External	17	0	6	0
Motivation	36	11	20	8
Structure	37	39	18	38

For each category, the comments were explored for common factors. Each comment below indicates the academic performance of the student (Weak, Average, Strong) and the student's group (Elec or C/M). Comments have been grouped together, but the complete journal entry has been included to provide a general idea of students' attitudes and perceptions.

External Category

Comments for the External category were associated with either students' personal workload or requirements for the program, including how other courses in the program affected their progress in the physics course. There were no positive comments. The majority of comments were from the Electronics students. Many comments related to jobs that limited available time for studying.

- (Weak, Elec) Study 2 hours per day because of job.
- (Weak, Elec) Not ready for term 1 final exam, cannot keep up because of job.
- (Average, Elec) Limited study time because of job.
- (Average, Elec) No money/time to study.
- (Strong, C/M) Haven't started studying - external factors - job.

Students perceived a strong division between those who were and those who were not financially independent. Many students received funding from a variety of government agencies and within that group there were two subgroups: those who had long-term funding, often due to job-termination programs, and those whose funding came from less certain sources, particularly the Canada Student Loan program.

- (Weak, Elec) Funding determines achievement on tests.
- (Weak, C/M) Filling in forms for student loan eats into study time.
- (Average, Elec) Need more financial support for poor students.
- (Strong, Elec) May not be able to continue since student loan money has not arrived.

Many students were not prepared for the required workload in the program that tended to increase as the terms progressed. As a consequence, similar comments about workload occurred throughout the two terms of the Access Program.

- (Weak, C/M) Hard to get back to school after 10 years in the workforce.
- (Weak, C/M) Having trouble concentrating, keeping up but cannot get ahead.
- (Weak, C/M) Workload overwhelming, having hard time with problems, working on physics 4 to 6 hours per day.
- (Average, Elec) Behind, can't catch up, no time, make the best of it.
- (Strong, Elec) Too much work.

Several comments in the journals and during class discussions focused on conflicting demands between other classes and the physics class.

- (Weak, Elec) Could not study for physics because of math test.
- (Average, C/M) Hard to study with all assignments due.
- (Strong, Elec) Too many demands for assignments in other classes to spend time outside class on physics that is not collected.

A number of comments referred to the awareness of the conflict between studying and a range of distracting activities. This was most common in the stronger students.

- (Weak, C/M) Helping others leaves little time for studying myself.
- (Weak, Average, Strong, C/M) The sunnier it gets the less I want to be in school.
- (Strong, C/M) Time wasted in class socializing.
- (Strong, C/M) Lots of distractions; need to start studying.

Motivation Category

In the Motivation category, the majority of positive motivation comments were about improving self-motivation to achieve academic success while the negative motivation comments were in two areas: (1) student statements recognizing that their lack of motivation was the prime reason for lack of academic success, and (2) support for students who lacked appropriate motivation. Many of the negative comments were supplemented by the suggestion for an increase in the time for learning skills included in the program.

- (Average, Elec) I have improved time management and now I know what I am doing wrong as a student.
- (Average, Elec) Behind in homework because of lack of motivation.
- (Average, Elec) Not caught up because I am lazy.
- (Average, C/M) keep motivated by doing work regularly. The term schedule is good.
- (Average, Elec) Motivation and knowledge are not enough. Need to know how to ask questions in a systematic, organized fashion.
- (Average, C/M) No motivation from high school.

Some comments were about self-motivation; and other comments noted the need for external motivation, particularly checking and grading homework. Different and conflicting attitudes appear about the need for either more or less assigned work.

Several comments referred to the term schedule where students were given the recommended completion date for each section of the text.

- (Average, Elec) Important for motivation that homework is checked.
- (Average, C/M) I keep motivated because there are due dates.
- (Average, C/M) Did not know how much work I would have to do when I started. In this term it is easier because I know how to work. The learning assistant tutor is the most valuable.
- (Strong, C/M) Hard to keep motivated when no weight or flexible due date.
- (Strong, C/M) The work from the text does not need to be checked. The schedule is enough. Too many people aren't doing work unless it is checked.

Six comments from Electronics students in the week before the final exam for Physics 150 stated that they "hadn't started studying for the final." At the same date in the journals for the Electronics students, 6 students stated that they were confident about the upcoming term while 6 others were not confident about the upcoming term. The same topics for Civil/Mechanical students elicited comments from 8 students who said they were ready for the final examination, 6 others said they were not ready for the final exam, 13 students said they were confident about the upcoming term, and no students in the Civil/Mechanical group indicated they were not confident about the upcoming term.

The schedule for working on problems in the textbook provided a focus for several comments. In general, the stronger students had less difficulty with the material and were more likely to be up to date with class work and sometimes willing to work ahead of the schedule.

- (Weak, Elec) There is not adequate time or resources for success to be achieved.
- (Average Elec) Ready to go, up to date.
- (Average, C/M) Not ahead enough. Need to know exactly what to study.
- (Strong, Elec) Can't get far enough ahead.
- (Strong, C/M) Finished all course material. Want to do more.

Testing provided topics for many comments. A routine schedule for formative testing that was not recorded for grades was unique to most students and positively received. Several students received very low scores on early tests, and the postponement of summative testing may have encouraged these students to remain in the program longer than might have been the case in earlier years.

- (Weak, C/M) first time taking physics. Haven't passed a test yet.
- (Weak, Elec) I know the material but can't do it on tests.
- (Weak, Elec) I can't study for tests and learn new stuff at the same time.
- (Weak, Elec) Can't take the test seriously, bad mark.
- (Average, C/M) Test easy, dumb mistakes, not enough attention from teachers. Ready for first year in technology.
- (Strong, C/M) Choosing to fail tests because accepted at another school. Workload large and demoralizing and none of the teachers want to be here.
- (Strong, Elec) Test good, didn't get good mark. I understand a concept for a few days then forget.
- (Strong, C/M) Test was wake-up call for what I need to know.

The only comment regarding the relationship between mathematics and physics:

- (Average, C/M) Strong math makes physics easy.

Structure Category

Comments about Structure were interpreted as directly related to the curriculum and instruction of the physics courses. The Electronics students' comments were approximately one-half negative and one-half positive. The Civil/Mechanical students were generally more positive. Negative comments were overwhelmingly focused on the textbook and related to an acknowledged difficulty with the text as previously discussed. Comments from Electronics students indicated that they perceived too many problems and discussions as unrelated to physics. In contrast, few negative comments were received from Civil/Mechanical students on this topic; in fact, several positive comments were received about how basic mathematical facts were incorporated into physics problems. Positive comments were generally of two types: (1) the structure of the physics courses, with fewer lectures and more tutorial time, was beneficial, and (2) the laboratory activities were much better than formal laboratory activities previously experienced. Twenty-seven positive comments related to the elimination of formal laboratory reports. Journal entries in this category tended to be more detailed and provided evidence of differing attitudes to the physics class and its structure.

- (Weak, Elec) Hardest course. Didn't like teaching method.
- (Weak, Elec) Physics seems irrelevant. I only focus on relevant courses but hope to be more flexible about it.

- (Average, Elec) Better classroom structure. Math components in physics should be done before in math.
- (Average, Elec) Supply notes. Futile and frustrating, waste of time going over points no one understands. Teach the methods of analytical thinking and understanding.
- (Average, Elec) Learn more from tutor than in class, not that teaching is bad but not always sure what is being taught. Tutor says "this is what you need to know, here's how to do it."
- (Average, C/M) Like short lectures, going over the material at the end of the week, answering questions slowly, and in-class work. I would like more note-taking in class rather than use the text. The lab and the layout were good.
- (Average C/M) I like lectures more than work periods, but I have fallen behind on the work (needs a better balance). Should ask in class if anyone has a question then answer it rather than answer the same question 4 or 5 times to individuals.
- (Average, C/M) I don't think the open learning style for this course is preparing me for what I know will be the style in Technology but it has helped me here.
- (Average, Elec) Have no physics background. Good prep. Need to use tutor more. Lectures don't help.

Comments about the allocation of time in the classroom where lectures were minimized and replaced with tutorial activities were mostly positive but some students, particularly stronger students, showed a preference for more time allocated to lectures.

- (Average, Elec) Need more time for problems. Too much time in class discussing things not on topic.
- (Average, C/M) Needs a better balance with more lectures.
- (Strong, Elec) Lecturing gets in the way. Prefer when teacher acts as facilitator. I would rather be doing work.
- (Strong, Elec) Teacher needs to teach more rather than have us reading about it. Should go through examples in detail.
- (Strong, Elec) Class structure good. Problems done in class.

The unstructured laboratory exercises rather than exercises with specific directions received mixed responses. Almost all students were positive about the informal laboratory reports although several students suggested the complete elimination of laboratory reports.

- (Weak, Elec) Lab: should explain what exactly to do and what to write in report.
- (Weak, Elec) Lab: informative but don't like write-ups.
- (Weak, C/M) Labs are good but not relevant to Mechanical.
- (Average, Elec) In physics, waste some time in labs and don't spend enough time on problems.
- (Average, Elec) Lab intimidating. Lab report hard to figure out what to do.
- (Strong, Elec) Want to create own hypothesis in lab.
- (Strong, Elec) Lab: confused about data. Don't like lab write-ups.
- (Strong, Elec) Class discussion good. Lab good. Lab write-up bad.

The students' attitude about teaching and learning was reflected in some comments.

- (Weak, Elec) More lecture time, bad text. Grading scheme not fair. More organization.
- (Weak, Elec) Bad text, ineffective teaching, more teacher focus on me is needed.
- (Average, Elec) Need better support for students. Why read text for 1 hour when you can ask and have it explained in 10 minutes.
- (Average, Elec) Teach what needs to be known regardless of their level of education. Frustrating when assignments in class and labs are not worth marks. I do well on assignments but badly on tests.
- (Strong, C/M) Like this class where I have the opportunity to work at my own pace. Why are some people complaining so much. They only have themselves to blame.
- (Strong, Elec) Learned lots, textbook bad. Math and physics should be put together.
- (Strong, C/M) Concept learning method is best part of course. Number crunching doesn't help.

The textbook provided a focus for uniformly negative comments.

- (Weak, Elec) Bad text. Material good.
- (Average, Elec) Text bad. Good problems and well shown.
- (Average, Elec) Bad text. Learned a lot in a little time. Liked teaching method. Like in-class work.
- (Strong, Elec) Need new text. More evaluations from tests, labs and homework. Cumulative tests not fair.

- (Average, Elec) Bad text. Pace too fast. Learned a lot. Prerequisite for Access should be B- in all courses.
- (Strong, Elec) Labs good, teacher approachable, class enjoyable, class not long enough, bad text.

Students' opinions about the value of the Access Program were mostly from the strongest students who were confident about progressing from the Access Program to the Technology Program.

- (Weak, C/M) I am getting the grades I deserve for the work I am doing. Not enough time to do all the work. I like the chance to do work in the class. The labs are fun and I like not having to write a report. We are learning about report writing in the other class so we don't need it here. I don't think I will get into technology but I may go into the technician program
- (Average, C/M) In Access Program I haven't learned anything new in Math or Physics. Should have shorter program.
- (Strong, Elec) Access is good preparation for technology program.
- (Strong, Elec) I will never be prepared for the technology program. Knowledge has increased.
- (Strong, Elec) Program is important, especially for ones away from school a long time. Helps to upgrade knowledge step by step.
- (Strong, Elec) Good value, gets student up to speed fast. Bad text. Not enough prep in first term. Motivation slowed in second term. Need more structure, better text.
- (Strong, C/M) I don't spend any time outside class on this course. About 2 hours a week on Math. This program is too easy and not preparing me for Technology. Need to increase the level of Physics to match Math.

Academic Achievement in Physics 150/151/3/4

Academic achievement and progress were measured by final grades in four consecutive physics courses: Physics 150 and 151 in the Access Program and Physics 3 and 4 in the Technology Program. The number of students in each course is shown below (Table 7). Table 8 shows the number of students in each grade category for each physics course.

Table 7: Number of students in each physics course.

Physics 150			Physics 151			Physics 3			Physics 4		
Tot	El	C/M	Tot	El	C/M	Tot	El	C/M	Tot	El	C/M
50	24	26	44	22	22	34	14	20	29	9	20

Table 8: Number of students in each course for each grade category.

Grade	Physics 150	Physics 151	Physics 3	Physics 4
A+, A or A-	6 (12%)	13 (30%)	17 (50%)	15 (52%)
B+, B or B-	14 (28%)	17 (39%)	12 (35%)	12 (41%)
C+ or C	28 (56%)	7(16%)	4 (12%)	1 (3%)
D or F	2 (4%)	7 (16%)	1 (3%)	1 (3%)

The graphs below (Figure 6) show the comparison of historical results with those of the Access Program for all students and for each of the two groups. To compare these data, the percentage attrition per course averaged over the four courses was calculated. The historical data indicate that attrition rates had been similar for both groups: 23% per year for the Electronics students and 25% per year for the Civil/Mechanical students. From this study's data, the attrition rate for Electronics students was 21% but the attrition rate for the Civil/Mechanical students fell to 7%. Details from these graphs also show slight changes in the rate of attrition from term to term. For both groups, the attrition rate from Physics 150 to 151 was reduced. The likely causes were the increased flexibility in the course structure, early identification of difficulties without negative effect on evaluation and assessment, and increased time for tutorials. For the Electronics students, the trend continued between Physics 151 and Physics 3; but by the term of the final physics course, the attrition rate was essentially the same as for the historical data. It is possible that the attrition rates, both for the students of this study and from the historical data between Physics 3 and Physics 4, are related to students' abilities to achieve success in their mathematics courses or in courses where a strong mathematical understanding was necessary. The results for the Civil/Mechanical students show a much different trend. The very low 7% attrition is largely accounted for in the first interval: between Physics 150 and 151, the number of students fell from 26 to 22. The number of Civil/Mechanical students enrolled in Physics 3 and 4 were 21 and 20, respectively, i.e., very low attrition.

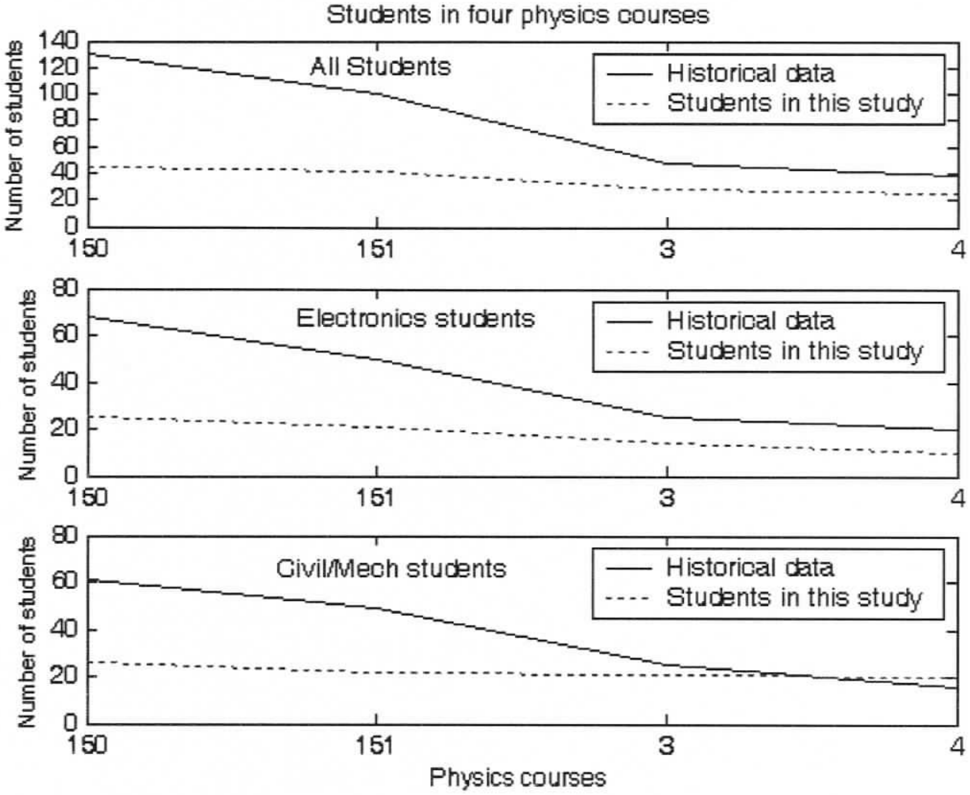

Figure 6: Number of students in each of 4 physics courses: Total, Electronics group, Civil/Mechanical group

The data were evaluated for the students who completed the fourth physics course (Electronics N = 9 and Civil/Mechanical N = 20) and at the same time the first year of the Technology Program. Of this group, all Electronics students completed the Technology Program and all but one Civil/Mechanical student completed the Technology Program. The average grade for Physics 4 for the Electronics group was 7.0 (A-) and for the Civil/Mechanical group was 6.15 (B+). However, a t-test on the data indicated that the difference was not significant at $\alpha = 0.05$. A whisker plot (Figure 7) better illustrates the students' grades in Physics 4. The box represents the interquartile range containing the half values. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers. The heavy bar across the box indicates the median; the mean is shown as a dashed line. This graph displays different distributions for the two student groups. While the mean for the Electronics students was higher (7.0 compared to 6.15 for Civil/Mechanical), the number of students was fewer (9 Electronics in Physics 4 compared to 20 in Civil/Mechanical). Half the Electronics students had grades between 6 and 8 (B+ and A) compared to 4 and 7 (B- and A-) for the

Civil/Mechanical students, with the lowest grade for Electronics students being a B- compared to a D for the Civil/Mechanical students. The data for these students' grades in Physics 150 were compared to their grade in Physics 4. For the Electronics students, the average change in grade between Physics 150 and Physics 4 was 1.7 compared to 2.6 for the Civil/Mechanical students, a difference of almost one grade. These results show that the Electronics students who completed Physics 4 achieved high grades and were from the group of students who started the Access Program with relatively high grades. The grades of Civil/Mechanical students in Physics 4 were more broadly distributed and show more improvement in grades than the students in Physics 150.

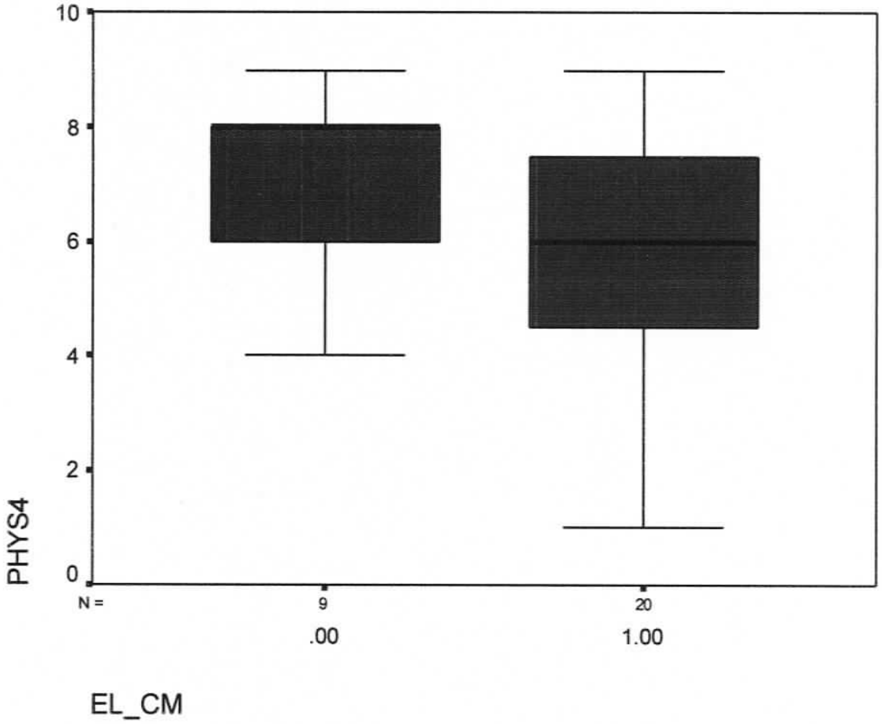

Figure 7: Box and whisker plot for students' grades in Physics 4 for Electronics students and Civil/Mechanical students.

The data for students' grades in each of the four physics courses were compared for each of the three grade groups (A, B, and C) to compare to the historical data. For both groups, there were 3 students whose grade in Physics 150 was an A; all students completed the combined program. Results for students with a B grade were similar for both groups. For the Electronics group, 4 of the original 7 students completed the combined program; for the Civil/Mechanical group, 5 of the original 7 students with a B in Physics 150 completed the combined program. While only 2 of the original 14 students in the Electronics group with a C in Physics 150 completed the combined program, 12 of the original 16 students in the Civil/Mechanical group with a C in Physics 150 completed the combined program. Thus, many of the students in the Civil/Mechanical group categorized as underprepared at the time of their enrolment in the Access Program were achieving success in the combined program. For students who completed the combined program, their Physics 4 grades were mostly independent of their Physics 150 grade. Three students in the Civil/Mechanical group and 1 student in the Electronics group whose first grade in Physics 150 was a C achieved A grades in Physics 4.

CHAPTER 5

SUMMARY AND DISCUSSION OF RESULTS

Introduction

This study was a research and development project with the goal of evaluating the history, curriculum, and instruction for two physics courses that would enable the revision of the instruction as part of a multi-year, curriculum development cycle. While physics education research results provided background and guidelines to undertake these tasks, the unique nature of the Access Program, the diversity of students in the program, and the lack of previous studies about these students limited comparisons to established findings. Thus, the research and development were exploratory in nature; and the data and results provided a basis for describing the program and instruction that could be used for future studies of this program or in alternate settings where similar difficulties exist.

The Access Program was initiated to provide opportunities for nontraditional students to meet the normal entry requirements (high school graduation) for the engineering technology program. The physics courses were traditional and, in common with most introductory physics courses, appeared to have the goal of preparing students for higher-level physics courses. No specific consideration was given to nontraditional students in the physics classes — many of whom were part of the large percentage of students who dropped from the program. A learning skills workshop was part of the Access Program but was restricted to immediate needs of students; while providing an important resource for students, it had not reduced the high attrition rate. This high attrition rate did not appear to be a cause for concern with the faculty or provide impetus for curriculum evaluation or development. This study provided an opportunity to address broader issues and formulate results for curriculum and instructional development in these and other introductory physics courses that were not achieving course goals.

The complexity of a classroom environment usually results in challenges in interpretation and presentation of results. While a narrow, particularly quantitative analysis is valuable in situations where previous results provide guidance for future research, in this study the lack of comparable programs or previous studies suggested a broader approach. The ongoing debate in the PER community about the use of scientific research models for physics education research influenced the decisions for this study. Scientific research is most often presented using quantitative data to substantiate claims with some measure of uncertainty related to the validity of results. As in previously unstudied areas, models may represent a very simplified representation of a complex system with large uncertainties in results. The use of descriptive and anecdotal information is not part of scientific research where most often there is instrumentation that acquires quantitative data. Alternately, analytical or numerical mathematical models provide a quantitative basis for scientific research from a theoretical perspective. PER has been recognized as a research discipline for about 50 years, as compared to 300 to 400 years for physics. The PER community, while growing, is microscopic compared to the scientific community and has not yet acquired similar status or structure. While results from PER formed the foundation for this study, it was more difficult to interpret the results in the same context.

Parallel situations between medicine and education have been discussed. In a review of anecdotal information in health care, Enkin and Jadad (1999) provided cautious justification for using anecdotal information when "(formal) research is shown to be irrelevant, inconclusive, biased or imprecise" (p. 965) and that in situations where no formal evidence can be found, then anecdotal information provides the best and only information on which to base understanding and decisions. The inclusion of anecdotal information can be justified for this study since the Access Program was sufficiently unique that integrating these results into the body of knowledge from PER proved very difficult. This discussion is a best attempt at presenting the mixed-method data and interpretation to use as a basis for future research and in a helical spiral of curriculum development.

Year 1: Historical Results

Experience in offering the physics courses of the Access Program provided anecdotal information about attrition rates that required validation. Although the Access Program was intended as a one-year preparatory program, data from the previous five years showed a wide range of individual student enrolment with many students repeating courses, leaving and re-entering, or dropping from the program.

The anticipated completion time for the Access Program was nine months (3 terms); but for the 52% of students who completed the program, the average completion time was 3.4 terms. Many students who ultimately dropped from the program either failed or dropped physics courses and then repeated those courses. Instructors had observed in previous years that students who entered the program directly from secondary school or from engineering-related jobs were more likely to pass their first physics courses. The students entering directly from secondary school can be described as traditional students. The successful students whose background included jobs with engineering applications may have had the attributes of traditional students and a rich store of relevant experience to supplement any currency in these attributes. Students most likely to be described as nontraditional students were less likely to pass the first physics courses or to succeed in the combined Access/Technology Program.

The historical data provided a sample of students (N=130) that had been enrolled in the Access Program in the previous five years. Twenty-four percent (24%) of these students completed the combined Access/Technology Program. Of those students who completed the Technology Program, 52% had an A grade in their first physics course (Physics 150) while 38% had a B grade and 10% a C grade. These results indicate that factors for success were most likely prior knowledge in physics and ability to achieve early success in a traditional academic environment. A linear fit to the grades data showed that a minimum grade of B- (4.2 out of 9) in Physics 150 was predictive of ultimate success in the Technology Program. The historical data also confirmed the strong relationship between mathematics and physics grades. Thus, successful students with good backgrounds in mathematics and physics were those most likely to succeed.

The results showed that the traditional philosophy and goals for the physics courses of the Access Program were ineffective for nontraditional students, and it was proposed to alter the curriculum or instruction to better meet the needs of these students. Several factors constrained any changes: (1) a lack of PER results directly related to nontraditional students, (2) no guiding principles from PER on philosophy or goals (Meltzer, 2004), and (3) institutional constraints and departmental attitudes that made curriculum change very difficult. Consequently, an alternate classroom setting for the existing curriculum provided the best opportunity to accommodate a wider range of academic backgrounds and greater opportunities for students whose background did not prepare them for the traditional curricula of courses in the Technology Program. Although the Civil/Mechanical and Electronics students had different mathematics sequences, it was decided that the classroom setting and instruction for the physics courses would be the same for both groups. While a more flexible curriculum might have achieved results that were judged to be of greater benefit to a larger number of students, there was concern that such a curriculum would not prepare students for the Technology Program.

Physics 150/151 Course Development

The topics for the curriculum of the two physics courses had been the traditional topics represented in most introductory physics textbooks. The course book chosen provided the necessary conceptual items with a wider range of examples and problems used in previous years. While no changes were made to the topics covered in the course, the focus was changed from transfer of knowledge to the acquisition and development of necessary skills for undertaking future courses. Broader goals, such as improving scientific literacy or improving conceptual understanding, were limited due to the challenges of instructing underprepared students and preparing them for the Technology Program in the two or three terms of the Access Program.

Results from all areas of educational research show that students are not highly engaged during traditional lectures; therefore, lecture time was decreased. A primary objective was to maximize the time students were engaged in tasks related either to necessary prerequisite content knowledge or for improving their learning skills in science, mathematics, and engineering contexts. The implementation of the revised curriculum was expected to improve the academic success of the weaker students while not harming the more successful students. In order to evaluate the effects of mathematics on success in physics, the sequence of the mathematics and physics courses was changed for the Civil/Mechanical students. It was expected that their academic success in physics would be enhanced by an earlier exposure to mathematics.

Results for Year 2

The second year of this study was used to implement the revised curriculum and gather data that could be used to compare academic success rates with the historical rates for the two groups of students. The results were interpreted for (1) calculating success rates in the Access Program for Civil/Mechanical and Electronics students and comparing to rates from the historical data, (2) changes in the academic achievement in the first two physics courses, (3) comparison of mathematics and physics grades in the Access Program, and (4) other qualitative factors related to achievement in physics.

Success Rates

The data for academic progress showed that in the years of this study more students progressed to the higher-level physics courses and completed the combined Access/Technology Program. The improvement for Electronics students was noticeable;

while for Civil/Mechanical students, the improvement was dramatic. Figure 8 shows results for the two groups as a percentage of the number of students who completed Physics 150.

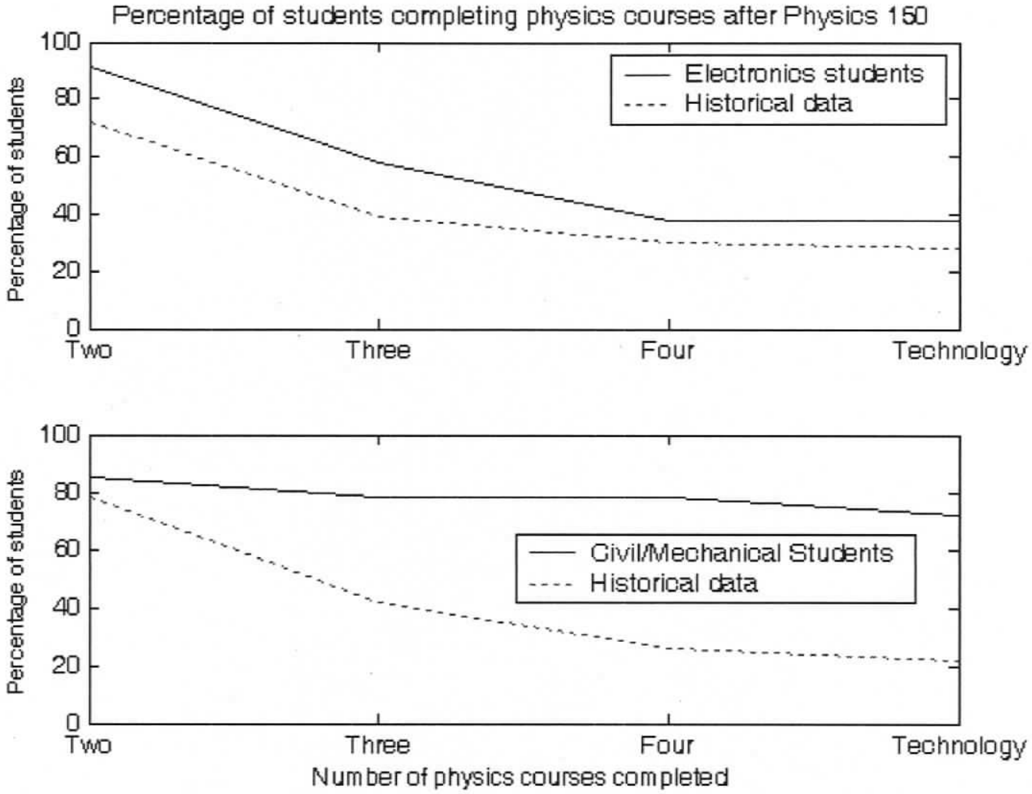

Figure 8: Percentage of students who completed each physics course subsequent to Physics 150 and who completed the Technology Program.

The increase in number of students completing Physics 151 in the year of this study was a consequence of the decision to modify the evaluation procedures in Physics 150. Students who in the past would likely have dropped from the program due to failing grades on tests and mid-term examinations in Physics 150 were given greater time and opportunity to acquire the skills necessary for academic success. The persistence of the high retention rates, particularly for Civil/Mechanical students, through the three subsequent physics courses and through completion of the Technology Program indicates improvement due to causes other than the assessment method of Physics 150.

Several factors other than changes to the instruction for the two physics courses must be considered when evaluating the higher proportion of students who completed the Access Program and enrolled in Physics 3 of the Technology Program — 58% compared to 39% historically for Electronics students and 73% compared to 23%

historically for Civil/Mechanical students. The different structure for Civil/Mechanical students — who were in the second of three terms and who had completed their first mathematics course at the time they were enrolled in their first physics course (Physics 150) — may have resulted in several possible and interacting causes for the improved retention. The extra term of studies for Civil/Mechanical students may have resulted in three effects:

1. The weakest students had already dropped from the program in the first term. Although no data were available for these students, there were four students in the Civil/Mechanical Access Program in the first term who did not register for Physics 150 in their second term of studies.
2. Civil/Mechanical students should have had improved academic maturity as a consequence of the extra term's work.
3. Civil/Mechanical students should have had fewer difficulties in relating their mathematics knowledge to the problems encountered in their physics classes.

In making an estimate for the effect of the instructional changes to the two physics courses of the Access Program, the graphs in Figure 8 can be interpreted to determine the effect due to the different program structure for the Civil/Mechanical group and the effect due to the changed instruction for both groups. The improved retention for Electronics students for Physics 3 may represent the improvement due to instruction for both groups. For Electronics students, the increase was 19% compared to 35% for Civil/Mechanical students. Thus, the remaining 16% for Civil/Mechanical students may represent the residual effects from their first term of study. For subsequent terms, when improvement for Electronics students declined to 8% for Physics 4 and 11% for completion of the Technology Program, the number of Civil/Mechanical students continuing in the program remained very high. It is likely that several factors related to the extra term in the Access Program for these students contributed to this high retention rate. Additional time with less academic pressure in the first term provided Civil/Mechanical students with the opportunity to develop academic skills and maturity resulting in improved self-concept and academic identity. These students may have been better equipped to take advantage of the alternate instructional setting of the revised physics courses.

The outcome of administering the Force Concept Inventory (FCI) to the students is difficult to interpret in comparison to published results. The high precourse scores and the high values for gain <g> were above the values expected for students in the Access program. The published data show scores comparable to those of the Access students from university students in the United States. While 2 Electronics students achieved gains over 70%, 13 Civil/Mechanical students achieved gains of over 70%. The 70% threshold for <g>, widely observed in published data, is seen as the limit to pre-post testing gain. The Access students were different from the students represented in the published results in two ways: (1) they were enrolled in an engineering program, as compared to students' PER results who were in general studies at universities, and (2) the published results are for students in the United States. The results from this study may reflect different secondary school science curricula in the United States and Canada; however, this is unlikely since the high FCI scores from this study were poorly correlated ($r = 0.045$ @ $p > 0.5$) to years since enrolled in school. The high FCI scores for Civil/Mechanical students may have been affected by the interests of students enrolled in the program. In previous years, it had been observed by instructors that Civil/Mechanical students had interests and previous employment experiences related to engineering while Electronics students were most often students with better academic records in secondary school mathematics and science courses. The absence of topics related to electricity and magnetism, which may have been of greater interest to Electronics students, may have also affected the results of Electronics students compared to the Civil/Mechanical students who could be expected to be more interested in topics from mechanics. The distribution of mechanics topics over two terms in Physics 150 and 151 may have also affected the results for the FCI gain <g>. Traditional introductory physics courses usually cover topics of mechanics in one term. The increased time in the Access physics courses allocated to mechanics and introducing one dimensional kinematics and dynamics in Physics 150 that were then revisited in Physics 151 where two dimensional problems were presented may help to improve conceptual understanding with consequential higher values for <g>.

Results for the MPEX Survey

Results of the MPEX survey are best interpreted in conjunction with the observations from previous years regarding changes in academic maturity of students as they progressed through the combined Access/Technology programs. Students in the early stages of the Access Program were often encouraged to be aware of the time commitments necessary for academic success. Many students, particularly those away from formal education for many years, were in a situation where effort and commitment to the academic program was in conflict with jobs and personal circumstances; these students may have been at the limit of their personal resources. Those students who remained in the combined program after one and two years often commented that the instructors' comments were acknowledged and validated only later in the program, when the required commitment to the academic program was much greater than that necessary for success early in the Access Program. However, these comments were from students who had succeeded and remained in the program and who were most likely to have the required resources and commitment for success when they first enrolled in the program. Students lacking these attributes perceived that there was a mismatch between the program's requirements and the minimal prerequisite requirements for enrolment. Although academic maturity has not been formally defined, instructors were aware of each student's combined attitude, motivation, and ability to undertake required work that was informally characterized as academic maturity. Instructors observed changes in students' attitudes and behaviour as they progressed in the programs. The average academic maturity of students in the combined Access/Technology Programs could be expected to increase as weaker students dropped from the program. However, all of the physics instructors had some experience in teaching undergraduate courses at universities and in university preparatory courses at this community college and observed higher improvement rates in Access/Technology students than observed in either of the other situations. These observations were reinforced by the results of Technology Program graduates who then enrolled in a bridge program where they undertook two terms of work to achieve entry to third year university engineering programs. The results for these students, in their third and fourth years of the university programs, were often as good or better than students from the four-year university engineering program, even though the students from the technology programs most often had not met the first-year admission requirements for university programs. Thus, it was expected that students' attitudes, as measured by the MPEX, should improve for the two reasons discussed and independent of changes to instruction. Since the MPEX had not been administered in previous years, there was no historical data for comparison to determine the effect of the changes to instruction.

MPEX – Independence

The results for Independence showed improvement that was consistent with comments from student journals about the relationship between motivation and achievement and personal responsibility for motivation. The improvement for both groups and the higher precourse scores for Civil/Mechanical students support the hypothesis of improvement in Independence and academic maturity for each subsequent term of enrolment.

MPEX – Coherence

Coherence provides a measure of how students relate concepts and applications in physics. Low precourse and postcourse values for Electronics students and very high precourse and postcourse values for Civil/Mechanical students indicated a difference in the two groups that cannot be accounted for by the previous term's work of the Civil/Mechanical group. Electronics students' postcourse scores are far below those of the Civil/Mechanical students' precourse results. The higher scores for Civil/Mechanical, as compared to Electronics, students may have been due to their greater awareness of the relationship of physics topics to civil and mechanical engineering applications. The overweighting of mechanics topics in the two physics courses had been speculated as the cause of negative comments from Electronics Access students in the past. Topics directly related to electronics were not included in the curriculum for the physics courses until the first term of the Technology Program.

MPEX – Concepts

The Concept results showed similar precourse scores for both groups with higher postcourse scores for Civil/Mechanical students. The relatively low precourse scores for both groups indicate a low level of concern for conceptual understanding that may be consistent with the students' low academic maturity. While conceptual understanding was a part of the instructional goals for the physics courses, there was greater focus on problem solving and improving mathematical skills in solving physics problems so there was limited expectation for improvement. The higher postcourse scores for Civil/Mechanical students may be related to other courses in their program or marginal improvement as a consequence of their additional term of work.

MPEX – Reality Link

It was expected there would be a strong positive correlation between the Reality Link and Concept categories. However, while the results for Civil/Mechanical students are consistent with this supposition, the precourse results for Electronics students appear to be opposite: low Concept scores with high Reality Link scores. The low precourse scores in both categories for Civil/Mechanical students are also difficult to interpret in the context of their extra term's work, but may be related to the absence of a science course in their first term. These results suggest a different interpretation for the

MPEX survey questions by these students than might be the case for physicists. The MPEX statements for Conceptual (Appendix 2; Questions 4, 14, 19, 23, 26, 27) relate explicitly to conceptual ideas and problems encountered in a physics class; while for Reality Link (Questions 10, 18, 22, 25), the MPEX statements are about the relationship between physics and real situations. It is difficult to speculate about why Electronics students might have different precourse attitudes for the two categories or to explain the very high postcourse Reality Link score for Electronics students.

MPEX – Mathematics

For this measure of students' awareness of Mathematics as a tool for representation of physical relationships, the average precourse results for the Electronics group (3.3) were higher than the Civil/Mechanical group (2.9) but overall were not significantly different. Both groups showed improvement between their precourse and postcourse scores. The statements from the MPEX survey for Mathematics focus on the use of formula and equations in physics problems. It is a common perception of physics instructors that students have difficulty relating the mathematics from their mathematics class with the same topic applied to problems in their physics class. The precourse scores may reflect an attitude of this independence between mathematics and physics. The lower precourse scores for Civil/Mechanical students may justify this conclusion since the mathematics course prior to their first physics course was largely a review of mathematical topics from the secondary school curriculum with limited applications in the problems of Access Program physics courses. The revised Physics 150/151 should have improved this attitude to the relationship between mathematics and physics. Both groups showed improved postcourse scores (mean = 3.5) indicating that they were beginning to relate concepts from mathematics to problems they would encounter in physics and to recognize the interrelationship of mathematics and physics.

Student Journals

Most data collected for this study were quantitative; and while providing evidence about the students and the program, there were difficulties in using these data to contribute to evaluating the program or suggesting improvement as part of the helical spiral of curriculum development. The students' journals provided an overview of their sentiments and attitudes related to their academic progress and issues of the curriculum and instruction. The journal entries provided corroborating evidence for faculty opinions that were based on observations and informal conversations with students. The general tone of students' comments remained relatively constant over the two terms of the Access Program, i.e., a negative tone in both written comments in the journals and in-class discussions of the journal topics. Civil/Mechanical students were observed to be more positive than Electronics students. This was in contrast to other years when the faculty perceived that Electronics students had a more positive attitude toward the program while Civil/Mechanical students were more often the source of negative attitudes and complaints. Student comments were classified to evaluate external factors, motivation, and course structure.

External Factors

Most comments in the External Factors category concerned jobs and funding and were often related to comments in the Motivation category about available time. Weaker students appeared to be more aware of time and motivation issues. These students were also most likely to have external job commitments that affected their academic progress. Journal entries, particularly in the second term, indicated that weaker students were aware of the decreasing probability of continuing to the Technology Program even though they may have achieved the minimum grade(s) required for admission. In common with other engineering programs where students are in a set program, there was a very strong, feedback network of students in all three years of the Access and Technology Programs. Students in the Access Program were very aware of the academic difficulties of students in the Technology Program and of the perception of increasing academic demand and associated difficulty in each subsequent term of both programs. Comments from stronger students tended to be directed to self-improvement even when achieving very high grades, while weaker students' comments were more often simple statements of their poor probability for academic advancement.

Motivation

The most common attitude expressed by faculty toward the academic coverage of the program was that the two physics courses must provide the necessary prerequisite knowledge so that students could undertake the physics courses in the Technology Program. The high failure rate did not seem to affect this attitude. The success of students who ultimately graduated from the combined Access/Technology Programs was used as a benchmark for the program, even though there was acknowledgement by faculty that many of these successful students could have achieved success if they had entered the Technology Program directly, without the benefit of the Access Program. While the majority of Access Program students were non-traditional, some students were academically better prepared than others. Students' perception before starting the Access Program was that most students would ultimately be prepared for and accepted in the Technology Program. The reality of the Access Program was that there was a minimum level of academic preparedness below which a student was unlikely to achieve academic success. The journal entries, which began several weeks after the start of the first term of the Access Program, in many cases reflected sentiments of frustration related to lack of success. The very low attrition from Physics 150, as a consequence of the new grading practice, resulted in more students remaining in the program when previously they may have failed or dropped from the program during the second term. The negative tone of Electronics student comments may have been partially due to a greater number of weak students in the class. In contrast to previous years, Civil/Mechanical students were observed as more focused on academic success than Electronics students. The weaker Civil/Mechanical students also appeared to receive more support from stronger students than was the case in the Electronics class where weaker students tended to form groups independently from groups of stronger students.

Structure

The most common journal entries for the Structure category related to the instructional environment, textbook, laboratory exercises, and a variety of comments about teaching and learning in the physics classes. No comments were written about topics included in the curriculum. The students provided conflicting evidence for acceptance of the teaching environment. Many students liked the increased allocation of time for working on problems; this sentiment was widely expressed in discussions, although there was also discussion on wasting time in an unstructured setting. Some students, particularly those achieving better results, indicated a preference for more lectures. This situation confirms similar attitudes from studies in the PER literature where the most successful students were reluctant to embrace alternate teaching methods and perceived lectures as an effective mode for learning.

Comments about evaluation were mixed. Regardless of the academic strength of students, most wanted more grading and recording of results from assignments and tests. While formative evaluation was discussed and recognized as a valuable mechanism for learning, students were anchored to a belief that grades and advancement depended on the accumulation of marks.

Comments about the structure of the classroom reflected the students' attitude toward traditional academic courses where transmission of knowledge through lectures is the dominant instructional method. The revised instructional setting provided opportunities for students to be more aware of the relationship between teaching and learning and alternate forms of evaluation. Students were generally positive about increased opportunity for engaged learning yet commonly expressed the sentiment for increased lecture time.

In previous years, student comments were very negative about the laboratory component of the physics courses, which was strongly confirmed by their journal comments. While the attitude of instructors varied, there was a general sentiment that the laboratory setting provided a necessary function in relating theoretical components to applications. The role of measurements in physics was often expressed as a fundamental reason for requiring students to undertake laboratory sessions. However, there was a common admission from faculty that the attitude of many students toward laboratory exercises was negative and that the laboratory component of the physics courses was not achieving the results many faculty expected. The reduction in formal laboratory reports received widespread, positive support from students. It was hoped that reducing the emphasis on laboratory reports would engage students in more self-directed, exploratory work. Although it was judged by the instructor that the students were more engaged than in previous years, many students expressed frustration with lack of explicit instructions on how to undertake the laboratory exercises.

The journals, when combined with class discussions and observations, can be used for a broad interpretation of students' attitudes toward the revised instruction. Overall, the sentiment was positive with some reservations about an educational environment that was outside the experience of most students. Since the other courses in the program were taught using traditional methods, many comments compared the physics courses to those courses. A common sentiment — expressed in several comments and observed in several PER studies using alternate curricula — related to students' perception of efficiency of learning. Many students perceived that it would have been better to use class time to help them overcome specific problems, often by showing a solution. Achieving grades on tests and in the course to meet admission requirements of the Technology Program may have overwhelmed other longer-term goals, such as acquiring skills and attitudes necessary for ultimate success in the Technology Program.

The Access Program provided admission to postsecondary education for academically weaker students who would not normally be admitted to college or university physics courses. A sentiment was expressed by many of these students that there was a lack of appropriate academic support. Their personal situations, particularly the requirement for employment in addition to enrolment in the program, were expressed as cause for limiting academic success. This sentiment was much more common for Electronics students. In contrast to Civil/Mechanical Access students (most of whom were confident about advancement to the Technology Program), many Electronics students were aware of their low probability of success and had begun to make alternate plans long before completion of the Access Program. These differing attitudes were reflected in comments from the two groups.

Average students appeared to be more aware of the need for self-motivation as well as their opportunity to succeed in the program. Although the instructional changes had focused on average students who were judged as most likely to benefit from the changes, there was no clear indication that students perceived a better educational environment than other classes that were traditionally structured, i.e., lectures and tutorials.

Discussion

Physics courses in senior secondary schools and postsecondary institutions are often taught in a traditional manner, i.e., the dominant form of instruction is the transmission of information through lectures, problem sets and assigned readings support and complement the ideas presented in lectures, and laboratory components are often confirmatory exercises. Curriculum, instruction, and textbooks are designed for students to acquire the necessary foundation to undertake more advanced physics courses and to ultimately become professional physicists — even though fewer than 5% of students who undertake introductory physics courses enroll in higher-level courses. These students are most often traditional and successful, and their continued success is used as evidence of success for the physics curriculum and instruction. Many students, regardless of their degree of success, and most physics instructors have strong convictions that traditional instruction is effective. Even though results from PER apply mostly to university (i.e., traditional) students, there is consistent evidence of limited improvement in students' conceptual understanding after taking a physics course.

Although there have been no long-term studies on retention of factual information, there is some evidence that students understand and retain very little of the factual knowledge covered in introductory physics courses. In studies of student attitude to physics, there is evidence that enrolment in introductory physics courses often results in a decrease in desirable attitudes. Yet introductory physics courses remain as required courses for many students in postsecondary programs, including the Access Program of this study. In spite of the apparent negative outcomes, there is an expressed conviction by faculty members that the experience of undertaking an introductory physics course is beneficial to students.

Using quantitative data to investigate factors that affected achievement, this study also used qualitative data collected from student journals to investigate more subtle relationships between the students and their achievement in the Access and Technology Programs. This objective developed into a descriptive process to integrate student comments with anecdotal information about students from previous course offerings and with student achievement. This approach to evaluating physics courses had not been observed either in the PER literature or for this Access Program. While these results are both tentative and tenuous due to the context, sample size, and limited data, they provide some insight into the complex relationships between teaching, learning, student achievement, and personal characteristics of at-risk, non-traditional students that do not appear to have been fully considered in PER literature or by physics instructors.

In most physics classes, instructors are aware of and informally divide students into groups: academically strong or weak, attentive or disruptive, engaged or inattentive; they also evaluate each class in comparison to others they have taught. Although there was no direct interaction between the Civil/Mechanical and Electronics groups, the students were enrolled in the same courses. In common with most engineering programs, the high number of contact hours per week reinforced an academic environment. The Access students' contact with Technology students made them aware of the increasing academic difficulty and high attrition rate in the Technology Program. Before completion of the Access Program, many students had decided to pursue programs other than the Technology Program. These decisions also affected students' attitudes toward the physics courses and the Access Program. This situation produced varying degrees of conflict between different groups of students and the instructor about the role of curriculum, instruction, evaluation, and assessment to a much greater extent than would normally be the case in a typical, introductory physics class.

Student probability of long-term success can be used as the basis for evaluating the Access Program and making recommendations about the program. The Access Program was initiated to provide an opportunity for nontraditional students. Students most likely to achieve success in the program were the most traditional students with recent experience in formal education, good learning skills, good mathematics skills, but who frequently lacked the prerequisite physics course required for direct entry to the Technology Program. Previous academically-successful students had better than average grades in their first physics course. Early success appeared to provide a sound conceptual and skills foundation and strong self-concept for future studies. The traditional curriculum and instruction of the physics courses prior to the year of this study were adequate for these students. A requirement for the revised instruction for this study was that this group of students would not be negatively affected. The improved retention results for both groups of students (recent high school graduates and early success students) confirmed this outcome.

The remaining students were categorized into two groups: those who could benefit from the revised instruction and those who were unlikely to achieve success. Using the model of triage from medicine, students with C or D grades in their first physics course were least likely to survive in the program; it would have been inappropriate to develop an instructional program for these students. The results for Electronics students (2 of 14 who completed the Technology Program) indicate that the revised instruction for the physics courses did not improve outcomes for most students in this group. Yet the results show dramatic improvement for Civil/Mechanical students, where 12 of 16 completed the Technology Program. Students' scores on the Mathematics 10 precourse test provides evidence for the minimum level of mathematics knowledge and skills that may have contributed to this result. Five of 26 Civil/Mechanical students had scores below 30% on this test, while 14 of 24 Electronics students were below 30%. The threshold mark for this test was set at 50% to indicate ability to undertake the problems encountered in Physics 150. Nineteen Civil/Mechanical students scored higher than 50% while only 4 Electronics students achieved this threshold score. It is likely that students with low mathematics scores would have great difficulty with the multiple tasks of learning physics concepts while applying even simple mathematics. The problems presented in the physics courses often require mathematics at the level of the program's first mathematics course. However, Electronics students were enrolled in that first mathematics course concurrently with their first physics course, while Civil/Mechanical students had completed the first mathematics course at the time they started their first physics course. The better results for the 12 Civil/Mechanical students may have being affected by having successfully completing the mathematics course prior to their first physics course. Time to develop and integrate knowledge has been acknowledged as an important factor in both education research and PER. The Civil/Mechanical students were given time and opportunity that were not available to the Electronics students.

Final Remarks

This study was the first formal study of the Access Program. The physics courses had been offered for over five years; and the information and ideas accumulated by faculty, while anecdotal, provided a representation of the students and program. The nature of the study allowed for latitude in interpretation to include more conjecture than primary interpretation of the data might have justified. An objective of the study was to provide the initial steps in a multiple-year, curriculum development cycle. In many areas of engineering, an iterative cycle requires an initial process called bootstrapping. The results of this study indicate that it was possible to reduce the very high attrition in the combined Access/Technology Programs. The low attrition for Civil/Mechanical students had not been observed in the past. While it is not possible to be specific about causes, these results may provide a starting point for curriculum development opportunities and suggestions for specific research programs, as well as proposals for restructuring the Access Program. Many of these ideas replicate discussions, ideas, and proposals for changes to the Access Program that had not been pursued previously. In the context of a bootstrapping process, the results of this study could provide a new base line from which curriculum and instructional reform could proceed — an opportunity that did not appear possible in the past.

One solution to high attrition rates is the use of pre-course testing to restrict entry to the program to those applicants most likely to succeed. Although this would increase success rates, it would most likely reduce the number of students to a level beneath the administrative requirement for offering the program. Alternately, from the perspective of reducing the distribution of students in the class and thus increasing attention that weaker students receive from the instructor, a pretest could be used to prohibit entry to those students who would likely achieve success without benefit of the Access Program.

This would also reduce the number of students in the program and at the same time might increase attrition rates by eliminating stronger students. A proposal had been made previously to adapt the Access Program's admission policies so as to delay entry for students with better academic records. This would have allowed the first term's curriculum and instruction to better meet the needs of weaker students. In order to avoid funding problems by maintaining the same faculty/student ratio over the three terms of the Access Program, it would have been necessary to combine the Electronics and Civil/Mechanical students into one class for the first term. This proposal was not pursued because of departmental resistance to combining these two groups of students. Among other proposals was a plan to initiate a new, one-term, program prior to the Access Program to provide general academic and learning skills to students identified as unlikely to achieve success. This program was informally referred to as the 'Pre-Access Access Program'. Funding was not available for this idea. Thus, it was apparent that alternate solutions were necessary to accommodate the wide-ranging academic abilities of students entering the program.

Mathematics skills and knowledge play an important role in determining academic success in this combined program. Since many students entering the Access Program were identified as lacking necessary mathematical skills, the curricula of the mathematics and physics courses could have been adapted to better suit their needs. Existing mathematics courses provided this function but were not deemed suitable for the Access Program where the expressed purpose was to prepare students for the Technology Program. An institutional barrier also existed that limited changes to curricula. All courses were required to provide academic links to prior and subsequent courses so that any course provided prerequisite credit for higher-level courses. Proposed changes to the mathematics courses of the Access Program would have violated this principle, particularly since Access students would enroll in mathematics courses of the Technology Program with well-defined, prerequisite requirements.

The contrasting results for Civil/Mechanical and Electronics students provide the robust results for suggesting changes to the program or for the instructional setting of the physics courses. While the effects of the extra term and the prior mathematics courses for Civil/Mechanical students cannot be separated, it is also not necessary. It is clear that these results provide evidence for changing the Access Program to three terms for all students and scheduling the physics courses in the second and third terms. However, in the year following this study, government funding for technology programs was revised; the College restricted funding for the Access Program, which reduced the program to two terms. Thus, the opportunity of repeating this study over three terms for both groups was lost. It was, therefore, necessary to evaluate the improved outcome for Civil/Mechanical students to suggest changes that could be implemented in a two-term program.

Several alternate proposals were formulated that combined research possibilities with varying degrees of change to physics instruction and to the Access Program structure. As in the setting for this research project, the probability of implementing any change was greatest for instructional change and least for any proposal that required institutional approval. In the year following this study, the Civil/Mechanical Access Program was reduced to two terms, with mathematics and physics courses in both terms as for the Electronics Program. At the same time the instruction returned to that prior to the year of this study. Thus the opportunity exists to study the effect of the first and additional term for Civil/Mechanical students and of the alternate instructional setting in the physics courses. The data for attrition and academic progress are available. It would be possible to develop inventories or collect data to better differentiate the effect of prerequisite mathematics knowledge as a separate factor in determining academic success and progress.

The results of this study provide some evidence to confirm improved learning as a consequence of the changes to physics instruction. The changes did not appear to have any negative consequences relative to the traditional lecture/laboratory/recitation model. The small class sizes in this program did and continue to provide the opportunity to maximize student/instructor interaction that is not available in large classes. Innovations from PER investigations in small classes may provide teaching models that could be implemented with positive results for student outcomes, but measuring techniques do not exist to effectively measure the value of different instruction. Effective instruction is difficult to define and measure. It has not been proven that traditional instruction results in more or less long-term conceptual change than innovative instruction. The present situation for proposing a research approach for the Access Program is that the objectives do not match those of the majority of PER. The goal of PER, improving conceptual understanding, is difficult to implement where attrition rates as high as 75% indicate that more fundamental curriculum change is necessary for the majority of students.

A recognized failure of PER has been the lack of data from more than individual situations or of any longitudinal studies. The FCI, or another similar test of mechanics concepts, has been used for about 20 years without psychometric evaluation or testing. The MPEX is one of a few inventories to measure attitudes. While the data collected from these inventories are valuable, there is no model for physics education that can be compared to scientific disciplines where the data are the basis for numerical or theoretical models. In most scientific research, there is limited need to justify the reasons for undertaking research; investigations are undertaken because there are questions to ask and answer. This approach, which is also common in PER, has not produced equivalent results in physics education as it has in science and engineering. Discussions and research into philosophy of education have not significantly affected PER and are not part of the structure of physics education. Proposals for implementing a physics curriculum that focuses on objectives different from preparing students for careers in physics have been discussed here. There is no indication of any impact on PER from those proposals. Due to the unique situation of the Access Program, it might be important to address these issues before proposing new instructional changes and research. Most introductory physics courses are undertaken by students as terminal courses required in disciplines other than physics. In comparison, the physics and mathematics courses in the Access Program have major consequences for those students. The acceptance of the very high attrition in the program in the past did not acknowledge the consequences for students who failed or dropped from the program. Inadequate discussion has occurred to evaluate the role of the physics or mathematics courses in the Access Program, other than as academic prerequisites for courses in the Technology Program. The exceptional results for the Civil/Mechanical students in this study may provide an opportunity for discussion that could lead to a new curriculum and instructional model to accommodate a wider range of students and provide true access to the Technology Program.

In this study, academic achievement and success were defined as success in physics courses and in the combined Access/Technology Program. The success in re-introducing students to postsecondary education was not considered. An alternate study could be undertaken to measure this outcome. Although no data has been collected to measure this effect for students who did not achieve success in the combined Access/Technology Program, the experience of previous years was that many students who dropped from either program enrolled in other programs. Thus, the 25% retention in the Access Program represents a very narrow definition of success. It is likely that the success of the Access Program in providing other educational opportunities is very high. The role of the physics courses in this broader definition of success and in providing students with skills and knowledge for programs other than the Technology Program should also be investigated.

Physics Education Research Today and Future Research Opportunities

In this study, the results of research within the PER community as well as from others studying physics, general science, and education have been evaluated in the context of the Access Program, which presented a different context than the original studies. The completion of this study provides an opportunity to reflect on how its outcomes relate to physics education research in a more global context and for a wider group of students, including traditional physics majors, engineering students, students who require physics service courses, and the new array of nontraditional courses with underserved and underrepresented students.

Extending PER Beyond Traditional Students and Curriculum

Although results from the PER community dominate the reference list in this study, many other sources of physics education research have been cited that, while not in conflict with PER studies, differ in focus and objectives. The majority of PER research is aimed at improving conceptual understanding of traditional students in introductory physics courses. Many instructional methods have been developed that have been shown to improve conceptual understanding, in most cases by increasing student involvement in the learning process. A stated goal of the PER community is to use scientific methods for educational research and to use these results to increase the credibility of PER with the general physics research community who will then adopt new methods for teaching physics courses. However, the focus of most PER and most physics instructors is to improve instruction for traditional students in traditional courses with the traditional curriculum. An alternate perspective, which has only isolated support, is that the traditional curriculum may not be appropriate for the majority of students who take a single introductory physics course and will not graduate with physics degrees or for nontraditional students seeking entry or re-entry into science- and engineering-related programs or careers. Currently, PER qualitative and anecdotal data indicate a poor match between many students and the curriculum, while results from alternate instruction indicate improved results for a wide range of students. The evidence to support these claims is dominated by results from precourse and postcourse application of the FCI or alternate tests for conceptual understanding in mechanics in which little growth is documented. The breadth of research topics is relatively narrow when compared to the wide range of proposals and innovations related to curriculum change in the 1990s. Marchese (2006) stated:

> The final two decades of the last century — the 80's and 90's — were a remarkable period for innovation … So what happened? ... The fact is, it's hard to know for sure where we are with undergraduate reform, hard even to know what evidence would assess our progress. … Good as yesterday's ideas may be, I fear we are not asking hard, new questions … (pp. 1-2).

It is, however, noteworthy that response to this article at the Carnegie Foundation's website (http://www.carnegiefoundation.org) provides a vigorous challenge to the idea that innovation has stalled. The growth of the PER community is helping to address the problem of attitudes within the general physics education community that has limited implementation of alternate curricula. A cool or negative climate to the 1990s' proposals may be a reason why reform appeared to stall. This study targeted a specific group of students who were nontraditional and underprepared. However, the Access Program instructors could best be described as traditional and, as a consequence, were reluctant to allow curriculum changes that may have been more appropriate for the nontraditional students.

Matching Curriculum to Students

Students who enroll in introductory physics courses present a wide range of academic and career goals. A curriculum that acknowledges and accommodates these differences may be more successful in improving outcomes for a broader range of students. Most introductory physics programs provide courses for three groups: (1) physics and science majors, (2) engineering students, and (3) nonscience students. The first group is being well served by research from PER groups. The second and third groups provide opportunities for future research, but different approaches may be appropriate for the two groups. The Access Program is unique, and its students do not easily fit into any of these groups.

Engineering Students

Recent efforts in engineering education by the National Academy of Engineering illustrate a new receptiveness in Faculties of Engineering to both curriculum change and alternate instruction. Although Faculties of Engineering restrict entry to their courses, unlike physics courses where a broad range of students are enrolled, there is also a different culture for education than is apparent in physics departments. In 1994, the Engineering Deans Council and Corporate Roundtable of the American Society for Engineering Education stated that, although engineering education has served the nation well, "there is broad recognition that it must change to meet new challenges." (Ambrose, 2006). A similar sentiment has not been widely expressed within the physics education community. While most physics instructors are aware of the differences between physics major and engineering students the curriculum and instruction in many physics courses are similar for both groups. While several physics textbooks have been designed for engineering students, the potential exists for greater change in physics courses to address engineering students' interests and improve outcomes without significant changes to the physics curriculum. Unpublished research in the Department of Electrical Engineering and Computer Science at Oregon State University indicates that reversing theory and applications can improve results. A concept named *platforms for learning®* provides an interdisciplinary foundation. In one case, a robot is used as the platform and the curriculum of different courses relate to components or systems of the robot. This approach presents an alternative to traditional physics instruction that students often perceive as unrelated to the real world. While engineering students may be aware of the relationships between physics and engineering, they do not always value the presentation of physics theory in a context that appears unrelated to the engineering curriculum.

Non-Science Students

Introductory physics courses for students outside the sciences are much more problematic. The Physics Education Group at the University of Washington developed the curriculum and resources for a physics course for elementary teacher education students. While the curriculum from the teacher education physics courses has not been adapted for introductory courses in physics departments, the Tutorials in Introductory Physics (McDermott, Shaffer & The Physics Education Group at the University of Washington, 2002) was a workbook developed using the principals developed in the elementary teacher education classes for students in either introductory algebra or calculus based physics courses. Several textbooks are available that stress conceptual understanding and their use is increasing. One such textbook is Conceptual Physics (Hewitt, 1997) appropriate at the introductory level but was not judged to be appropriate for use in the Access physics courses. Another PER based textbook is Physics: A contemporary perspective (Knight, 1997) for calculus based introductory physics courses. The expansion of the PER community and improved instructional methods justified by students' improved conceptual understanding have resulted in more textbooks that are founded on principals of PER. However, traditional textbooks continue to dominate introductory physics courses. Informal proposals for expanding the curriculum often include areas of physics that do not fit into the traditional set of topics. Biophysics and the physics of sports are often suggested as additional units of instruction, but resources to teach these are limited. Since these and other topics are not viewed as part of the traditional set of topics by publishers, resource development is not funded. The inclusion of either example may not be simple since both involve system analysis that is not part of the tradition of introductory physics education. The development of ideas for these proposals could more accurately be called educational reform (Dagher, 2004). The resources to undertake a project of this nature are significant. It is not clear why resources have gone into implementation of alternate instruction, e.g., at the Massachusetts Institute of Technology and Harvard University, but not into more innovative curriculum development. The Physical Science Study Committee (PSSC) program may be the only major example of physics education reform. Its focus was on high school students who would continue to university physics programs. Nothing comparable has been undertaken for other students in physics courses.

Interdisciplinary Education Relevant to Physics Education

While PER has included ideas from other areas, particularly educational psychology, the importation of alternate teaching philosophies and research approaches has been limited. Engineering education and medical research are two areas that may provide ideas for improved teaching and research in physics education.

In recent years the focus of teaching, evaluation, and assessment in engineering appears to have shifted from traditional lectures, tests, examinations, and assignments to greater emphasis on projects, teamwork, and formative evaluation. Evaluation and assessment are being used to measure attributes related to the practice of engineering rather than course content. While these alternate instructional practices may be difficult to implement in large-size introductory courses, they do provide models of instructional practice that should be investigated for use in physics.

Several parallels exist between physics education and medical education and research that may also provide research opportunities. In many medical schools, clinical models for instruction have replaced traditional instruction and rote memorization. Research studies with patients rather than controlled studies using animal testing are becoming more common. This situation presents many of the same difficulties as in education. Multiple factors affect the progress of a disease, and results may appear to be independent of treatment. However, for rare diseases, the patient population may be too small to use statistical methods thereby requiring in-depth case studies with limited numbers. The models and methodologies used in medical education and research may be adaptable for use in physics education and should be investigated.

Resistance to Change: A Culture of Traditions

These ideas for future research have not considered an important factor for physics education. Many physics instructors do not perceive that it is important to change the physics curriculum or instruction. Almost all students who graduate with degrees in physics have multiple opportunities for varied career paths (Benka and Lubkin, 2001). The exposure to a wide range of topics prepares them for advanced studies. They have had opportunities to develop skills in learning and problem solving valued in graduate studies. People in charge believe that changes to the traditional curriculum risk reducing or losing these benefits. Notwithstanding the evidence that most nonmajor students who undertake an introductory physics course do not benefit in the same way as physics majors, there is still a perception that these benefits exist and, thus, make it difficult to argue for major change. It is apparent that there has been little effect from previous proposals or studies for significant curriculum change.

The majority of physics instructors have a solid grounding in a wide range of topics in physics. A significant component of physics is mathematical derivations and development that is presented in a clear and concise manner. Yet the majority of students from outside the sciences do not have the necessary mathematical understanding required by the traditional physics curriculum and do not have scientific experience or skills. An alternate curriculum for physics courses that more realistically addresses the reality of these students' background may be the only solution to improve the outcome of their enrolment in a physics course. There is presently little support for this view.

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Appendix 1

Access Students Personal & Academic Histories

	Age	Years Out of School	Previous Mathematics		Age	Years Out of School	Previous Mathematics
Electronics Students				Civil/Mechanical Students			
Average	22.5	4.3		Average	26.3	6.1	
	19	2	0		42	14	0
	19	2	0		28	9	0
	24	7	1		33	15	0
	24	7	1		22	5	1
	29	11	0		21	1	1
	22	1	0		23	3	1
	26	7	0		31	6	0
	24	6	1		23	1	0
	20	3	0		30	13	0
	23	2	1		26	6	1
	20	2	1		22	5	0
	18	1	0		19	1	0
	23	6	1		18	1	0
	18	1	1		29	11	1
	28	7	0		34	11	0
	27	9	0		29	1	1
	18	1	0		32	8	1
	28	1	1		19	1	1
	23	6	1		28	9	1
	22	3	0		28	1	0
	18	1	0		24	3	1
	22	5	0		27	10	1
	23	5	0		22	3	0
	22	7	0		19	2	1
					27	8	1
					28	11	1
Note: For Previous Mat	0 = Previous mathematics course at or below Mathematics 10						
	1 = Previous mathematics course at or above Mathematics 11						

Appendix 2

Tests and Inventories

1) Gregorc Learning Styles Inventory

Directions

You must assess the relative value of the words in each group using your self as a reference point.

The words used in the Gregorc Style Delineator matrix are not parallel in construction nor are they all adjectives or all nouns. Just react to the words as they are presented.

Rank in order the ten sets of four words. Put a 4 in the box above the word in each set that is the best descriptor and most powerful descriptor of your self. Give a 3 to the word which is the most like you, a 2 to the next and a 1 to the word which is the least descriptive of your self. Each word in a set must have a ranking of 4, 3, 2, or 1. No two words can have the same rank.

SET 1	**Set 2**	**Set 3**	**Set 4**
objective	**perfectionist**	**solid**	**practical**
evaluative	**research**	**quality**	**rational**
sensitive	**colourful**	**non-judgmental**	**lively**
intuitive	**risk-taker**	**insightful**	**perceptive**

SET 5	**SET 6**	**SET 7**	**SET 8**
careful with detail	**thorough**	**realistic**	**ordered**
ideas	**logical**	**referential**	**proof**
aware	**spontaneous**	**empathy**	**attuned**
creative	**trouble shooter**	**innovative**	**multi-solutions**

SET 9	**SET 10**
persistent	**product oriented**
analytical	**judge**
aesthetic	**person oriented**
experimenting	**practical dreamer**

2) Math Review

Math Review

1. Evaluate a) $\frac{10^2}{10^5}$ b) $\frac{10^{-3}}{10^3}$ c) $10^2 \times 10^{-6}$ d) $\left(10^2\right)^3$ e) $\frac{3.4 \times 10^{-6}}{5.6 \times 10^7}$

2. Simplify a) $\frac{5(-8)}{(-4)} + \frac{(-4)(-6)}{3}$ b) $\frac{18}{(-5)} \times \frac{(-10)}{27}$

3. Evaluate a) $\left(\frac{3}{4}x\right) - 5$ for x = -12 b) $\sqrt{\frac{6 \times 3.4}{4\pi}}$

4. Simplify a) 5(4m-3n) - 8m - 7n b) $\frac{m}{\left(m/s\right)}$ c) $\frac{kg}{\left(kg/m^3\right)}$

5. Write an algebraic expression for three-quarters of a number, subtracted from ten.

6. Solve

a) 7 + y = -6 b) 5x-3 =2x + 6 c) $\frac{4}{3} - \frac{1}{2}x = \frac{2}{3}x$ d) 1.4x -3.6 = 0.4 (2x +1.5)

e) $\frac{r}{3} = \frac{8}{15}$ f) $\frac{19}{t} = \frac{57}{42}$ g) $\frac{r^2}{2} = 4.3$

7. In an orienteering exercise, Sharon's location is 3.2 cm from town A on the map. If the actual distance is 24 km, what is the scale of the map.

8. 24% of a number is 18. What is the number?

9. A patio table has a circumference of 36 cm. What is its diameter?

10. A pizza measuring 36 cm in diameter is cut into 6 equal pieces.
   a) What is the sector angle (of each piece)?
   b) What is the arc length of each piece?
   c) What is the area of each piece?

11. Evaluate $5x^2 - 2x + 9$ for x = -2

12. Expand (x - 4)(x + 11)

13. Factor a) $6m^2 - 15m$ b) $t^2 + 3t - 28$ c) $x^2 - 1$ d) $4x^2 - 49$

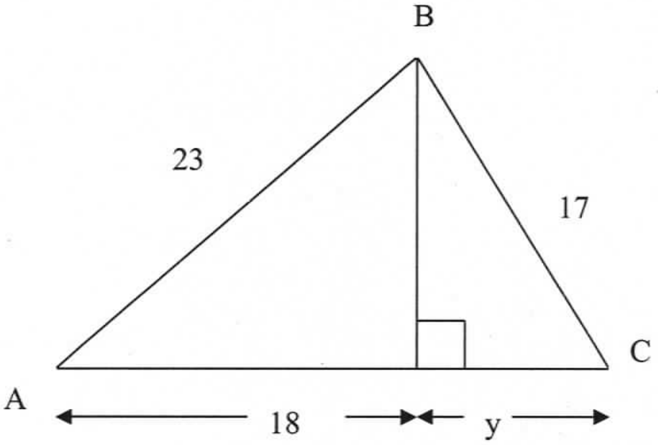
14. Simplify $\frac{4x^2y}{9xy^2} \times \frac{15xy}{16y^3}$

15. Simplify $\frac{3(2a-5)}{4a} + \frac{2(a+3)}{4a}$

16. Plot these points. A(-3,1), B(3,3), C(5,-3), D(-4,-6)
Join the points and name the figure drawn

17. Draw a graph for the relation y = 2x + 1

18. Find the value of x and y to one decimal place. Angle ABC is a right angle



19. How much oil is in a barrel of height 1.2m and radius 0.65 m?

20. What would it cost to paint the outside of 1200 barrels similar to the one in question 19 if the paint costs $ 8.40 per litre and 1 litre covers 9.5 m^2?

3) Maryland Physics Expectation Survey

Note: (June7, 2005) Questions 10, 18 and 24 have had the question statement reversed so that there is a consistent relationship to that of the expert responses.

Questions 1, 5, 9, 11, 28, 29, 29, 30, 32, 33, 34 were not used in the analysis.

University of Maryland Physics Education Research Group

Student Expectations in University Physics: MPEX

The Maryland Physics Expectations Survey

PERG Info | PERG materials | PERG HOMEPAGE | PER on the web | Resources on the web

Here are 34 statements which may or may not describe your beliefs about this course. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1: Strongly Disagree	2: Disagree	3: Neutral	4: Agree	5: Strongly Agree

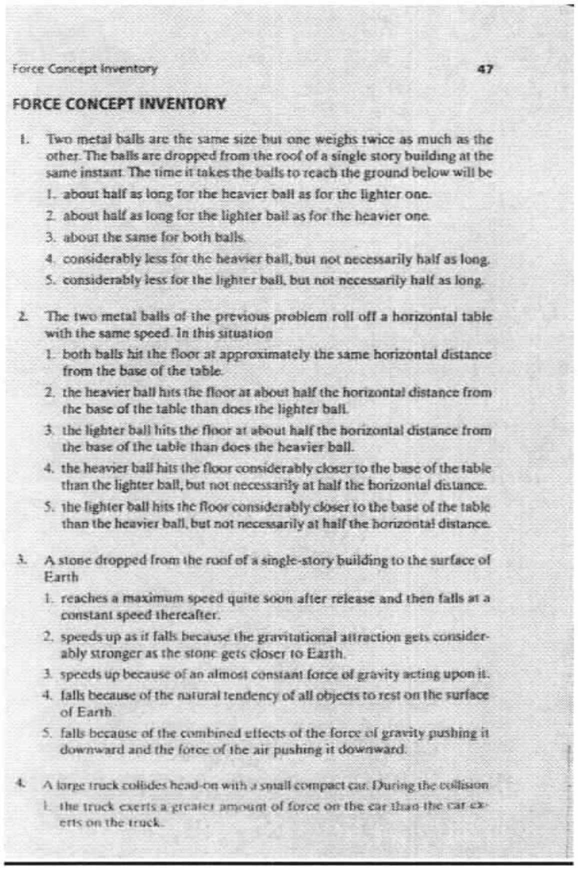
Answer the questions by circling the number that best expresses your feeling. Work quickly. Don't over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple. If you don't understand a statement, leave it blank. If you understand, but have no strong opinion, circle 3. If an item combines two statements and you disagree with either one, choose 1 or 2.

1	All I need to do to understand most of the basic ideas in this course is just read the text, work most of the problems, and/or pay close attention in class.	**1 2 3 4 5**
2	All I learn from a derivation or proof of a formula is that the formula obtained is valid and that it is OK to use it in problems.	**1 2 3 4 5**
3	I go over my class notes carefully to prepare for tests in this course.	**1 2 3 4 5**
4	"Problem solving" in physics basically means matching problems with facts or equations and then substituting values to get a number.	**1 2 3 4 5**

5	Learning physics made me change some of my ideas about how the physical world works.	1 2 3 4 5
6	I spend a lot of time figuring out and understanding at least some of the derivations or proofs given either in class or in the text.	1 2 3 4 5
7	I read the text in detail and work through many of the examples given there.	1 2 3 4 5
8	In this course, I do not expect to understand equations in an intuitive sense; they must just be taken as givens.	1 2 3 4 5
9	The best way for me to learn physics is by solving many problems rather than by carefully analyzing a few in detail.	1 2 3 4 5
10	Physical laws have little relation to what I experience in the real world.	1 2 3 4 5
11	A good understanding of physics is necessary for me to achieve my career goals. A good grade in this course is not enough.	1 2 3 4 5
12	Knowledge in physics consists of many pieces of information each of which applies primarily to a specific situation.	1 2 3 4 5
13	My grade in this course is primarily determined by how familiar I am with the material. Insight or creativity has little to do with it.	1 2 3 4 5
14	Learning physics is a matter of acquiring knowledge that is specifically located in the laws, principles, and equations given in class and/or in the textbook.	1 2 3 4 5
15	In doing a physics problem, if my calculation gives a result that differs significantly from what I expect, I'd have to trust the calculation.	1 2 3 4 5
16	The derivations or proofs of equations in class or in the text has little to do with solving problems or with the skills I need to succeed in this course.	1 2 3 4 5
17	Only very few specially qualified people are capable of really understanding physics.	1 2 3 4 5
18	To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.	1 2 3 4 5
19	The most crucial thing in solving a physics problem is finding the right equation to use.	1 2 3 4 5
20	If I don't remember a particular equation needed for a problem in an exam there's nothing much I can do (legally!) to come up with it.	1 2 3 4 5
21	If I came up with two different approaches to a problem and they gave different answers, I would not worry about it; I would just choose the answer that seemed most reasonable. (Assume the answer is not in the back of the book.)	1 2 3 4 5
22	Physics is related to the real world and it sometimes helps to think	1 2 3 4 5

	about the connection, but it is rarely essential for what I have to do in this course.	
23	The main skill I get out of this course is learning how to solve physics problems.	**1 2 3 4 5**
24	The results of an exam don't give me any useful guidance to improve my understanding of the course material. All the learning associated with an exam is in the studying I do before it takes place.	**1 2 3 4 5**
25	Learning physics helps me understand situations in my everyday life.	**1 2 3 4 5**
26	When I solve most exam or homework problems, I explicitly think about the concepts that underlie the problem.	**1 2 3 4 5**
27	"Understanding" physics basically means being able to recall something you've read or been shown.	**1 2 3 4 5**
28	Spending a lot of time (half an hour or more) working on a problem is a waste of time. If I don't make progress quickly, I'd be better off asking someone who knows more than I do.	**1 2 3 4 5**
29	A significant problem in this course is being able to memorize all the information I need to know.	**1 2 3 4 5**
30	The main skill I get out of this course is to learn how to reason logically about the physical world.	**1 2 3 4 5**
31	I use the mistakes I make on homework and on exam problems as clues to what I need to do to understand the material better.	**1 2 3 4 5**
32	To be able to use an equation in a problem (particularly in a problem that I haven't seen before), I need to know more than what each term in the equation represents.	**1 2 3 4 5**
33	It is possible to pass this course (get a "C" or better) without understanding physics very well.	**1 2 3 4 5**
34	Learning physics requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text.	**1 2 3 4 5**

4) Force Concept Inventory



Force Concept Inventory 47

FORCE CONCEPT INVENTORY

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. The time it takes the balls to reach the ground below will be
   1. about half as long for the heavier ball as for the lighter one.
   2. about half as long for the lighter ball as for the heavier one.
   3. about the same for both balls.
   4. considerably less for the heavier ball, but not necessarily half as long.
   5. 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
   1. both balls hit the floor at approximately the same horizontal distance from the base of the table.
   2. the heavier ball hits the floor at about half the horizontal distance from the base of the table than does the lighter ball.
   3. the lighter ball hits the floor at about half the horizontal distance from the base of the table than does the heavier ball.
   4. 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.
   5. 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 Earth
   1. reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
   2. speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to Earth.
   3. speeds up because of an almost constant force of gravity acting upon it.
   4. falls because of the natural tendency of all objects to rest on the surface of Earth.
   5. 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
   1. the truck exerts a greater amount of force on the car than the car exerts on the truck.

2. the car exerts a greater amount of force on the truck than the truck exerts on the car.
3. neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
4. the truck exerts a force on the car but the car does not exert a force on the truck.
5. 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 its 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*.

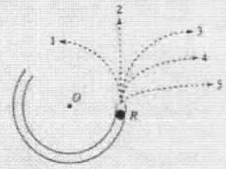
5. Consider the following distinct forces:

   A. a downward force of gravity.
   B. a force exerted by the channel pointing from *Q* to *O*.
   C. a force in the direction of motion.
   D. 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*?

   1. A only.
   2. A and B.
   3. A and C.
   4. A, B, and C.
   5. A, C, and D.

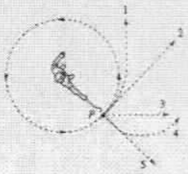
6. Which of the paths 1–5 below would the ball most closely follow after it exits the channel at *R* and moves across the frictionless table top?



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

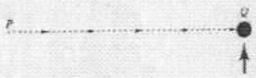
   At point *P*, the string suddenly breaks near the ball.

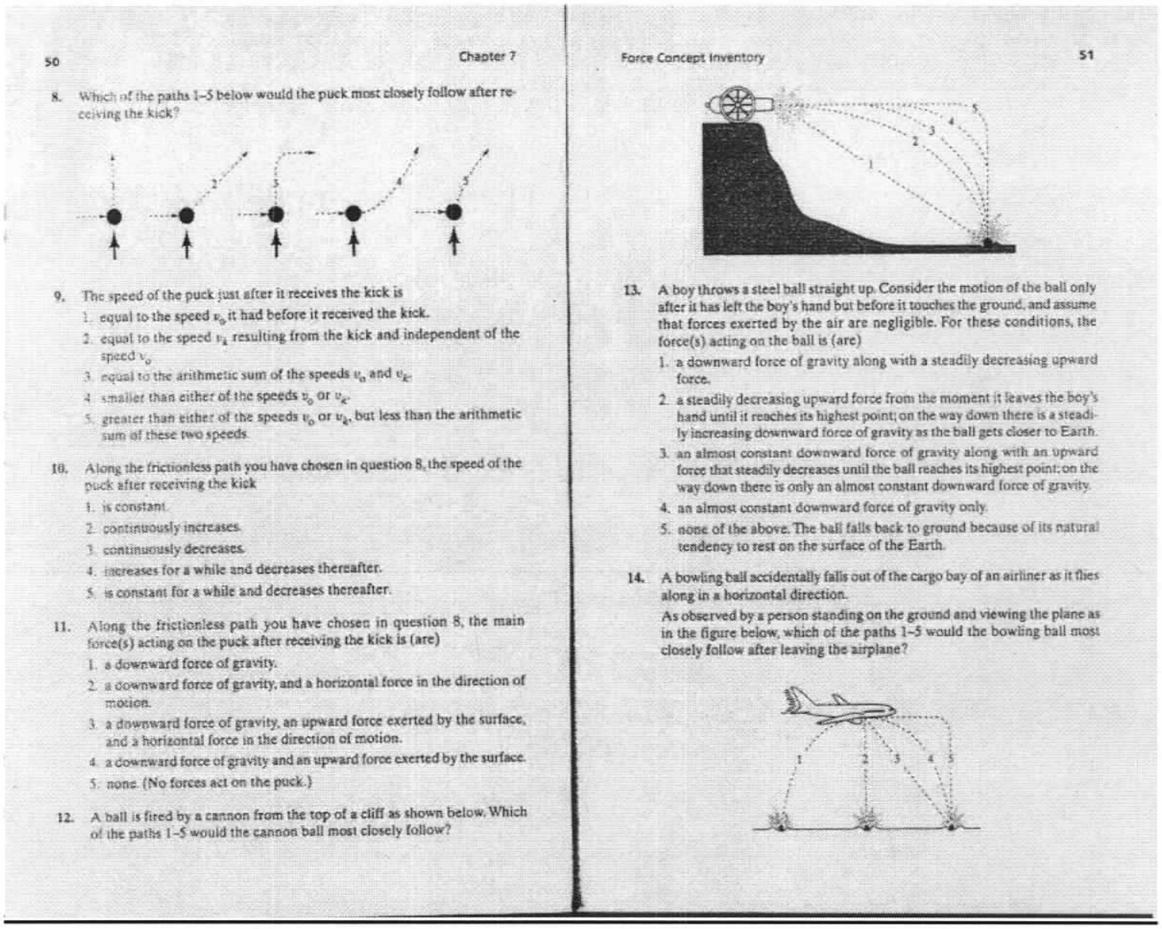
   If these events are observed from directly above, which of the paths 1–5 below would the ball most closely follow after the string breaks?



Use the statement and figure below to answer the next four questions (8–11).

The figure depicts a hockey puck sliding with constant speed v_0 in a straight line from point to *P* to point *Q* on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point *Q*, it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point *P*, 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 1–5 below would the puck most closely follow after receiving the kick?

9. The speed of the puck just after it receives the kick is
   1. equal to the speed v_0 it had before it received the kick.
   2. equal to the speed v_k resulting from the kick and independent of the speed v_0
   3. equal to the arithmetic sum of the speeds v_0 and v_k.
   4. smaller than either of the speeds v_0 or v_k.
   5. greater than either of the speeds v_0 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
    1. is constant.
    2. continuously increases.
    3. continuously decreases.
    4. increases for a while and decreases thereafter.
    5. 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)
    1. a downward force of gravity.
    2. a downward force of gravity, and a horizontal force in the direction of motion.
    3. a downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion.
    4. a downward force of gravity and an upward force exerted by the surface.
    5. none. (No forces act on the puck.)

12. A ball is fired by a cannon from the top of a cliff as shown below. Which of the paths 1–5 would the cannon ball most closely follow?

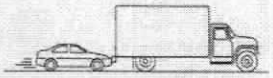
13. A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are)
    1. a downward force of gravity along with a steadily decreasing upward force.
    2. 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 ball gets closer to Earth.
    3. 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 an almost constant downward force of gravity.
    4. an almost constant downward force of gravity only.
    5. 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 below, which of the paths 1–5 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).

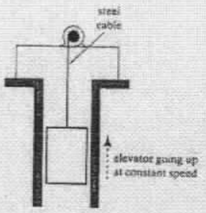
A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below.



15. While the car, still pushing the truck, is speeding up to get up to cruising speed.
    1. 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.
    2. 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.
    3. 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.
    4. 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.
    5. neither the car nor the truck exerts any force on the other. The truck is pushed forward simply because it is in the way of the car.

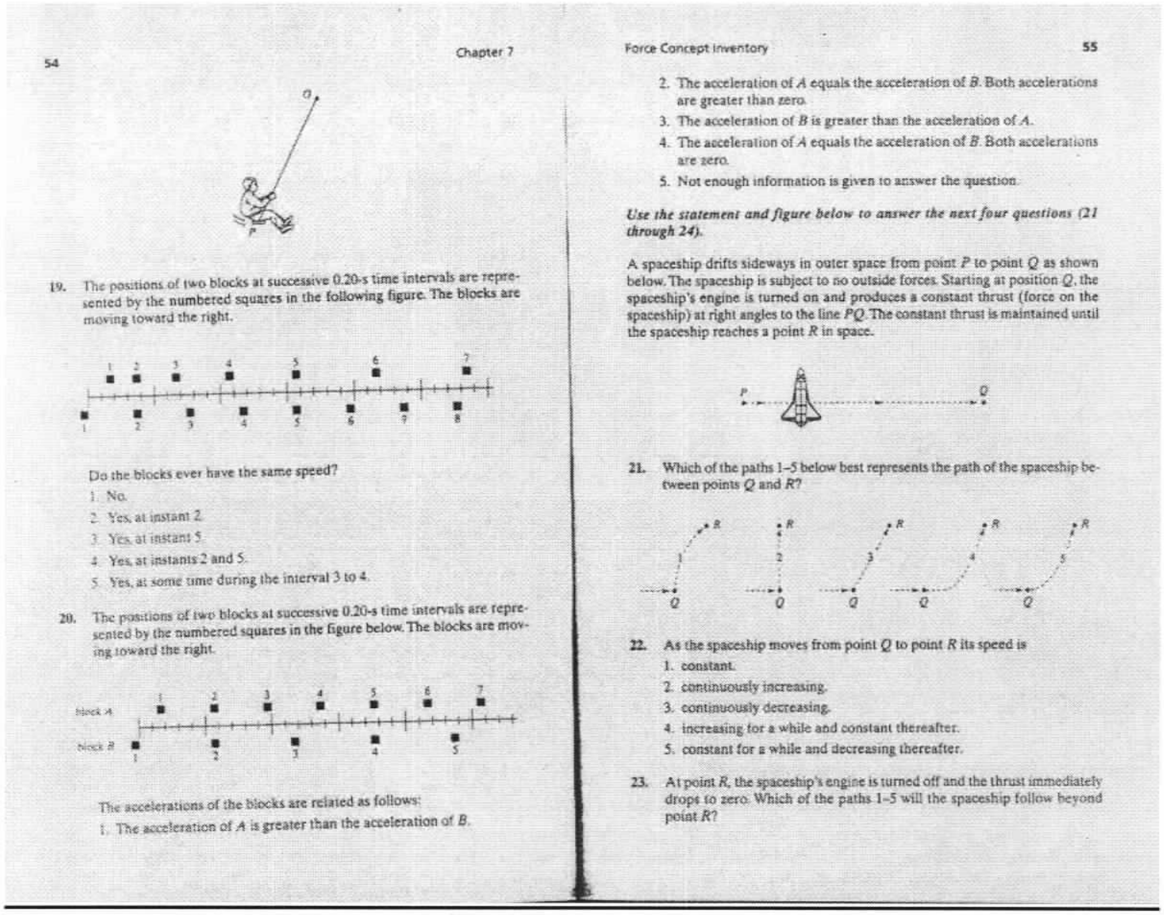
16. After the car reaches the constant cruising speed at which its driver wishes to push the truck,
    1. the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
    2. the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
    3. 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.
    4. 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.
    5. neither the car nor the truck exerts 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 following figure. All frictional effects are negligible. In this situation, forces on the elevator are such that
    1. the upward force by the cable is greater than the downward force of gravity.
    2. the upward force by the cable is equal to the downward force of gravity.
    3. the upward force by the cable is smaller than the downward force of gravity.
    4. 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.
    5. 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).



18. The following figure shows a boy swinging, starting at a point higher than P. Consider the following distinct forces:
    - A. a downward force of gravity.
    - B. a force exerted by the rope pointing from P to O.
    - C. a force in the direction of the boy's motion.
    - D. a force pointing from O to P.

    Which of the above forces is (are) acting on the boy when he is at position P?
    1. A only
    2. A and B
    3. A and C
    4. A, B, and C
    5. A, C, and D



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

Do the blocks ever have the same speed?

1. No.
2. Yes, at instant 2.
3. Yes, at instant 5.
4. Yes, at instants 2 and 5.
5. Yes, at some time during the interval 3 to 4.

20. The positions of two blocks at successive 0.20-s 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:

1. The acceleration of *A* is greater than the acceleration of *B*.

2. The acceleration of *A* equals the acceleration of *B*. Both accelerations are greater than zero.
3. The acceleration of *B* is greater than the acceleration of *A*.
4. The acceleration of *A* equals the acceleration of *B*. Both accelerations are zero.
5. 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 spaceship drifts sideways in outer space from point *P* to point *Q* as shown below. The spaceship is subject to no outside forces. Starting at position *Q*, the spaceship's engine is turned on and produces a constant thrust (force on the spaceship) at right angles to the line *PQ*. The constant thrust is maintained until the spaceship reaches a point *R* in space.

21. Which of the paths 1–5 below best represents the path of the spaceship between points *Q* and *R*?

22. As the spaceship moves from point *Q* to point *R* its speed is
    1. constant.
    2. continuously increasing.
    3. continuously decreasing.
    4. increasing for a while and constant thereafter.
    5. constant for a while and decreasing thereafter.

23. At point *R*, the spaceship's engine is turned off and the thrust immediately drops to zero. Which of the paths 1–5 will the spaceship follow beyond point *R*?

24. Beyond position R the speed of the spaceship is
    1. constant.
    2. continuously increasing.
    3. continuously decreasing.
    4. increasing for a while and constant thereafter.
    5. 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.

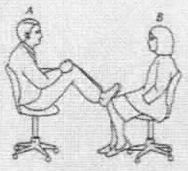
    The constant horizontal force applied by the woman
    1. has the same magnitude as the weight of the box.
    2. is greater than the weight of the box.
    3. has the same magnitude as the total force that resists the motion of the box.
    4. is greater than the total force that resists the motion of the box.
    5. is greater than either the weight of the box or the total force that 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
    1. with a constant speed that is double the speed v_0 in the previous question.
    2. with a constant speed that is greater than the speed v_0 in the previous question, but not necessarily twice as great.
    3. for a while with a speed that is constant and greater than the speed v_0 in the previous question, then with a speed that increases thereafter.
    4. for a while with an increasing speed, then with a constant speed thereafter.
    5. with a continuously increasing speed.

27. If the woman in question 25 suddenly stops applying a horizontal force to the block, then the block
    1. immediately comes to a stop.
    2. continues moving at a constant speed for a while and then slows to a stop.

    3. immediately starts slowing to a stop.
    4. continues at a constant speed.
    5. increases its speed for a while and then starts slowing to a stop.

28. In the following figure, student A has a mass of 75 kg and student B has a mass of 57 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,
    1. neither student exerts a force on the other.
    2. student A exerts a force on student B, but B does not exert any force on A.
    3. each student exerts a force on the other, but B exerts the larger force.
    4. each student exerts a force on the other, but A exerts the larger force.
    5. 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:

    A. a downward force of gravity.
    B. an upward force exerted by the floor.
    C. a net downward force exerted by the air.

    Which of the forces is (are) acting on the office chair?
    1. A only
    2. A and B
    3. B and C
    4. A, B, and C
    5. 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:

    A. a downward force of gravity.
    B. a force by the "hit."
    C. 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?
    1. A only
    2. A and B
    3. A and C
    4. B and C
    5. A, B, and C

Appendix 3

Curriculum for Physics 150/151

1) Physics 150

OUTLINE:

1. **Measurement & Units**
1.1 Concepts of physics
1.2 Accuracy and precision
1.3 Significant figures
1.4 Scientific notation
1.5 Systeme Internationale (SI)
1.5.1 Base units
1.5.2 Prefixes
1.5.3 Derived units
1.6 Conversion of units – Metric and British units
1.7 Problem solving

2. **Graphical Analysis**
2.1 Graph construction
2.1.1 Plotting data
2.1.2 Fitting curves to data
2.2 Analyzing linear graphs
2.2.1 Determination of slope and intercept
2.2.2 The linear equation
2.3 Analyzing non-linear graphs
2.3.1 Recognition of power graphs
2.3.2 Changing variables to produce linear graphs
2.3.3 Writing equations for non-linear graphs

3. **Kinematics in One Dimension**
3.1 Kinematic quantities
3.1.1 Vector and scalar quantities
3.1.2 Position, distance and displacement
3.1.3 Average speed and velocity
3.1.4 Acceleration
3.1.5 Definition of instantaneous values
3.2 Kinematic graphs
3.2.1 Position versus time
3.2.2 Displacement versus time
3.2.3 Velocity versus time
3.3 Uniformly accelerated motion
3.3.1 Equations of uniform motion
3.3.2 Solving kinematic problems
3.3.3 Acceleration due to gravity

3.3.4 Vertical motion near the Earth

4. **Dynamics in One Dimension**
4.1 Concept of force
4.2 Newton's first law of motion
4.2.1 Concept of inertia
4.3 Newton's second law of motion
4.3.1 Dependence of acceleration on net force
4.3.2 Dependence of acceleration on mass
4.3.3 Dependence of net force on mass
4.3.4 Dynamics examples – One-body problems
4.4 Newton's third law of motion
4.4.1 Interpretation of examples of the law

5. **Work, Energy and Power**
5.1 Work
5.1.1 Definition
5.1.2 Calculating work done by a force
5.1.3 Positive and negative work
5.2 Types of Mechanical Energy
5.2.1 Kinetic energy
5.2.2 Gravitational potential energy
5.2.3 Elastic potential energy
5.3 Work-Energy Theorem
5.4 Conservation of Mechanical Energy
5.5 Power and Efficiency

2) Physics 151

OUTLINE:

1. **Mechanical waves**
1.1 Properties of waves
1.2 Wave types
1.3 Wave speed in a string/in air
1.4 Interference
1.4.1 Constructive and Destructive interference
1.4.2 Superposition principle
1.4.3 Beats
1.5 Standing waves
1.5.1 Conditions
1.5.2 Vibrating strings
1.5.3 Harmonics

2. **Sound**

2.1 Nature of sound waves
2.1.1 Speed
2.1.2 Dependence on medium
2.1.3 Harmonics
2.1.4 Pitch and loudness
2.2 Vibrating air columns
2.2.1 Open and closed pipes
2.2.2 Harmonics

3. **Kinematics**
3.1 Review of one dimensional kinematics
3.2 Motion in two dimensions
3.2.1 Vectors and scalars
3.2.2 Scaled diagrams
3.2.3 Vector components
3.2.4 Displacement and velocity
3.2.5 Acceleration
3.3 Relative velocity
3.4 Projectile motion in two-dimensions
3.5 Uniform circular motion

4. **Dynamics**
4.1 Concept of force and inertia
4.2 Newton's laws of motion
4.3 Applications of Newton's second law
4.3.1 Component method
4.3.2 Connected objects
4.3.3 Uniform circular motion

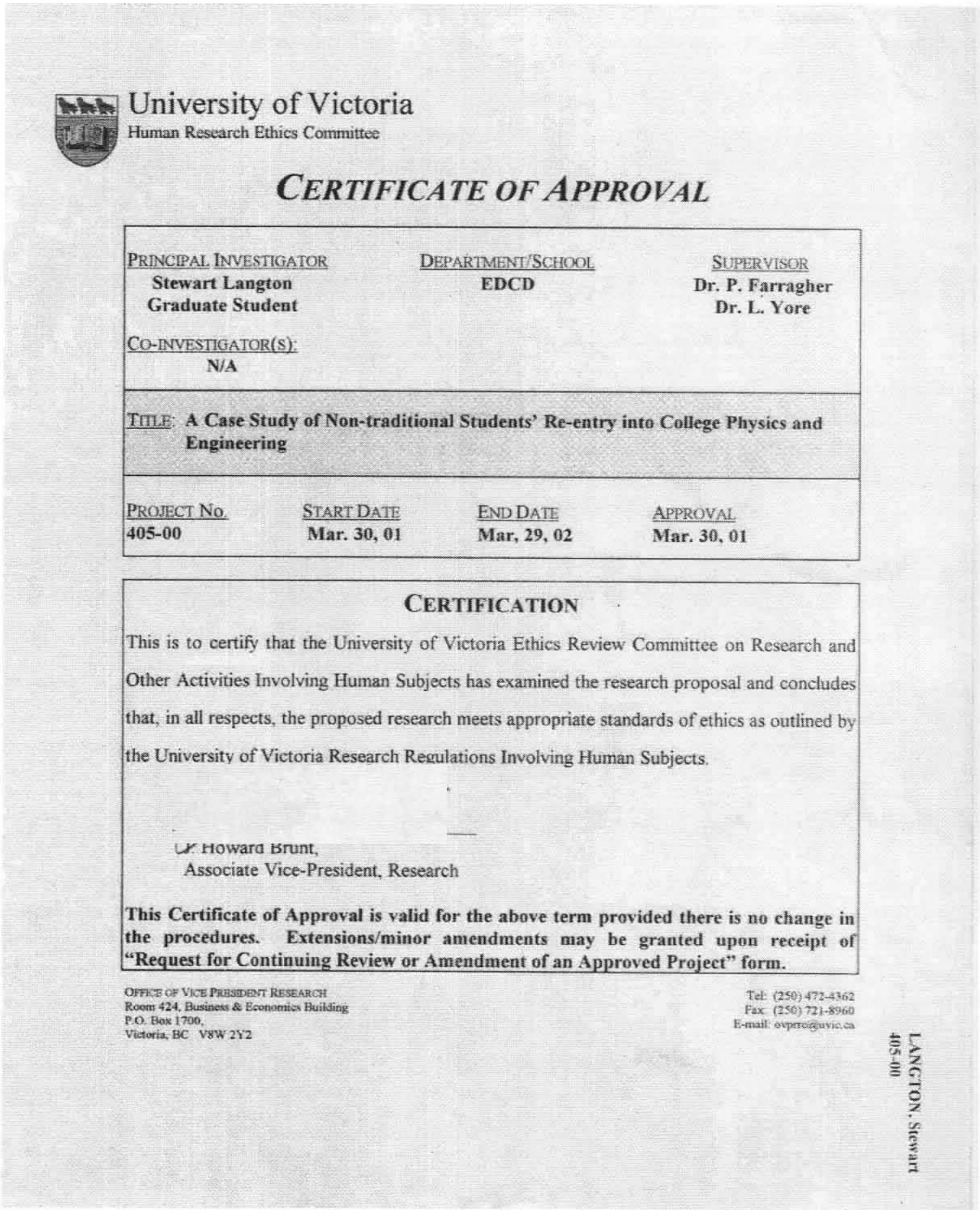
5. **Equilibrium**
5.1 First condition
5.1.1 Forces in equilibrium
5.2 Second condition
5.2.1 Non-concurrent forces
5.2.2 Torque
5.2.3 Center of gravity
5.2.4 Torques in equilibrium

6. **Light**
6.1 Properties of light
6.1.1 Wave/particle nature
6.1.2 Electromagnetic spectrum
6.1.3 Wave speed
6.2 Reflection
6.2.1 Law of reflection
6.2.2 Images formed in flat mirrors
6.2.3 Images formed in spherical mirrors

6.2.4 Ray tracing
6.2.5 Mirror equation
6.2.6 Magnification
6.3 Refraction
6.3.1 Index of refraction
6.3.2 Snell’s law
6.3.3 Total internal reflection
6.3.4 Images formed by refraction
6.3.5 Ray tracing
6.3.6 Lens equation
6.3.7 Magnification

Appendix 4

Human Research Ethics Approval



University of Victoria
Human Research Ethics Committee

CERTIFICATE OF APPROVAL

PRINCIPAL INVESTIGATOR	DEPARTMENT/SCHOOL	SUPERVISOR
Stewart Langton **Graduate Student**	**EDCD**	**Dr. P. Farragher** **Dr. L. Yore**
CO-INVESTIGATOR(S): **N/A**		

TITLE: **A Case Study of Non-traditional Students' Re-entry into College Physics and Engineering**

PROJECT NO.	START DATE	END DATE	APPROVAL
405-00	**Mar. 30, 01**	**Mar, 29, 02**	**Mar. 30, 01**

CERTIFICATION

This is to certify that the University of Victoria Ethics Review Committee on Research and Other Activities Involving Human Subjects has examined the research proposal and concludes that, in all respects, the proposed research meets appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Subjects.

Dr. Howard Brunt,
Associate Vice-President, Research

This Certificate of Approval is valid for the above term provided there is no change in the procedures. Extensions/minor amendments may be granted upon receipt of "Request for Continuing Review or Amendment of an Approved Project" form.

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405-00

Appendix 5

MPEX Data

MPEX data, pre-course and post-course applications, for Electronics students and Civil/Mechanical students.

Format of responses in same format as University of Maryland Physics Education Research Group (2005).

ITEM	Experts	Electronics Precourse	Electronics Postcourse	Civil/Mechanical Precourse	Civil/Mechanical Postcourse
1	D	(A)	(D)	(D)	(D)
2	D	D	D	(D)	D
3	A	(A)	(A)	(D)	(D)
4	D	(D)	(D)	(A)	(D)
5	A	(A)	(A)	(A)	(A)
6	A	(A)	(A)	A	A
7	(A)	(A)	(A)	(D)	(A)
8	D	(A)	(D)	(D)	D
9	(D)	(A)	(D)	(D)	(D)
10	D	D	D	(A)	(D)
11	A	(A)	(A)	(A)	A
12	D	(D)	(D)	(D)	D
13	D	(D)	D	(D)	D
14	D	(D)	D	(D)	(D)
15	D	(D)	(D)	D	D
16	D	(A)	(D)	D	D
17	D	(D)	(D)	D	D
18	A	(A)	A	(D)	(A)
19	D	(A)	(D)	(A)	(D)
20	D	(D)	D	(D)	D
21	D	(A)	(D)	(D)	D
22	D	D	D	(D)	D
23	D	(D)	D	D	D
24	D	(A)	(D)	(D)	(D)
25	A	(A)	A	(A)	(A)
26	A	(A)	(A)	A	A
27	D	(A)	(D)	(D)	D
28	D	(D)	(D)	D	D
29	D	(A)	(D)	(D)	D
30	A	(A)	(A)	(A)	(A)
31	A	(A)	(A)	(D)	(A)
32	A	(A)	(A)	(A)	A
33	D	(A)	(D)	(D)	D
34	(A)	(A)	(A)	(A)	(A)

Appendix 6

1 week Instructional Plan

Each week of instruction had 7 hours of class time, in either one or two hour blocks. The topics and work schedule for the complete term were handed out to students on the first day of class each term. Activities with whole class were limited to the short lecture, normally in the first 10 to 15 minutes of class. These lectures normally occurred on, at most, three day of the week. The lectures introduced new topics with an overview of new ideas. Specific details and problems involving new concepts were not part of these lectures.

The majority of time in class involved students working in groups on problems from the textbook. The instructor's role during these periods was to provide assistance to individuals or groups. In rare cases, if a similar difficulty was being presented by several people a general discussion was initiated. Although the students had a schedule for undertaking problems, many students were ahead of the schedule, while a few were behind such that they had fallen behind the minimum criterion for the course of not being more than one week behind. In most cases attention to these students resulted in improving this situation.

Formative testing included short quizzes, 2 or 3 questions, which were not collected. Solutions were provided after the 10 minutes allowed for these quizzes. Weekly testing was undertaken on each Friday for 1 hour. These tests were cumulative; i.e. test items could be included from any unit covered since the start of the course or in the case of Physics 151, since the start of Physics 150. The grades from these tests were recorded and the original tests and solutions returned the following week.

Either one or two laboratory exercises were undertaken each week. These could be either one or two hours in duration depending on the complexity of the exercise. Although the original idea for the revised instruction had been to allow students to work on these laboratory exercises at any time during the week the actual implantation, with the whole class working on the same laboratory exercise, was the actual outcome. The laboratory exercises were directly related to the topics being studies that week.

The time in a typical week was proportioned as 5% administration, 15% lectures, 25% laboratory exercises, 40% group work, and 15% testing.

Appendix 7

Sample Laboratory Exercise

The American Association of Physics Teachers has a set of goals for introductory physics laboratories available at: http://www.aapt.org/Policy/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=4700#search=%22introductory%20physics%20lab%20exercise%22

Goals of the Introductory Physics Laboratory*
American Association of Physics Teachers

I. -The Art of Experimentation: The introductory laboratory should engage each student in significant experiences with experimental processes, including some experience designing investigation.
II.- Experimental and Analytical Skills: The laboratory should help the student develop a broad array of basic skills and tools of experimental physics and data analysis.
III.- Conceptual Learning: The laboratory should help students master basic physics concepts.
IV.-Understanding the Basis of Knowledge in Physics: The laboratory should help students understand the role of direct observation in physics and to distinguish between inferences based on theory and the outcomes of experiments.
V.- Developing Collaborative Learning Skills: The laboratory should help students develop collaborative learning skills that are vital to success in many lifelong endeavours.

Many of the goals are not explicit in traditional laboratory programs. However, the American Association of Physics Teachers believes that laboratory programs should be designed with these five fundamental goals in mind.

The laboratory exercises used in the physics courses of the Access Program were not comparable to most introductory physics course laboratory activities. While the above goals were general objectives there was much less emphasis on the formal nature of most physics laboratory activities and more emphasis on evaluation and discovery that better represented authentic scientific practices.

The curriculum included friction in several different units and represented a relatively complex process that is reduced to a simple linear equation $F_f = \mu F_N$. This equation had been included in topics of 1-D kinematics and dynamics and evaluated for static and kinetic coefficients of friction μ. The objective of the laboratory exercise was to evaluate the frictional force in stationary and moving systems and to evaluate the validity of the relationship $F_f = \mu F_N$ for parameters not in the formula. Previous laboratory exercises had included processes so that the students were familiar with setup and measurement for timing and measuring forces necessary to undertake this exercise.

A discussion of friction, for about 5 to 10 minutes, reviewed the ideas presented in class and was used to elicit ideas for evaluating friction. Since no reference to surface area is included in the formula and rarely in the theoretical evaluation of friction, the suggestion was made to try to determine if surface area is a factor in the frictional force.

The equipment for the exercise included a 2 metre long plank with a pulley at one end. The plank could be elevated to form a ramp. Blocks of different size, shape and material were available. String connected a block with calibrated masses the hung vertically below the pulley. The students worked in their usual groups and, with no further instructions, proceeded to work with the equipment.

In this laboratory exercise very little guidance was necessary since the ideas of static and kinetic friction had been extensively discussed. Several groups immediately began experiments that were appropriate for the exercise. Other groups then followed with similar equipment set-ups.

There are two main difficulties in this experiment: 1) determining the point where a block begins to move; i.e. determining the maximum value for static friction and 2) in kinetic friction to avoid accelerations in the system; i.e. making sure the block is moving slowly but with constant velocity. After allowing the class to work for approximately ½ hour these two ideas were discussed.

This laboratory exercise did not require a formal report. Each student was required to prepare a one page report on the activities of their group.

In comparison to other formal laboratory exercises in other courses this exercise best exemplifies the potential for allowing students to undertake guided inquiry rather than follow direction for undertaking the activity. These students were able, with very little guidance, to accomplish at least as much, and in several cases, more than students in introductory calculus based courses at the same college. The level of enthusiasm shown by the students was also much greater than typically observed in laboratory settings.