# PART III. EVALUATION OF RESEARCH-BASED TEACHING METHODS

## Chapter 8. Courses, Teaching Methods, and Schools

### I. OVERVIEW

While many of the results of student difficulties in introductory physics can be generalized to students in similar contexts,[1] the results of modified instruction and interventions are often dependent on the nature of the institution, the nature of the students, and the specific details of the implementation. This is one reason why when an institution adopts a curriculum or teaching method developed at another school, the results of the adopting institution are often not as impressive as they are at the developing institution. Each of the three research-based teaching methods discussed in this chapter have several factors that can contribute to its success or failure.[2]

For example, the best result on a mechanics concept test using tutorials at University of Maryland was obtained by the instructor who best integrated the ideas of the tutorial into his lectures. Other professors who did not adapt their lectures as much improved their students' scores on conceptual tests but not as much. Any teaching method beyond a single brief intervention has many factors that must be considered. Among them are the following:

1. How well integrated is the course as a whole? Do the various components of the course build on one another? Does the course make use of underlying themes?
2. Are the course goals explicitly stated and adequately reinforced through student assignments and grading?

In order to understand what the research is telling us about what students are learning in the introductory class, it is important to put the results in the context of the school, the teaching method, the details of implementation, and the student population. The purpose of this chapter is these provide these details. To help the reader interpret and make sense of these results in later chapters, a brief description of the schools, teaching methods, and implementations follows. Information on the schools is briefly summarized in Table 8-1 in the next section. A summary of the teaching methods and details on the implementations for each course can be found in Table 8-2. Since not all introductory physics courses cover the same material, topic coverage for each of the courses is summarized in Table 8-3. Table 8-4 offers a quick reference as to what data was collected at each of the ten schools. Note that not all types of data were collected at all schools.

## II. SCHOOLS AND STUDENT POPULATIONS

Three types of institutions were used in this study: (a) large public universities, (b) small liberal arts colleges and universities, and (c) community colleges. In this dissertation, I discuss results obtained from the following schools:

1. UMD - University of Maryland (a)
2. MIN - University of Minnesota (a)
3. OSU - Ohio State University (a)
4. CAR - Carroll College (b)
5. DCK - Dickinson College (b)
6. DRY - Drury College (b)
7. MSU - Moorhead State University (b)
8. NWU - Nebraska Wesleyan University (b)
9. SKD - Skidmore College (b)

10. PGCC - Prince Georges Community College (c)

A brief description of each school including total number of full-time undergraduate students, student SAT/ACT scores, and selectivity is given below in Table 8-1.[3] Note that the most of the schools are easily typed by the size of the undergraduate student population with the exception of Moorhead State University which is a moderately sized state school. However, because of their small class sizes (see table 8-2) and the lack of an engineering major program, for the purposes of this study they are considered a small liberal arts university.

The three research-based teaching methods discussed in the next session were developed at University of Washington (Tutorials), University of Minnesota (Group Problem Solving), and Dickinson College (Workshop Physics). These schools will be referred to as developing schools. The descriptions of the three research-based curricula describe the implementations at the developing schools. (Note, however, that University of Washington is not one of the schools included in this study.) The other schools listed below using the research-based teaching methods developed at one of these three schools are referred to as adopting schools. These adopting schools include University of Maryland (Tutorials), Ohio State University (Group problem solving), Drury College (Workshop Physics), Moorhead State University (Workshop Physics), Nebraska Wesleyan University (Workshop Physics), and Skidmore College (Workshop Physics). Traditional classes were studied at the University of Maryland, Carroll College, and Prince Georges Community College.

Table 8-1: A description of schools participating in this study

| School | Type | # of Students | SAT Ver/Mth ACT[3,4] | Selectivity[3] |
|---|---|---|---|---|
| University of Maryland (UMD) | a | 20,344 | 500 /590 M | 72 |
| University of Minnesota (MIN) | a | 16,457 | 570/590 M ACT 24 | 77 |
| Ohio State University (OSU) | a | 30,500 | 540/550 M ACT 23 | 66 |
| Carroll College (CAR) | b | 1,542 | na | 63 |
| Dickinson College (DCK) | b | 1,789 | 600/590 M | 74 |
| Drury College (DRY) | b | 1,221 | ACT 25 | 74 |
| Moorhead State University (MSU) | b | 6,252 | ACT 22 | 67 |
| Nebraska Wesleyan University (NWU) | b | 1,378 | ACT 24 | 72 |
| Skidmore College (SKD) | b | 2,150 | 610/600 M ACT 22 | 76 |
| Prince Georges Community College (PGCC) | c | 34,000 | na | na |

Types of Schools: (a) Large public research university, (b) small liberal arts college or university, and (c) community college

# of Students: This indicates the total number of full-time undergraduates as of 1995

SAT: Verbal/Math (the M designates the math SAT score)

Selectivity: The selectivity ranking was determined by the 1996 Princeton Review. The ranking is determined by a formula that considers the college's acceptance rate and the percentage of acceptees who actually enroll as well as the class rank and average test scores of the entering freshmen. Selectivity rankings range from 56 to 100. Selectivity scale as follows:

- 56 - 69 Not Selective
- 70 - 79 Selective
- 80 - 89 Very Selective
- 90 - 100 Mega Selective

There is no selectivity score or college entrance exam scores for the community college. Any student with a high school diploma or equivalent may apply and attend.
Selectivity Average for the nine schools = 70.6 ± 4.8

## III. TEACHING METHODS

In this project we studied courses that made use of four different teaching methods:

1. Traditional (TRD)
2. Tutorial (TUT)
3. Group Problem Solving and Problem Solving Labs (GPS)
4. Workshop Physics (WP)

The last 3 teaching methods are research-based curricula that make use of active-learning cooperative-group activities. They vary in both the amount of time spent on group activities (from a minimum of one hour per week in tutorials to a maximum of five hours each week in Workshop Physics) and in the type of group activities (described in detail later in this section). Since we are studying the effects of research-based instructional methods, the traditional teaching method is used as a control. All three of the research-based teaching methods are based on the same philosophy, namely, that students learn more effectively when they are actively engaged: physically, mentally, and socially. In each of the three research methods, the students are given the opportunity to interact with each other in cooperative groups where they discuss and dispute each others ideas. Each research-based method also encourages the "less is more" approach to content coverage currently advocated by many physics educators. All three research-based teaching methods have been in use at the developers' home institution since 1989 and have been adopted by other schools. All three are described by the developers in detail as sample classes in *The Changing Role of Physics Departments in Modern Universities: Proceedings of the International Conference on Undergraduate Physics Education.*[5]

Each researched-based teaching method is described in this section as implemented by the developers and includes the motivation for development of the curriculum, details of the implementation, problems and difficulties with the implementation, and a summary of whatever evaluation was performed by the developers.  The details of the implementations at each of the schools participating in the study are discussed in the next section.

## A.  TRADITIONAL INSTRUCTION

### 1.  Motivation

The traditional lecture method is in widespread use for two reasons, tradition and cost effectiveness.  This method has been used to teach physics for over one hundred years and almost every college and university physics instructor learned physics this way. It is relatively inexpensive in that one professor can lecture to hundreds of students while the smaller recitation and laboratory sections are taught by multiple, often less expensive and less experienced instructors such as TAs.

### 2.  Implementation

Here, a course using traditional teaching methods means a traditional lecture course with recitation and sometimes laboratory sections.  In lecture, the instructor presents material to the students sometimes making use of demonstrations and multimedia.  The students are mostly sitting passively, listening (hopefully), taking notes, and occasionally asking questions.  In the recitation, the students typically ask questions about their  homework assignment which the TA will work through on the chalkboard. In the laboratory, the students perform structured recipe-like experiments to verify principles given in lecture; then they write up the activity in a lab report. Total class time per week is six to eight hours consisting of three hours of lecture, one to two hours of recitation, and two to three hours of laboratory per week. This method is used at most large universities, many small colleges, and even many community colleges in the United States.

**3. Difficulties**

For most students, lecture and often recitation are very passive. There is little opportunity for the students to discuss ideas and ask questions with the instructor or anyone else in class. Even in recitation, only a few minutes can be spent on a particular student's questions. However, students often don't make use of office hours, their one opportunity to work one on one with an instructor. In one sense, this is fortunate because there usually aren't enough office hours to work with a large fraction of the students.

These characteristics present a problem because many students need help to build their understanding of introductory physics. In addition, when instructors go over the course material and problem solutions in this method, they often don't model how to build an expert-like understanding or expert-like problem solving skills. While physics faculty often successfully master their field with classes taught in this style, there are two points to consider. One, most of them had three iterations of basic physics courses. And two, they did not learn physics by just repeating what was lectured. At some point in their undergraduate or graduate careers, they sat down with the material and made sense of it for themselves.

The traditional lecture style of instruction also encourages the view that learning science is learning the facts that experts know about the world rather than the view that learning science is the process of trying to make sense of the world.

**4. Evaluation**

Anecdotal evidence from observations, conversations with faculty, and the research literature strongly suggest that less than half (perhaps only 20%) of the students are effectively achieving the main goal of a useful, functional knowledge of physics in calculus-based introductory classes taught by this method. Some students succeed by memorizing and solving problems by algorithmic pattern matching.[6] The evidence for this is discussed in more detail in chapter 2. The three most general results from PER with implications for teaching are the following:

1. Students bring their own ideas of physics, learning, mathematics, and problem solving into the introductory class based on their own experiences. This can have a strong and often negative effect on what students learn in traditional introductory physics classes.
2. Curriculum carefully designed to take students from where they are to where instructors would like them to be can be effective for addressing these student ideas and making progress towards achieving our primary goal as stated above.
3. Since most students do not have the mental tools to construct their own understanding from the traditional course structure, structured active learning (mentally active) activities with peer interaction in class can be effective in helping students build a better functional understanding of physics. This is a common element of most research-based physics curricula.

Since in most large universities it is impractical to change the course format to small classes, some research-based curricula, including tutorials and group problem solving, are variations on the lecture format to produce more active-learning in large classes.

## B. Tutorials

### 1. Motivation

Many different schools use the word tutorials to describe certain course activities. The tutorial method described below was developed by Lillian C. McDermott and the Physics Education Group at the University of Washington (UW) to improve student understanding of fundamental physics concepts in a cost-effective manner within the traditional large lecture structure.[7] The tutorials grew out of the group's research on students' common sense beliefs and their work developing the *Physics by Inquiry*[8] curriculum for pre-service and in-service K-12 teachers.

### 2. Implementation

These UW tutorials have the following components:

1. A 10 minute ungraded "pretest" is given in lecture once a week. This test asks qualitative conceptual questions about the subject to be covered in tutorial the following week. Often the material covered in the pretest has already been covered in lectures and homework assignments. Students receive points for taking the pretest but not for the correctness of their responses. The pretests play two roles. One, they help focus the students' attention on issues that will be discussed in tutorial the following week. And two, the pretests give an indication of student thinking and difficulties before the tutorial.
2. The teaching assistants and faculty involved participate in a 1.5 hour weekly training session. In the training session they take the pretest, go over both the student responses to the pretests, and then go over the tutorial to be used in the coming week. The emphasis of the discussion on the tutorial is on developing appropriate questions to ask the students to illuminate their thinking and lead them towards a physics point of view.
3. A one hour (50 minute) tutorial session replaces the traditional problem-solving recitation section. Students work together in groups of three or four and answer questions on a worksheet that guides them through building qualitative reasoning on a fundamental concept. At least two teaching assistants serve as facilitators in each tutorial section, asking leading questions in a semi-Socratic dialog[9] to help the students work through their difficulties by encouraging them to think. The students' worksheets are not collected. The students select their own group with little or no intervention by the TAs.

4. Students have a brief qualitative homework assignment in which they explain their reasoning. This is a part of their weekly homework which also includes problems assigned from the text. No solutions of tutorial homework are made available to the students.
5. At least one question emphasizing material from tutorials is asked on each examination.

At the University of Washington, tutorial worksheets are developed over a period of many years through an iterative cycle of research/curriculum-development/instruction. The tutorials often make use of "cognitive conflict." In this approach, situations are presented which trigger the common student conceptual difficulties revealed by research. After the student difficulty is triggered, a situation is presented where the difficulty brings about a contradiction with what the students have been taught. The facilitators then help those students who show the predicted difficulties work through their ideas themselves. McDermott refers to this process as elicit/confront/resolve. The facilitators are mostly graduate and undergraduate TAs who receive no special training prior to their assignment to teach tutorials. The tutorial program is administered by the Physics Education Group. Note that lecturers may choose not to be facilitators or to participate in the weekly training meeting. If so, the tutorials have no adverse impact on instructor time outside of the weekly ten minute pre-test during lecture. However, the instructors are required to include at least one tutorial problem written by the Physics Education Group on each exam.

To address more difficult concepts in the introductory sequence, cover more concepts, and make use of recurring themes, at University of Washington tutorials are now taught in both recitation and the first hour of laboratory every week of the quarter.

The laboratory tutorials provide a qualitative introduction to the experiment performed later in the class.  These lab tutorials do not have homework assigned.

### 3.  Difficulties

The key to effective tutorials is in helping the students form effective groups.  An effective group is one where the issues and difficulties are discussed and resolved but the group continues to progress through the tutorial.  Some groups go through the tutorial too quickly and don't develop a good grasp of the tutorial issues.  Other groups have the opposite problem.  They often get stuck and have difficulty resolving the contradictions that arise.  These students can become frustrated when they can not finish the tutorials.  One difficulty that has come up is that many students' have the perception of conceptual understanding and quantitative problem solving as separate dimensions of the introductory course.  They do not always see how the concepts learned in tutorials relate to the problems they are being asked to solve on exams and homework.  For the facilitators, typically the hardest part of teaching tutorials is learning to listen to what the students are saying, to ask leading questions, to not tell them the answers, and to know when to just listen and leave well enough alone.

### 4.  Internal evaluation

At University of Washington, individual tutorials are evaluated through classroom observations, tests, course examinations, and post-tests administered one or more quarters after the relevant course was completed.[10]  Before full implementation of tutorials, course examinations and post-tests were administered to calculus-based classes with and without tutorials taught in parallel.  The tutorial students did "markedly better" on qualitative and quantitative problems on course exams.[11] They also did better on post-tests on circuits and Atwood's machines. In several cases the tutorial students did as well as graduate students who were given the qualitative problems on qualifier exams.

After going to full implementation, new tutorials are evaluated by exam problems written specifically to test concepts emphasized by that tutorial. The problems are given to classes with and without that tutorial. After several cycles of development for a given tutorial, students who take the introductory course with tutorials do significantly better on the exam problems.[12] A sample of students are interviewed to probe more deeply into their understanding of the key concepts and validate the problems.

## C. Group Problem Solving and Problem Solving Labs

### 1. Motivation

The Group Problem Solving approach was developed by Patricia Heller and the Physics Education Group at University of Minnesota.[13] Since a primary goal of instruction in the introductory physics course is to help students build a good functional understanding of physics that they can use to solve problems in new contexts, the Minnesota group focused on problem solving instead of conceptual understanding. Their approach is to use cooperative group activities that work explicitly on building expert problem solving skills. This addresses one of the difficulties in traditional physics instruction and in tutorials; namely, that students in introductory courses often consider problem solving and conceptual understanding to be independent. (See chapter two for more detail).[14]

They developed this approach for two reasons. One, cooperative group problem solving has been shown to be an effective technique for developing expert problem solving skills;[15] and two, of the recommended techniques for helping students become better problem solvers, cooperative grouping places the least demand on the instructors, in this case graduate teaching assistants who require and receive minimal training to implement this approach.[16]

Although the group problem solving method uses the same format as the traditional large lecture course, the curriculum changes all three aspects of the course at University of Minnesota: lecture, recitation, and lab.[17] The course goals, as established by surveying the departments served by the introductory physics sequences, are for students to learn:

1. the fundamental principles of physics,
2. general quantitative and qualitative problem solving skills that they can apply to new situations, and
3. to overcome their misconceptions (common sense beliefs) about the behavior of the physical world.

Note that these goals are very similar to the main course goals discussed in chapter 1.

**2. Implementation**

The three components of the course are coordinated to cover the material coherently by a course team consisting of the lecturer and the TAs teaching the associated labs and recitations.[18] The course team meets biweekly to brief the TAs on the direction of the lectures, to give feedback to the lecturer, to decide on problems and course emphasis for the next two weeks, and to discuss student performance. In addition, all three aspects use and/or support the following strategies:

- use of a story line to determine specific content,
- modeling the construction of knowledge,
- use of multiple contexts for each concept,
- focus on the fundamental principles and concepts,
- use of an explicit problem solving strategy,
- use of realistic context-rich problems, and
- use of testing and grading practices to reinforce desired student behavior.

One of the key elements of the course is that the students are taught an explicit problem solving strategy based on expert problem solving strategies. The problem solving strategy they use was strongly influenced by the work of Frederick Reif and Joan Heller[19] as well as Alan Shoenfeld's framework for mathematics problem solving.[20] The five steps of the prescribed problem solving strategy are listed below:[21] (A more detailed description of the five step strategy is presented in Table 2-1.)

1. Visualize the problem
2. Describe the physics of the situation (Qualitative physics description)
3. Plan a solution
4. Execute the plan
5. Check and evaluate

The student groups apply this strategy in solving problems in both the recitation and the laboratory. In order for the groups to function properly, the choice of problems is crucial.[22] The problems need several characteristics to encourage the students to work together to solve the problem.[23] Namely,

- They need to be challenging enough that a single student cannot solve it, but not so challenging that a group cannot solve it.
- They need to be structured so that the groups can make decisions on how to proceed with the solution.
- They should be relevant to the lives of the students.

- They cannot depend on students knowing a trick nor can they be mathematically tedious.

Most ordinary textbook problems are inadequate for this task. Heller *et al*. designed their own complex problems incorporating these characteristics which they call context-rich problems. They are designed to focus students' attention on the need to use their conceptual knowledge of physics to qualitatively analyze a problem before they begin to manipulate equations. They are essentially short stories that include a reason for calculating some quantity about a real object or event. In addition, context-rich problems may have one or more of the following real world characteristics:

1. The problem statement may not explicitly identify the unknown variable,
2. There may be more information available than is needed to solve the problem,
3. Some information may be missing from the problem statement but may be easily estimated, and
4. Reasonable assumptions may be needed to solve the problem.

An example of a Context Rich Problem is shown in Table 2-2.

Students have the same TA and work in the same groups for both recitation and laboratory. This helps the course coherence as well giving the students more practice in group work. Each section of 18 students is broken into groups of three based on their ranking in the class. Each group has one student each from the top third, the middle third, and the bottom third of the class. The students are reassigned into new groups after each exam, two to three times a quarter.

The operation of the lecture, recitation, and laboratory components of the course are described below. (The following is paraphrased from the University of Minnesota Web pages describing the method and philosophy of their group problem solving approach.)

*Lecture:* The majority of the lecture time is spent in the traditional manner. However, parts of the presentation explicitly model the construction of scientific knowledge and the prescribed problem solving method. Also, some cooperative group work (using groups of 2-3 students sitting near each other) is used to help the students develop concepts. This is sometimes followed by a short question and answer session. Occasionally, group predictions or answers to questions are written down and collected for grading. This lets the students know that their active involvement is an important part of the class.

*Recitation:* A typical 50 minute recitation section has three parts: introduction, task, and closure. First, the TA briefly goes over the learning goals for the session. Then the TA passes out the assigned context rich problem and assigns the roles of Manager, Recorder/Checker, and Skeptic to the three members of each group. The students have 30 minutes to complete the problem in their groups. The TA observes the groups and intervenes only when no progress is being made by a group or when the students have drifted from their roles. At the end of the session, the TA begins a class-wide discussion on the problem by randomly calling on one member from each group to write their solution on the board. The similarities and differences of the solutions are then discussed. Then the students are given five minutes to evaluate how they worked together and what they could do to improve next time. Students are given a complete written solution to the class problem at the end of the session. Part of each exam is a group problem that is worked in the recitation section.

*Laboratories:* The laboratories are coordinated with the other parts of the course to address the same content at the same time. The labs are not cookbook, verification labs. The laboratory problems are designed to allow students to apply the problem solving strategy to concrete situations and to help them confront their common sense beliefs. The learning process of the labs can be described as predict/explore/measure/explain. The lab manual is divided into 4 two to three week units, an equipment appendix, and five technique appendices. Each unit is comprised of an introduction page and several related problems. The lab manual contains no theory or background information on the experiments and few specific directions. This is intentional to emphasize that the laboratory is an integral part of the entire course. The write up for each problem refers to the relevant sections in the textbook. A computer check out is used to make sure that each students has a basic understanding of the necessary theory before coming to class.

To focus students' group discussions on the physics of the situation, the students are required to qualitatively analyze the situation and make group predictions about all measurements before they begin data collection and quantitative analysis. The student groups must decide what data to collect, how the data should be collected, and how the data should be analyzed to solve the experimental problem. The purpose of this is to get the students to make an intellectual commitment to the lab, not to make sure the students know the right answers at this point.

The lab format is similar to that of the discussion section: introduction, task, and closure. The main difference is that there is no set number of problems to complete; although, the goal is for each group to complete at least 2 problems in the two hour period. The students have the opportunity to return to a problem if their measurements conflict with their predictions. The role of the TAs is to coach the student groups through difficulties and weaknesses.

There are two kinds of lab problems, quantitative and qualitative. The quantitative problems require students to create a mathematical expression that they feel describes the system being investigated. The qualitative or 'exploratory' problems require students to use their intuition to predict how the system being investigated behaves. The labs do not currently use any computer data acquisition or analysis; however, the Physics Education Group at University of Minnesota has recently begun developing problem solving labs that use MBL tools and video analysis. They were scheduled to begin experimental implementation in the 1997 Summer quarter.

### 3. Difficulties[24]

There are three major difficulties in implementing the Group Problem Solving method. First, the method demands additional time from the lecturers to manage, coordinate, and observe the TAs. Second, the TAs must be educated in the story line of the course, students' common sense belief and everyday use of physics language, the problem solving strategy, cooperative group learning and their role as coaches, and constructive grading practices. Thirty hours of pre-course training are needed for new TAs to be effective and comfortable in their role. In addition, each new TA is assigned a mentor TA who observes them in class and gives feedback. Third, as with the other research-based teaching methods, both the lecturers and the TAs must break the cycle of teaching-as taught. They must be aware of the course structure and strategy as well as the student difficulties while preparing to teach this way. In particular, the lecturer must use this awareness in modeling the construction of knowledge through a story line and modeling problem solving in lecture. Also, as with tutorials the TAs must learn to guide and coach in a semi-Socratic manner similar to that used in tutorials and not just tell the students how to do it right.

**4. Internal evaluation**

An evaluation of this curriculum by the Minnesota group is in preparation.[25] However, Heller, Keith, and Anderson investigated the effects of this curriculum on the problem solving performance of students in an experimental section of the two-quarter algebra/trig based introductory course at University of Minnesota.[26] First, they developed and validated a rating scheme for problems to determine relative difficulty. Then they developed a scoring scheme to evaluate the student solutions. They defined 'better' student solutions as those exhibiting following six expert solution characteristics: evidence of conceptual understanding, usefulness of physics description, match of equations with physics description, reasonableness of plan, logical presentation, and appropriate mathematics.

They studied the student exam problem solutions for a single two-quarter sequence. Each exam had two parts: first, a context-rich problem to be solved in cooperative groups in the recitation, and second, a short qualitative problem and two context-rich problems to be solved individually in the lecture period the following day . The students received a solution to the group problem at the end of the group exam. In the first part of the study they studied individual and group student solutions of problems where the individual problem on the exam was of equal or of slightly less difficulty than the group problem on the same exam.

Using their expert solution scoring scheme, they found that that average score on the solutions to the group problems was more than three $\sigma$'s better than the individual solutions of the best student in each group as determined by exam grade. When the scores were broken down by category, the biggest differences were in the categories of evidence of conceptual understanding, usefulness of physics description, and the matching of equations with the physics description. By analyzing student solution scores over time, they also found evidence that top third, middle third, and bottom third of students improved at roughly the same rate in all categories except evidence of correct conceptual understanding.

Heller *et al.* also compared the problem solving skill of the experimental section with a traditional section.[27] Questionnaire results indicated that the students in the two sections had similar backgrounds and characteristics. Since even the easy context-rich problems were judged by the instructors of the traditional section to be too difficult for their students, two standard problems from the traditional section's final were used in the experimental section's final exam. The student solutions from both classes were evaluated using the expert characteristic scoring scheme described above. The students in the experimental class taught with group problem solving had an average score more than three standard deviations above that of the traditional section on both problems. Note that this does not reflect the numbers of students in either class who got the problems right; only that the students who were taught an explicit problem solving strategy as described wrote solutions that had more characteristics of expert problem solvers than the traditional class.

## D. Workshop Physics

### 1. Motivation

The first two research-based methods improve instruction by adapting the structure of the traditional large lecture class to make use of cooperative group activities while keeping the large lecture. But is the large lecture format, even with the modifications described above, the best way to teach physics? Priscilla Laws *et al.* decided to try another way. She and her colleagues at Dickinson College developed Workshop Physics, an activity-based laboratory curriculum. The Workshop Physics materials were developed from the outcomes of the available research in science education.[28] The primary goal of the designers for this curriculum was to help students acquire transferable skills of scientific inquiry based on real experiences. More specifically as stated in her recent project for disseminating Workshop Physics,[29] the goal of Workshop Physics is

*"… to enable students to:*

- construct conceptual models of phenomena and relate these to mathematical models;
- learn enough scientific literacy to learn without formal instruction;
- develop proficiency with computers and other research tools;
- appreciate science and want to learn more; and
- engage in the further study of science."

### 2. Implementation

The WP curriculum makes heavy use of spreadsheet, MBL, digital video analysis, and other integrated computer tools as well as devices that allow students to experience motions and forces with their own bodies (kinesthetic physics).[30] The use of MBL and digitized video allows the students to see graphical representations of physical systems in real time and to see how changing the conditions of an experiment affect the graph. Spreadsheets are used to create mathematical models that can be compared with the digitized data from experiments. The students meet for six hours a week in a laboratory classroom. The instructors still lecture at the beginning of each class, approximately one hour out of six per week, but the bulk of the time in class is spent performing and analyzing guided-discovery experiments working in groups of two to four students each. Part of the lecture time is spent going over homework problems. The course material is broken up into weekly units that have four parts:

1. exploration of the students preconceptions,
2. qualitative observations,
3. development of definitions and mathematical models, and
4. quantitative experiments centered on the mathematical models.

In addition to their in-class laboratory activities, the students also do homework problems out of a traditional text. Textbook-style problems are included as part of each exam. Students are allowed to use their activity guide on exams. The activity guide is a combination textbook, laboratory manual, and notebook. In addition to their weekly homework and classroom activities, the students are required to do a term physics project involving video analysis each semester. Past student projects have included the physics of Michael Jordan's lay-up and an analysis of cartoon motion.

Because of the additional time needed to cover material with this method, it is not possible to cover the same amount of material that a traditional course would cover. The Workshop Physics course[31] covers about 25% less material than was covered previously in the traditional one year calculus-based introductory physics course at

Dickinson College.  Each Workshop Physics institution makes it's own decisions as to what material is covered and what is left out.  At Dickinson College for example, they removed waves, AC circuits, optics, relativity, and quantum from their introductory course.  However, they did include some contemporary physics topics like chaos, radon monitoring, and digital electronics.

The classroom is specially designed to be conducive to group activities, classroom discussion, and demonstrations.  A typical class size is 24 students.  Each class has an instructor and an undergraduate TA (UTA) available during group work to listen and to help but not to give answers.  The UTAs and the Workshop Physics classroom are available to the students every weekday evening.  The UTAs are selected from students who have previously completed the Workshop Physics course.  They receive no other training.  They wander around the room while students are doing activities and give hints or suggestions if the students are very frustrated.  The UTAs also note completion of activities from the Activity Guide.  Other undergraduates are hired to grade for the course.

In the past two years at Dickinson College, they have begun assigning specially designed homework problems that incorporate the ideas and methods developed in class. Traditional text book problems were not providing good reinforcement of class activities.  According to Laws,[32]

> The text problems are too narrow in scope.  Students don't see how they relate to activities in class and many of them [text problems] allow for thoughtless plug and chug.  We like to assign extended problems that either have a context that extends in-class activities or something interesting and usually real world.  Often the assignments are many part problems that include conceptual questions and involve mathematical

analysis at the end [of the problem] after the students have thought about the probable behavior of the system from a qualitative perspective.

**3. Difficulties**

The Workshop Physics method at Dickinson College is very resource intensive in terms of equipment and instructors. The curriculum makes heavy use of digitized video, computers and sensor probes in addition to the standard laboratory equipment. There are at least two facilitators, the instructor and an undergraduate TA, in class at all times. Since the course is laboratory-based instead of lecture-based, class size is very limited. (Although, note that Jack Wilson at RPI has developed a similar introductory course called Studio Physics that can accommodate 50 students per class.[33])

The role of the instructor is important to the success of the course. The instructor needs to stay out of the way of the materials and not tell the students the answers. Poor scores on a concept test from a Workshop Physics class were traced to an instructor who basically used this format to lecture and teach a more traditional course. The instructor’s role in WP is to be more of a mentor, coach, and intellectual manager and much less of a traditional lecturer.[34]

**4. Internal evaluation**

The evaluation of Workshop Physics at Dickinson College uses several concept tests, exam results, and a survey of student attitudes[35] towards the introductory course. Students from the introductory course were tested before and after the Workshop Physics program was implemented at Dickinson. The preliminary results from a 1991 article can be summarized as follows (Note that no follow up report has yet been written).[36]

1. Based on written evaluations, two-thirds of the students in the calculus-based introductory class prefer the workshop approach over what they imagine a lecture approach to be.
2. Based on the results of "conceptual questions," a greater percentage of students master concepts that are considered difficult to teach because they involve classic student misconceptions.

[These conceptual questions range from multiple choice questions from concept tests such as the FMCE to qualitative exam problems from University of Washington similar to those described in the description of tutorials above.]

3. Performance of Workshop Physics students in upper-level physics classes and in solving traditional textbook problems is as good as that of students who had the traditional lecture course. Here, student performance is judged by scores, grades, and instructor impressions.
4. From observations by instructors and off-campus observers, the students who complete Workshop Physics are more comfortable working in a laboratory setting and more comfortable working with computers.
5. However, some students complain that Workshop Physics is too complex and demands too much time. It should be noted that the Workshop Physics students in this study worked an average of seven hours a week outside of class on physics. However, in a poll conducted by Laws the average time spent outside of class for physics at 16 other colleges was 6.5 hours.
6. A small percentage of students thoroughly dislike the Workshop Physics approach. They tend to be juniors and seniors who have been successful with more traditional instruction.[37]

[From my own observations and conversations with peers in my field, it seems that whenever an active learning format is implemented, it takes students anywhere from weeks to months to adapt and appreciate it.[38] About 10-20% of the students never seem to make this transition.]

One additional note is that of the three research-based curricula in this dissertation, Workshop Physics has been the most widely adopted. In fact, the chemistry and mathematics departments at Dickinson College have adopted this approach for introductory courses in chemistry, statistics, and calculus. However, few of the other schools implementing Workshop Physics have achieved the same degree of success as Dickinson College. Details on differences in implementations for adopting schools are described in the next section.

## IV. COURSES AND IMPLEMENTATIONS

Even if two schools use the same curriculum, the implementation may differ significantly due to differences in philosophy, resources, or student populations. Even two traditional courses at different schools may have subtle differences that would affect a study of this nature. The previous section described the four teaching methods used by introductory classes participating in this investigation. This section will review the implementation of each curriculum at each institution. A summary of the ten classes involved in this study is given in Table 8-2. A list of topics covered by each class broken down by terms is given in Table 8-3.

Special attention is paid to how the first-term mechanics section of introductory physics is taught since the concept tests described in chapter 4 and reported on in chapter 9 look primarily at students' understanding of Newtonian ideas of force.

### A. Traditional

#### 1. University of Maryland (UMD)

The introductory course at Maryland for engineering students is typical of such courses offered across the country with a few special characteristics. It is a three-semester sequence with no laboratory in the first semester. The second semester laboratory begins with mechanics experiments based on material from the first semester course. Note that both physics majors and pre-medicine majors are encouraged to take other introductory sequences. In the Fall 1996 semester the laboratory in the second and third semesters was increased from two hours to three hours in a move to de-emphasize the formal lab report and give students class time to finish their lab write-ups in class. The weekly course format for each semester is as follows:

| 1st Semester | 2nd Semester | 3rd Semester |
|---|---|---|
| 2-3 Lectures/wk | 2-3 Lectures / wk | 2-3 Lectures/wk |
| 150 min/wk | 150 min/wk | 150 min/wk |
| 1 Recitation/wk | 1 Recitation/wk | 1 Recitation/wk |
| 50 min/wk | 50 min/wk | 50 min/wk |
| no laboratory | 1 laboratory/wk | 1 laboratory/wk |
| | 110-170 min/wk | 110-170 min/wk |

The size of a lecture varies from about 40 to 170 students depending largely on whether the class is offered on or off sequence and at what time the class is offered. Evening classes were specifically excluded from the study to control for population variation, i.e. a large number of non-traditional students. Two or three midterm exams plus a final exam are given each semester. Students are often given key equations on exams or allowed to bring a reference sheet into the exam. The course textbook is selected by a faculty committee. Homework from the lecture course usually consists of a reading assignment and 10-14 end-of-chapter problems each week. In some semesters the lecturers for a course may confer and assign common homework problems. Homework solutions are usually posted shortly after the assignment is collected.

Recitation and laboratory section size varies from 10-30 students per section. Sections of 20-25 students are typical. The laboratory sections are taught as a separate course. They are the responsibility of a separate laboratory instructor and they are taught by separate laboratory TAs. Students can take any laboratory associated with the course but must take a recitation section associated with a particular lecture instructor.

The recitations are taught by recitation TAs who report to the lecture instructors. Most weeks there is a ten-minute quiz in the recitation section. Attendance is usually poor in recitation sections if quizzes are not given. Outside of class, students can take their questions from the reading, lecture, or homework to their lecture instructor's office hours or their TA's office hours. Additional help on homework is available from the Slawsky Clinic. The Slawsky Clinic is run by two retired physicists and offers help to students on specific homework problems.

We studied this sequence from the Fall 1991 semester through the Spring 1997 semester. Different aspects of the sequence were studied at different times during this period. Details on the data collected are given in table 8-4. MPEX and demonstration interviews were held with many students from Spring 1994 through Fall 1996.

**2. Prince Georges Community College (PGCC)**

The calculus-based introductory sequence at Prince Georges is a three-semester sequence designed to duplicate the introductory physics for engineers' sequence at Maryland with three exceptions. First, the class size is only 10-25 students. Second, all parts of the course are taught and graded by a single instructor. There are no TAs. Third, although the content coverage of the two courses is the same, the order of the topics is different as shown in table 8-3. For example: The second semester of the traditional course at Prince Georges covers electricity and magnetism while the Maryland course cover vibrations, waves, sound, fluids, heat & temperature, and electricity with magnetism covered in the third semester. Also, they have not yet followed Maryland's increase in lab time from 110 to 170 minutes per week in the second and third semesters.

There were no MBL activities or computer-assisted demonstrations at PGCC during this study.

Classes from Prince Georges Community College participated in this study from the 1994 fall semester through the 1996 spring semester. Because of the small class sizes, both day and evening students were studied. I interviewed two students in the 1994-5 academic year.

**3. Carroll College (CAR)**

The calculus-based introductory sequence at Carroll College is a typical, traditional two-semester course primarily designed for science majors. The course is unusual in that it meets for four hours of lecture and three hours of laboratory each week. There is no recitation section *per se*. The lecture is taught in a traditional format with demonstrations occurring on a regular basis. The instructor makes regular use of the computer for presentations, simulations, and demonstrations.

Classes from Carroll College participated in the study during the 1995-96 and 1996-97 school years. The instructors believe that the students in these classes were typical for this sequence. No interviews were conducted.

**B. Tutorials - University of Maryland (UMD)**

In the tutorial method as implemented at University of Maryland, the main difference with traditional lecture classes is that tutorials replace the traditional recitation. Since the fall semester of 1993, Maryland has been implementing tutorials in one or more of the classes in the engineering sequence each semester. The tutorials are run by the Physics Education Research Group (PERG) under Redish and Steinberg.

Although initially the tutorials were implemented in very much the same style as described in the previous section at University of Washington, the current implementation at Maryland differs in some ways from the implementation at University of Washington.

To begin with, Maryland has no laboratory tutorials. Instructors are encouraged to participate in the weekly training meeting as well as in the tutorials themselves. Undergraduate TAs are sometimes used as facilitators to make sure that there are at least two facilitators in each section. In addition, the PER group at Maryland has developed tutorials that make use of microcomputer based laboratory (MBL) equipment, digitized video (for waves and sound), and computer simulations (primarily using M.U.P.P.E.T[39] and EM Fields[40]) as well as tutorials that focus on mathematical ideas. In the first semester course, which covers mechanics, the University of Washington tutorials are supplemented with 3 MBL tutorials.

These three MBL tutorials assist students with the concepts of instantaneous velocity, Newton's 2$^{nd}$ Law, and Newton's 3$^{rd}$ Law. All three tutorials were created and implemented by us in the 1994-95 school year. Like the University of Washington Tutorials, each has undergone successive refinement. Our MBL equipment is a computer connected to a universal laboratory interface box (ULI) with a sonic ranger and two force probes.[41] These tutorials are included in Appendix D.

Redish and I wrote the instantaneous velocity tutorial based directly on the MBL activities developed by Thornton and Sokoloff labs in *Tools for Scientific Thinking*.[42] We extracted from their velocity labs what we considered the essential elements, following the guidance in their paper.[43] In the tutorial, students walk in front of a sonic ranger which provides immediate feedback and reduces data-collection drudgery. In the tutorial, students use their own bodies to

1. familiarize themselves with the equipment by creating a series of position graphs;
2. create a series of simple velocity graphs;
3. match a given complex velocity graph.[44]

In each case, the students work together in groups of three or four. They discuss and make predictions of what the graph will look like or how they have to move in order to produce the desired result and they write these predictions on their worksheets. The entire activity is easily completed in one fifty-minute period.

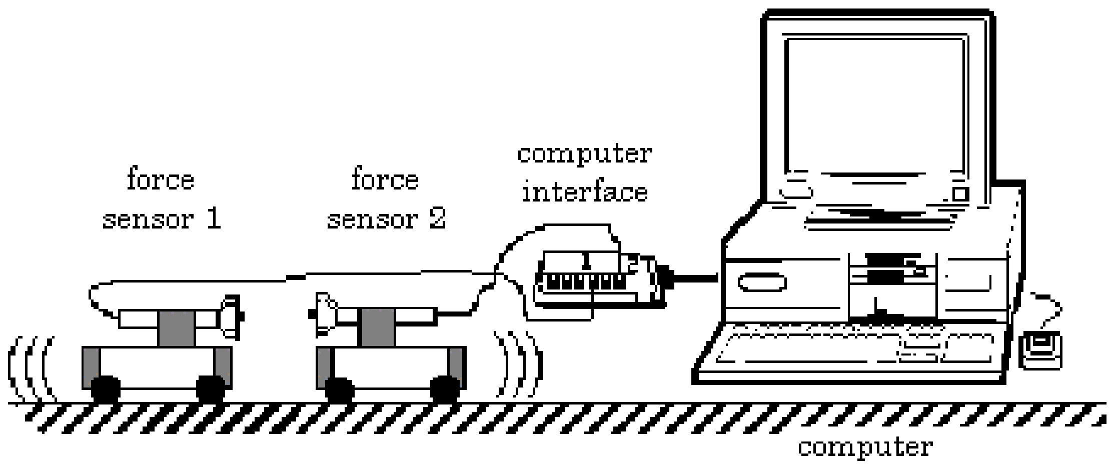
I wrote the Newton's second law tutorial based on activities developed by Morse,[45] Laws, Thornton, and Sokoloff.[34] Again, I extracted from their MBL labs what I considered the essential elements. In this tutorial, the students use the motion detector to analyze velocity-time graphs of the motion of a fan cart to determine its acceleration in various situations increasing in complexity. The students then compare the measured acceleration with predictions from an analysis of the forces from free-body diagrams.

I wrote the Newton's third law tutorial based on suggestions of Laws, Thornton and Sokoloff.[46] Newton's third law is explored by having students connect the force probes to two low-friction carts and observe the result of their interaction. The apparatus is sketched in Fig. 8-1.[47]

In the tutorial, the students do the following:

1. first psychologically calibrate the force probe by pushing and pulling on it and watching the result on the computer screen;
2. predict the relative size of forces for a light car pushing a heavy truck;

Figure 8-1. The arrangement for the Newton 3 tutorial.




3. predict and observe the forces two identical carts exert on each other when one pushes the other;
4. predict and observe the forces two carts exert on each other when one is weighted with iron blocks;
5. predict and observe the forces two identical carts exert on each other when one collides with the other;
6. predict and observe the forces two carts exert on each other when one collides with a second weighted with iron blocks.

In addition, the students are asked to draw free-body diagrams and use them in their predictions. Again, this activity is easily completed in one fifty-minute period. This sequence taught with tutorials was studied from the Fall 1993 semester through the Spring 1997 semester. However, like the University of Maryland traditional classes, different aspects of the sequence were studied at different times during this period. Details on the collected data are available in table 8-4. MPEX and demonstration interviews were held with many students from Spring 1994 through Fall 1996.

## C. Group Problem Solving and Problem Solving Labs

### 1. University of Minnesota (MIN)

The University of Minnesota has developed and implemented the GPS curriculum in their calculus-based introductory sequence. The GPS recitations and Problem Solving Labs were run by the physics education group at Minnesota from fall 1993 until spring 1996. In the fall 1996 semester responsibility for the course passed to the physics department. Unfortunately, several of the professors were new to the project and did not adequately supervise the TAs. As a result, the students were not encouraged to work in cooperative groups in recitations or labs, and the problems assigned did not follow the guidelines for context rich problems.[48] Also, the mentor TAs afforded less time to supervise the new TAs. Based on their own evaluation, the physics education group considers the Fall 1996 to Spring 1997 sequence to have been essentially taught with traditional instruction.

The sequence was studied using pre/post diagnostic tests from Fall quarter 1994 through Spring 1997. Details on the data collected can be found in table 8-4. Note that only FCI and MPEX was collected from the classes at the University of Minnesota.

### 2. The Ohio State University (OSU)

The engineering sequence at OSU is a three-quarter sequence with mechanics in the first quarter, electricity and magnetism in the second quarter, and oscillations, waves, optics & modern physics in the third quarter.[49] In the 1994-95 school year, Allen Van Heuvelen began implementing the GPS approach into this formerly traditional introductory physics sequence. Van Heuvelen is a member of the physics education group (PEG) at OSU and is well known for his own efforts in curriculum development with introductory physics courses.[50] Because the enrollment in the sequence is approximately 900 students a quarter and because the physics education group was just starting at that time, these changes were implemented by the physics department with regular graduate TAs. There was no special effort to put PEG graduate students as TAs for this course, but there was extensive TA preparation for the graduate students in the summer training program. A large portion of this program is given to surveying the literature on physics education research and physics curriculum development as well as providing TA training. The GPS implementation at OSU is based heavily on the implementation at MIN; however, there are significant differences in all three components of the course: lecture, recitation and lab.

> *Lecture*: (3 hours per week) The lecturers teach in their own way. Some instructors give very traditional lectures; others make substantial use of interactive lecture demonstrations (discussed previously in chapter 2). No attempt is made to model problem solving in lecture nor is any explicit problem solving strategy discussed. Homework is graded on how much of the assignment is attempted. Solutions are posted shortly after the homework is turned in. There are two midterm exams and a final exam every quarter.
>
> *Recitation:* (two 48 minute recitations per week) This is the only sequence in the study that has two recitation sections per week. The first weekly recitation is used for group problem solving. Students are assigned into groups at random and the student groups stay the same though out the quarter. Group roles are not assigned and there is no group evaluation of how to improve the group dynamics. The problems come from either ALPS Kits[51] or context rich problems from Minnesota and OSU. The TAs try to go over the group problems at the end of the class but if there is not enough time the problem will be discussed in the second weekly recitation. Students do a group exam problem in recitation either before or after each midterm and final exam.
>
> The second weekly recitation is mainly for going over homework interactively. The TA uses semi-Socratic dialog to get the students to discuss the problem and work through it as a class. The last 18 minutes of the recitation are used for a quiz based on the homework. The TAs grade student homework during the quiz by checking to see if two problems on the assignment were done

before passing the homework back at the end of the recitation. The students do not receive any feedback on the homework.

Each recitation section is associated with a particular lecture class. The recitation TAs meet weekly with their respective lecture instructor for an hour and a half to discuss how the class is going, where the students are having difficulties, and what problems will be used for group work and the quiz that week. The TAs spend one of their two office hours each week in the tutoring room which is open to students forty hours a week. While there is no discussion of problem solving strategies in the recitation, some TAs do go over strategies in recitation. Also, some of the ALPs problems lead the student through a strategy that emphasizes physics representations and an evaluation of the solution.

*Laboratory:* (1 two hour lab per week) The laboratory is conducted with cooperative groups performing problem solving laboratories similar to those in at Minnesota and guided investigative labs similar to Workshop Physics activities. Like Minnesota, in the PSL activities the OSU students are asked to design an experiment and make a prediction before they do the experiment. The student groups do the labs on worksheets and are checked out before they leave. The student groups are not the same as those in recitation and students from any lecture section may take any laboratory section. There is no effort made to coordinate the lab with a particular lecture class. Some laboratories are run by undergraduate TAs (UTAs) who have not gone through the 10 week summer program. The UTAs are mainly trained by a graduate super TA, who runs the laboratory portion of the course.

Occasionally experimental classes are taught by faculty from the physics education group to try out new ideas. One area being re-evaluated is the use of the GIL activities in laboratory. Van Heuvelen comments that they do not seem to work as well as they should.[52] The students do the activities but they do not seem to think deeply on what is learned. This parallels my own experience with similar materials at PGC. While Van Heuvelen is satisfied with the active-engagement activities for the first two quarters of the sequence, they are still developing the activities for the third quarter of the sequence.

A physics education graduate student at Ohio State commented that not all lecture instructors or TAs are equivalent. Some differ significantly in their attitudes and skills concerning cooperative group activities.[53] Some faculty and TAs use the cooperative group activities very effectively; others do not. Roughly three-fourths of the lecture faculty seem to want the cooperative group activities to work and support it with group work in lecture. The remainder do minimal or no group work in lecture. In fact, some faculty used the group work in recitation and laboratory only because it was required. In these cases, the group work did not fit well with the rest of the class.[54] This negatively affected both the students' and TAs' outlook towards the recitation and the lab.

We collected diagnostic test data at various times from the engineering sequence beginning in the 1995 winter and spring quarters and continuing through the 1996-1997 academic year. I conducted interviews with twenty-five students from all three quarters of this introductory sequence at the end of the winter 1995 quarter.

## D. Workshop Physics

### 1. Dickinson College (DCK)

The calculus-based Workshop Physics course at Dickinson College is a two-semester sequence. Some topics normally covered in a traditional introductory course are not included in the first year course. Waves and optics, for example, are covered in the 2nd year physics course for majors. The details of the implementation of Workshop Physics at Dickinson are described in the previous section. The mechanics modules make heavy use of MBL and spreadsheets.

As this is the only calculus-based introductory physics course offered, only a few of the students in the course are physics majors. The rest of the students are mainly liberal arts, education, and pre-med majors.

We collected pre/post diagnostic test data from the introductory sequence at Dickinson College from the 1994 fall semester through the 1997 spring semester. I interviewed eight students at Dickinson at the end of the 1994 fall semester, eight students at the beginning of the 1995 fall semester, and six students the end of the spring 1996 semester.

**2. Drury College (DRY)**

During our study, Drury College was is in transition from a traditional lecture format to the Workshop Physics format. They began implementing Workshop Physics in Fall 1995. During their participation in our study, one algebra/trig based class and their only calculus based class were taught in the Workshop format. Two additional algebra/trig courses were taught in parallel in the traditional lecture format. The calculus-based class used the activity guide from Dickinson College with the addition of a unit on optics from a sophomore level physics course at Dickinson.

While the program and equipment are similar to those at Dickinson, there are two major logistical differences. There is only one instructor in the room and the room itself is a traditional lab room with three long benches that is not conducive to cooperative group work or class discussions. The students in the calculus-based course are mainly science and pre-med majors. (However, most pre-meds take the algebra/trig-based course.)

I made a site visit at the end of the Spring 1997 semester to observe Drury's WP classes and interview several student volunteers. Because of the small size of the calculus-based class (8 students), having only one instructor is not a problem and despite the room layout, the three groups of 3-4 students each appeared to be working well. In the class I observed, there was a short lecture on the day's topics and then the students went to work on their activities. At the end of class there was a discussion on what the students had found.

We collected diagnostic test data from one complete sequence during the 1996-97 academic year. Four students from the calculus-based class were interviewed during my site visit.

### 3. Moorhead State University (MSU)

Moorhead State University had been running Workshop Physics classes for two years before participating in this study during the 1995-6 school year. The implementation was as close to the Dickinson implementation at they could make it. However, there were some differences. Because MSU does not use undergraduate TAs, there was only one instructor was in the classroom at all times. Also, MSU found that they need lab technician support for setup and repair of the lab equipment and the computer network to keep the WP laboratory running smoothly. There were also significant differences between the student population at MSU and the Dickinson students. The students in the MSU class were mostly engineering and chemistry majors and they tend to be older and have more non-academic commitments. In addition, many of them work part-time. Also, Dickinson is selective in its admissions while MSU is not.

We collected diagnostic test data from the full sequence during the 1995-96 academic year. No site visits or interviews were conducted at MSU.

**4. Nebraska Wesleyan University (NWU)**

NWU has been teaching the Workshop Physics format since fall 1995. They began implementation of Workshop Physics with support from a FIPSE grant headed by Priscilla Laws at Dickinson College to help the implement Workshop Physics at six schools across the country. NWU teaches one introductory sequence that is a hybrid algebra/trig- and calculus-based course. They use the calculus-based Workshop Physics Activity Guide and an algebra/trig-level physics text. Several units from the activity guide were adapted from the algebra-based WP activity guide. Some of these units are still being refined. Calculus is not required for this course. Some topics are covered with dual approaches: "For those of you with calculus, do this, and for those of you who haven't, do that." At the end of one of these sections, the class discusses what was learned by both types of groups.

I attended one session of both WP classes during a site visit to NWU at the end of the 1997 spring semester. The room is quite suitable for group work with lab tables on the side and open space in the middle. The students work in groups of three to four. Like Drury, there is only one instructor in the room, but here there are 25 to 30 students per class. This is a problem when several of the groups simultaneously need guidance to proceed. As part of the FIPSE project, Workshop Physics developers including Laws also made site visits to NWU. While they report that the implementation is going well, they did observe some problems.[55] The two classes Laws observed in the 1997 Spring semester seemed to flow well. In her words,

> The students worked at a steady pace and engaged in thoughtful collaborative interchange. They identified good questions to discuss with each other as they moved through the materials. However, the students

> seemed less intense than those we have at Dickinson. The benefit of the slower pace was that the students worked through ideas more carefully and enjoyed each other's company. On the other hand, it has been hard for the faculty here to cover as much material as we do at Dickinson.

Because of the broader than normal background and interests of the students, there has been some difficulty in deciding what topics to include and how much coverage for each topic. Also, while every group has a computer with a ULI, there seemed to be insufficient lab equipment for each group to do some of the activities themselves. In addition, the faculty felt they needed lab technician support (not available at the time) for equipment repair and setup. The equipment problems should be resolved next year, thanks to additional grants.

We collected MPEX and FCI data from the two complete introductory sequences taught between fall 1995 and spring 1996. I interviewed 10 student volunteers combined from both classes during my site visit.

**5. Skidmore College (SKD)**

Skidmore College is a liberal arts college in upstate New York. They began implementing Workshop Physics in the fall 1996 semester in a new specially designed laboratory space. Skidmore is also one of the six school funded by FIPSE grant for the dissemination of Workshop Physics. The course is designed primarily for science majors, primarily biology, chemistry, and mathematics. The implementation is similar to Dickinson's with the following exceptions:

1. As at DRY, MSU, and NWU, no undergraduate TAs are used at Skidmore. However, a department staff member set ups the equipment and serves as a TA so two instructors were available in both classes of 20-25 students each.
2. They use the Dickinson activity guide but they cover only 70% of the content. Laws determined that this is due to a combination of Skidmore's

semester being shorter, the students working at a slower pace, and fewer home problems being assigned each week.[56] NWU has similar difficulties with covering material.

3. SKD did not have a lot of the equipment they needed and what they had often did not work in class.

The Skidmore instructors commented that some of the upper-division students, especially pre-meds, were very resistant to the Workshop Physics approach. They found it too slow and too frustrating. Laws has observed this resistance of upper-

Table 8-2: Description of Introductory Calculus-Based Classes Studied (na indicates this course does not have lecture or recitation)

| Institution | Teaching Method | Class size Lecture (rec / lab) | Lecture | Recitation | Laboratory | Comments |
|---|---|---|---|---|---|---|
| University of Maryland College Park, MD (UMD) | Traditional | 50-150 (25 / 25) | 3 hrs/wk by faculty | 1 hr/wk by 1 TA | 2-3 hrs/wk by TA | 3 semester sequence with no lab in the first semester |
| University of Maryland College Park, MD (UMD) | Tutorials | 50-150 (25 / 25) | 3 hrs/wk by faculty | 1 hr/wk by 2 TAs | 2-3 hrs/wk by 1 TA | Similar to UMD traditional with tutorials replacing recitation |
| University of Minnesota Minneapolis, MN (MIN) | Group Problem Solving | 150-200 (18 / 18) | 3 hrs/wk by faculty | 1 hr/wk by 1 TA | 2 hrs/wk by 1 TA | 3 quarter sequence / Integrated themes / Large Lecture with GPS in recitation and PSL in labs |
| Ohio State University, Columbus, OH (OSU) | Group Problem Solving | 150-180 (25 / 25) | 3 hrs/wk by faculty | 2 hrs/wk by 1 TA | 2 hrs/wk by 1 TA | 3 quarter sequence / Large Lecture with interactive demos/ GPS in recitation and PSL in labs |
| Carroll College Waukesha, WI (CAR) | Traditional | 15-20 (na / 16) | 4 hrs/wk by faculty | na | 3 hrs/wk by Lab Asst. | 2 semester Sequence / Will begin using Workshop Physics in F97 |
| Dickinson College Carlisle, PA (DCK) | Workshop Physics | na (na / 25) | na | na | 6 hrs/wk by faculty & 2 TAs | 2 semester sequence with minimal lecture / uses undergraduate TAs |
| Drury College Springfield, MO (DRU) | Workshop Physics | na (na / 10) | na | na | 6 hrs/week by faculty | 2 semester sequence with minimal lecture |
| Moorhead State University Moorhead, MN (MSU) | Workshop Physics | na (na / 20) | na | na | 6 hrs/week by faculty | 2 semester sequence with minimal lecture |
| Nebraska Wesleyan Univ. Lincoln, NE (NWU) | Workshop Physics | na (na / 25) | na | na | 6 hrs/week by faculty | 2 semester sequence with minimal lecture |
| Skidmore College (SKD) Saratoga Springs, NY | Workshop Physics | na (na / 25) | na | na | 6 hrs/week by faculty | 2 semester sequence with minimal lecture |
| Prince Georges Community College, MD (PGCC) | Traditional | 25 (25 / 25) | 3 hrs/wk by faculty | 1 hr/wk by faculty | 2 hrs/wk by faculty | 3 semester sequence with no lab in the first semester |

Table 8-3.

**Table 8-4: summary of the Data collected for each course at each schools**

division pre-meds in Workshop Physics implementations at other schools including Dickinson.[57] She suggests that these pre-med students often fail to see how physics might apply to medicine and want to be able to get an A with a minimum time investment. We will come back to this issue in chapter 10.[58]

We collected FCI and MPEX Data from both calculus-based WP classes taught in the 1996 fall semester.

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[1] See for example: R.K. Thornton and D.R. Sokoloff, "Learning motion concepts using real time microcomputer-base laboratory tools," *Am. J. Phys.* **58** (9), 858-867 (1990); L.C. McDermott, "Millikan Lecture 1990: What we teach and what is learned — Closing the gap," *Am. J. Phys*. **59** (4), 301-315 (1990); R.R. Hake, "Active-engagement vs. traditional methods: A six thousand student study of mechanics test data for introductory physics courses," *Am. J. Phys*. **66** (1), 64-74 (1998).

[2] Personal observations from site visits and private communications with Edward F. Redish (UMD), Richard N. Steinberg (UMD), Priscilla Laws (DCK), Tom Foster (MIN), Chris Cooksey (OSU), Pat Cooney (Millersville College), Peter Shaffer (University of Washington), and Gregory Francis (Montana State University, Bozeman).

[3] Edward T. Custard, *The Princeton Review Student Advantage Guide: The Complete Book of College* (Princeton Review Publishing, New York NY, 1996).

[4] Test score averages are for students who entered that institution in 1995.

[5] E.F. Redish and J.S. Rigden (Eds.), *AIP Conference Proceedings No. 399 The Changing Role of Physics Departments in Modern Universities: Proceedings of the International Conference on Undergraduate Physics Education* (AIP Press, Sunnyvale NY, 1997).

[6] D. Hammer, "Two approaches to learning physics," *Phys. Teach.* **27** (9), 664-670 (1989).

[7] L.C. McDermott and P.S. Shaffer, *Tutorials in Introductory Physics* (Preliminary edition) (Prentice Hall, Upper Saddle River NY, 1997); For a description of tutorials as used at the University of Washington and an experimental result using them, see P.S. Shaffer and L.C. McDermott, "Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of an instructional strategy," *Am. J. Phys.* **60**, 1003-1013 (1992); L.C. McDermott, P.S. Shaffer, and M.D.

Somers, "Research as a guide for teaching introductory mechanics: An illustration in the context of the Atwoods's machine", *Am. J. Phys*. **62,** 46-55 (1994); L.C. McDermott, “Bridging the gap between teaching and learning: The role of research,” in *AIP Conference Proceedings No. 399 The Changing Role of the Physics Department: Proceedings of the International Conference on Undergraduate Physics Education*, edited by E.F. Redish and J.S. Rigden (American Institute of Physics, Woodbury, NY 1997), 139-166.

[8] L.C. McDermott, *Physics by Inquiry,* 2 Vols. (Wiley, New York NY, 1995).

[9] R.A. Morse, “The classic method of Mrs. Socrates,” *Phys. Teach*. **32**, 276-277 (1994).

[10] P.S. Shaffer, *Research as a Guide for Improving Instruction in Introductory Physics*, Ph.D. Dissertation, University of Washington (1993, unpublished).

[11] See Ref. 10

[12] See Refs. 7 & 10.

[13] P. Heller, T. Foster, and K. Heller, “Cooperative Group Problem Solving,” in *AIP Conference Proceedings No. 399 The Changing Role of Physics Departments in Modern Universities: Proceedings of the International Conference on Undergraduate Physics Education,* edited by E.F. Redish and J.S. Rigden (AIP Press, Sunnyvale NY, 1997), 913-934.

[14] There is an indication of this found in two comments frequently heard by physics instructors, “I understand the material, but I just can’t solve the problems,” and , “I can do the physics but I don’t understand ‘the theory’.” Note: Students in introductory courses often refer to the physics concepts and/or formula derivations as ‘the theory’.

[15] P. Heller, R. Keith, and S. Anderson, “Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving,” *Am. J. Phys*. **60** (7), 627-636 (1992).

[16] F. Lawrenz, R. Keith, P. Heller, and K. Heller, “Training the TA,” *J. Coll. Sci. Teach*. **22** (3), 106-109 (1992).

[17] See Ref. 13.

[18] The University of Minnesota Web pages offer a detailed description and course materials from the Group Problem Solving and Problem Solving Labs curriculum. (URL: www.physics.umn.edu/groups/physed/ )

[19] F. Reif and J.I. Heller, "Knowledge structures and problem solving in physics," *Ed. Psych.* **17** (2), 102-127 (1982).

[20] A.H. Shoenfeld, *Mathematical Problem Solving* (Academic, San Diego, CA, 1985).

[21] See Ref. 15.

[22] P. Heller and M. Hollabaugh, "Teaching problem solving through cooperative grouping. Part 2: Designing Problems and cooperative groups," *Am. J. Phys* **60 (**7), 637-644 (1992).

[23] See Ref. 22.

[24] The material in this section comes from Ref. (Heller), private communications with Tom Foster (the senior graduate student in the PER group at University of Minnesota, 1997), and the University of Minnesota Physics Education Research and Development web page at www.physics.umn.edu/groups/physed/ .

[25] T. Foster, *The Development of Students' Problem-solving Skill from Instruction Emphasizing Qualitative Problem-solving*, Ph.D. Dissertation, University of Minnesota (1998, unpublished).

[26] See Ref. 15.

[27] See Ref. 15.

[28] P. W. Laws, "Calculus-based physics without lectures," *Phys. Today* **44** (12), 24-31 (December 1991).

[29] Private communication with Priscilla Laws, Dickinson College, Fall 1995.

[30] H. Pfister and P. Laws, "Kinesthesia-1: Apparatus to experience 1-D motion," *Phys. Teach*. **33** (4), 214-220 (1995).

[31] See P.W. Laws, *Workshop Physics Activity Guide* (John Wiley & Sons, New York NY, 1997).

[32] Private communication with Priscilla Laws, Summer 1997.

[33] J.M. Wilson, "The CUPLE physics studio," *Phys. Teach*. **32** (10), 518-523 (1994).

[34] Private communication with Priscilla Laws, Dickinson College, Summer 1997.

[35] This does not refer to the MPEX survey but another survey that Laws developed and used for her own purposes in the late 1980's.

[36] See Ref. 28.

[37] P.W. Laws, P.J. Rossborough, and F.J. Poodry, "Women's responses to an activity-based introductory physics program," in *Fostering Student Success in Quantitative Gateway Courses*, edited by J. Gainen and E.W. Willemsen (Josey-Bass Publishing, San Francisco CA, 1995), 77-88.

[38] Private communications with Edward Redish, Pat Cooney, Priscilla Laws, Tom Foster, and Karen Keppler.

[39] E.F. Redish and J.M. Wilson, "Student programming in the introductory physics course: M.U.P.P.E.T., *Am. J. Phys*. **61** (3), 222-232 (1993); E.F. Redish, I. Johnston, and J.M. Wilson, *The M.U.P.P.E.T. Utilities* (Physics Academic Software, Raleigh NC, 1994).

[40] D. Trowbridge and B. Sherwood, *EM Fields: A program for studying electric and magnetic fields*, version 4.2 (Physics Academic Software, Raleigh NC, 1993).

[41] We used Intel 386, 486, and Macintosh SE personal computers. The ULI, sonic ranger, and force probes are from Vernier software, Portland, OR. Only the Motion and Datalogger software that comes bundled with the ULI were needed. Two Pasco carts or their equivalents are also required for the Newton 3 tutorial. A fan assembly was used in the Newton 2 tutorial. The current cost of the required equipment is about $2000 per station (including the computer.)

[42] Ronald K. Thornton and David R. Sokoloff, *Tools for Scientific Thinking* (Vernier Software, Portland OR, 1992 and 1993).

[43] R.K. Thornton and D.R. Sokoloff, "Learning motion concepts using real-time microcomputer-based laboratory tools," Am J. Phys. 58, 858-867 (1990).

[44] See Ref. 43, Figure 2..

[45] R.A. Morse, "Acceleration and net force: An experiment with the force probe," *Phys. Teach*. **31** (4), 224-226 (1993); R.A. Morse, "Constant acceleration: Experiments with a fan driven dynamics cart," *Phys. Teach*. **31** (8), 436-438 (1993).

[46] P. W. Laws, R. K. Thornton, and D.R. Sokoloff, *RealTime Physics* (Vernier Software, Portland OR, 1995); P.W. Laws, "A new order for mechanics," *Proc. of the Conference on the Introductory Physics Course*, Rensselaer Polytechnic Institute, Troy, NY, May 20-23, 1992, edited by Jack Wilson (Wiley, New York, 1997), 125-136.

[47] See Ref. 43.

[48] Private communication with Tom Foster, who ran the laboratory and recitation parts of the curriculum from 1994-5 (Summer 1997).

[49] There are no written materials available describing the implementation of the group problem solving curriculum at OSU. Consequently, the sources for the information on this sequence at OSU are private communications with Alan Van Heuvelen, Ed Adelson, and graduate students in the physics education research group at OSU as well as personal observations during a site visit.

[50] A. Van Heuvelen, "Overview, Case Study," *Am J. Phys*. **59** (10), 898-906 (1991); A. Van Heuvelen, "Using interactive simulations for conceptual development and problem solving," in *AIP Conference Proceedings No. 399 The Changing Role of Physics Departments in Modern Universities: Proceedings of the International Conference on Undergraduate Physics Education, edited by* E.F. Redish and J.S. Rigden (AIP Press, Sunnyvale NY, 1997), 1119-1136.

[51] A. Van Heuvelen, *ALPS: Mechanics* (Vol. 1), *Electricity and Magnetism* (Vol. 2) (Hayden-McNeil Publishing, Westland MI, 1994).

[52] Private communication with Alan Van Heuvelen at the Ohio State University, Summer 1997.

[53] Private communication with Chris Cooksey, a physics education graduate student at the Ohio State University who worked closely with this sequence during Ohio State's participation in this study, Fall 1997.

[54] See Ref. 53.

[55] Private communications with Priscilla Laws, Dickinson College, Fall 1997.

[56] See Ref. 55..

[57] See Ref. 37.

[58] See Ref. 56.