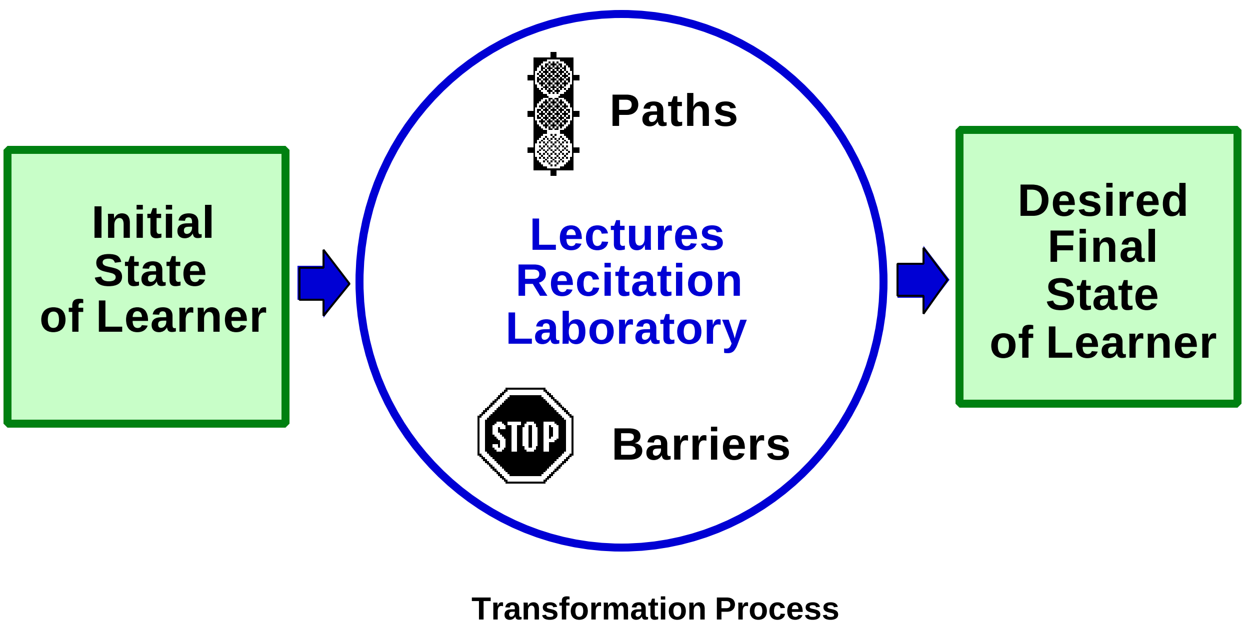
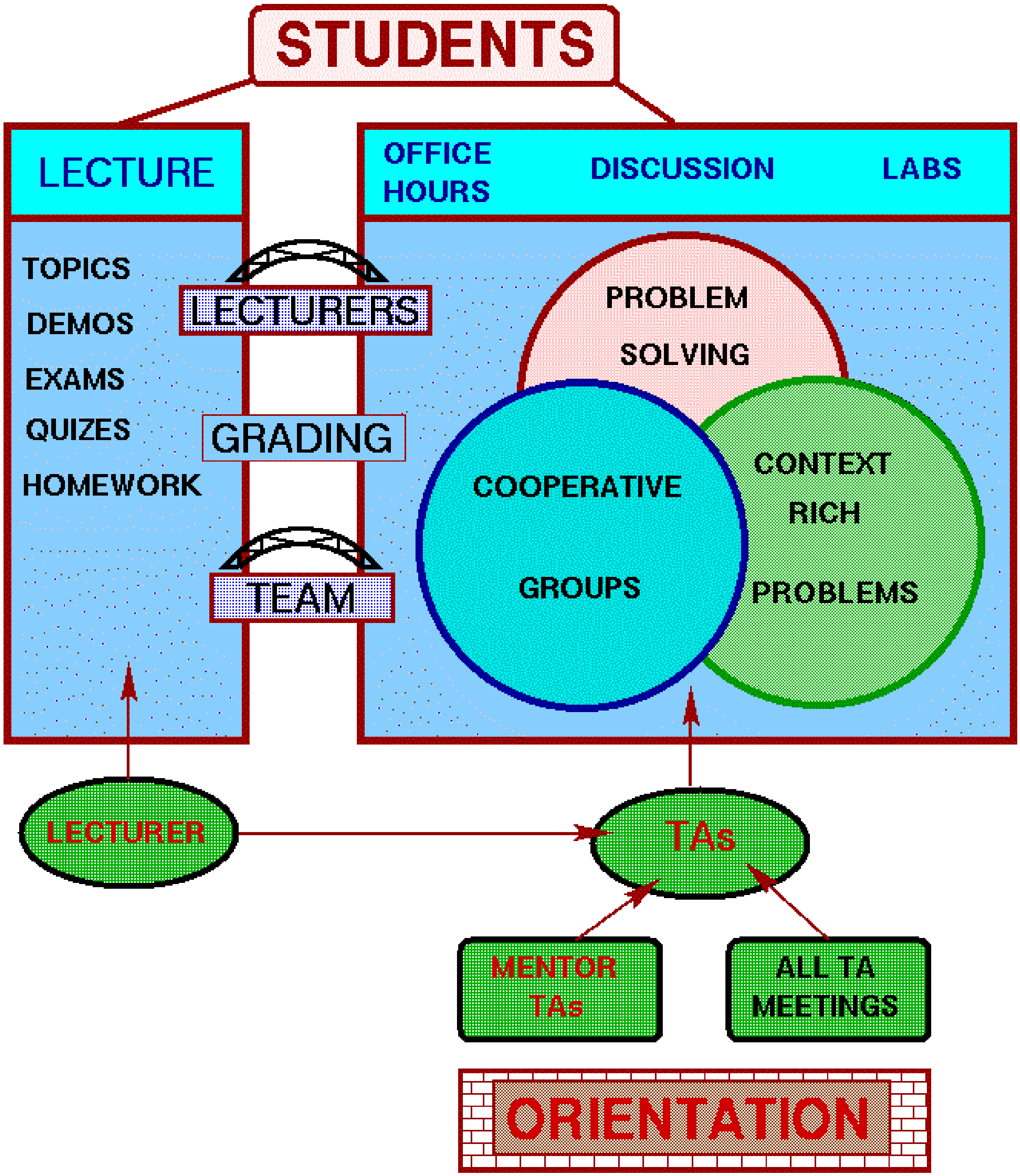
1. The Minnesota Model for Large Introductory Courses

This chapter gives a general background for all the components of the model for teaching large introductory physics courses at the University of Minnesota.

Instructional Design Model



University of Minnesota Collaborative Model
for Large Introductory Courses



Minnesota Model for Large Introductory Courses

I. INTRODUCTION

Recently there has been a movement recognizing the need for inventing and investigating innovative new models for teaching introductory physics.[1] These models seek to radically change the content of future courses, the structure of the courses, or both. For the present, however, we have been developing a conservative model that conforms with the usual structure and focus of the large introductory physics course in the United States, and is based on educational principles which have been widely accepted in the literature for some time. The application of these principles to the standard introductory physics course yields a result which is far from traditional.

The Minnesota model is based on the familiar triad of lectures, laboratories, and recitation (discussion) sections. The lectures are given by a professor with the laboratories and discussion sections conducted by graduate student teaching assistants (TAs). As is also traditional, the focus of the course is learning classical physics through solving problems. However, the specific content and instructional design are reorganized to better target students' learning needs. The model recognizes the existence and power of student preconceptions, the need for a "story line" to provide students with a conceptual framework for restructuring their preconceptions, and the need to teach explicitly a problem-solving heuristic. The model also recognizes that teaching encompasses several different actions which are most efficiently carried out in different environments. These environments are closely integrated to form a complete and coherent course.

II. THE INSTRUCTIONAL DESIGN

The goal of any instructional design is the transformation of students from an initial state to a final state of improved intellectual performance.[2] To achieve this goal, four basic problems must be analyzed: (1) What do students know and how do they think about physics when in the initial state before instruction? (2) What is the desired final state of intellectual performance after instruction, and what are the underlying knowledge and thought processes needed for the desired performance? (3) What learning and teaching practices take students from the initial to the final state? (4) What are the implementation methods by which we can achieve this transformation process?

A. What is the Initial State of the Learner?

There is a rapidly expanding body of research that characterizes the knowledge and thought processes beginning students bring to physics instruction.[3] When students listen to a lecture, read the textbook, or see a physical event, they interpret that sensory input in terms of their existing knowledge structure. Their knowledge structures usually include intuitive conceptions or "misconceptions" that have proven to be highly resistant to change.[4] Students also have misconceptions about the techniques of physics such as problem solving and experimentation. Indeed, most students have fundamental misconceptions about both the nature of scientific knowledge and the process of learning science. Students view scientific knowledge as a fixed and immutable collection of unrelated facts and formulas that have little connection to the real world. Their role as students is to memorize the facts and formulas and reproduce them on exams.[5] Thus, students tend to be passive learners. Their strategies for learning overemphasize the lower-order thinking skills of recall and comprehension, rather than the higher-order skills of analysis, synthesis and evaluation.

The traditional approach of using problem solving as a tool to teach physics is hampered because beginning students typically do not really know how to solve problems. ("I understand the material, I just can't solve the problems.") Students tend to get answers to problems by recognizing a memorized solution pattern for a given situation (e.g., block sliding down an inclined plane). To solve a problem, they select the "right" equation for the situation and plug in numbers. If necessary, they select the next equation and plug in numbers, and so on until an answer is obtained.[6] Students typically do not use their conceptual knowledge of physics to qualitatively analyze the problem situation, nor do they plan a solution before they begin numerical and algebraic manipulations of equations. Since they have little understanding of the logical relationship of the parts of a solution, these students are usually not able to generalize that solution to similar problems with different objects or events. ("I can follow the example problems in the text, but your test problems are too different.") Furthermore, students apply the same type of situation-specific reasoning to the laboratory and rarely view the laboratory as another aspect of problem solving. In this case, the students search for the "right" measurements to prove the validity of some equation.

B. What is the desired final state of the learner?

To determine an appropriate final state of intellectual performance for students in our introductory physics course, we surveyed the faculty in the departments that require the course. The survey revealed that their most important goals were for students to: (1) learn the fundamental principles of physics (e.g., force laws, conservation of energy, conservation of momentum); (2) learn general qualitative and quantitative problem-solving skills that they can apply to new situations.

To attain these goals, students must restructure their preexisting knowledge so the fundamental concepts and principles of physics can be remembered and appropriately retrieved for problem solving. They must also learn the thought processes required for problem solving: generating a description of the problem that makes it easier to solve, making judicious decisions in reaching a solution, and testing and evaluating the solution.

C. What instructional transformation processes take learners from the initial to the final state?

We found the cognitive apprenticeship model of learning and teaching to be a useful starting point for designing instruction that would transform students from their initial state to the desired final state of intellectual performance described above. Cognitive apprenticeship is an adaptation of traditional apprenticeship methods for teaching people to become experts in carrying out a complex physical tasks. Traditional apprentices are not segregated in special learning environments -- they are immersed in a "culture of expert practice." For example, a new apprentice would learn tailoring in a busy tailor shop, where he or she is surrounded both by master tailors and other apprentices, all engaged in the practice of tailoring at varying levels of expertise.

Masters teach apprentices through a combination of activities called modeling, coaching and fading. In this sequence of activities, the apprentice repeatedly observes the master executing (or modeling) the target process, which usually involves many different but related subskills. This observation allows the apprentice to build a conceptual model of the processes required to accomplish the task. The apprentice then attempts to execute each process with guidance and help from the master (i.e., coaching). A key aspect of coaching is the provision of "scaffolding," which is the support, in the form of reminders or help, that the apprentice requires to approximate the execution of the entire complex sequence of skills. In addition, the presence of other learners provides the apprentice with calibrations of his own progress, helping him to identify his own strengths and weaknesses and thus to focus his efforts for improvement. Once the apprentice has a grasp of the entire process, the master reduces his participation (i.e., fading), providing only limited hints, refinements, and feedback to the apprentice, who practices by successively approximating smooth execution of the entire process. The interplay between observation, scaffolding, peer interactions, and increasingly independent practice helps the apprentice to develop self-monitoring and correction skills and integrate the skills needed to advance toward expertise.

Cognitive apprenticeship refers to the adaptation of the modeling-coaching-fading paradigm to the teaching of cognitive or mental processes experts use to handle complex tasks such as reading comprehension, writing, and problem solving.[7] It involves drawing students into a "culture of expert practice," where teachers and students actively communicate about and engage in solving problems. The problems and tasks are chosen to illustrate the power of certain techniques or methods, to give students practice in applying these methods in diverse settings, and to increase the complexity of the tasks slowly, so component skills can be integrated. Since the cognitive apprenticeship model emphasizes expert-like practice, conceptual knowledge is learned by using it in a wide variety of contexts. Using conceptual knowledge in a variety of situations encourages a deeper understanding of the meaning and range of applicability of the concepts, and fosters its transfer to novel problems and new domains.

In the cognitive domain, students do not usually have access to the thought processes of the instructor as a basis for learning through observation and mimicry. Consequently, cognitive apprenticeship requires the externalization of usually internal processes by both the teacher and the student. Cognitive apprenticeship methods are designed to bring these tacit and hidden processes in the open, where students can observe, enact, and practice them with the help of the teacher and other students. Cognitive apprenticeship also requires techniques to encourage the development of self-correction and monitoring skills for these thought processes.

III. IMPLEMENTING THE COGNITIVE APPRENTICESHIP MODEL

A. Adapting the cognitive apprenticeship model for a large class

A variety of cognitive apprenticeship techniques (e.g., Socratic dialogues, reciprocal teaching, collaborative problem solving) have been developed and used successfully in small classes to teach reading comprehension, writing, and problem solving in mathematics.[7] To adapt the model to large introductory physics class taught by a faculty member and TAs, we structured our physics course so that the modeling is done be the faculty member during lectures, and the majority of the coaching is done by the TAs in discussion and laboratory sections. We used the technique of cooperative grouping in all phases of the course as a primary tool to externalize the cognitive process of learning physics.

1. Modeling

Physicists are in the business of constructing new knowledge in response to specific issues and problems in their fields. In a large introductory lecture course, it is difficult to immerse students in this culture of expert practice. It is possible, however, to provide students with a consistent "story line" or conceptual framework from which specific problems naturally arise. The story line can be used to model some of the thinking processes that physicists use to construct new knowledge. This helps to make the newly constructed concepts and principles initially intelligible and plausible to students, so they can compare the new information with their conflicting misconceptions. In addition, a story line can serve as a springboard for the modeling of how the newly constructed concepts and principles are used to solve problems.

Early in the course the lecturer introduces a problem solving strategy that is based on research describing the nature of effective (or "expert") problem solving in physics.[8] Every time a problem is solved in class, the instructor models explicitly all of the problem-solving steps and decision processes required to solve the problem. All problems are solved with this strategy, even when there are short cuts or more efficient ways to solve the problem that an expert problem solver might employ.

2. Coaching and Scaffolding

Coaching in the problem-solving strategy is provided by the TAs in the discussion and laboratory sections while students are engaged in solving problems in cooperative groups. Cooperative groups differ from traditional groups in that they are carefully structured and managed to maximize the active and appropriate participation of all group members.[9,10] In the discussion sections, cooperative groups practice using the strategy to solve physics word problems. In the laboratory sections, groups use the strategy to solve concrete, experimental problems.

Cooperative-group problem solving is not only a powerful motivator, but it provides students with a source of scaffolding in the form of the conceptual and procedural knowledge distributed throughout the group. Because collaboration distributes the thinking load among the members in a group, the entire problem-solving strategy can be applied successfully early in the course to problems on which most beginning students would initially fail.[8,11] The cooperative group process also gives students the collective ability to check whether their approach to the problem makes sense and provides possible alternatives. It is just this self-monitoring, now supplied by the others in the group, which is most lacking in beginning problem solvers. By rotating specified managerial and monitoring roles in the group from one problem to the next, individuals practice all parts of the self-monitoring process as well as experience the success of the strategy as a whole.

An additional source of scaffolding to help students implement the problem-solving strategy is a problem-solving booklet that describes and explains each step of the strategy and provides several worked examples and practice problems. Testing and grading practices reflect the importance placed on both cooperative-group problem solving and the use of a coherent organized problem solving strategy.

3. Fading.

Fading is accomplished in several ways. The practice and test problems progressively require students to apply previously learned concepts and principles as well as the most recently taught concepts and principles. The laboratory instructions become increasingly less detailed and structured over the course, requiring students to make more decisions about how to solve the experimental problems.

B. Changes in content and structure

The adaptation of the cognitive apprenticeship model to the teaching of a large introductory physics course required several changes in the content and structure of the course. The course in its fullest implementation uses a story line to determine the specific content, models the construction of knowledge, uses multiple contexts for each concept, focuses on the fundamental concepts and principles, uses an explicit problem-solving strategy, uses context-rich problems, and implements testing and grading practices to reinforce desired student behavior . Table 1 illustrates how each change was designed to facilitate the learners' transformation from the initial

Table 1: Reinforcing Desired Behaviors and Discoraging Initial Behaviors

Students' Initial Knowledge, Thought Processes and Learning Behaviors	Desired Knowledge, Thought Processes and Learning Behaviors	Reinforcement of Desired Behaviors & Barriers to Initial Behaviors
Students tend to learn physics as a unrelated collection of memorized facts and formulas. Consequently, many students • do not connect physics with the real world, • do not change their intuitive ideas (misconceptions) about the way the world works, and • cannot distinguish between fundamental principles and specific applications and elaborations of these principles.	Students will overcome their misconceptions, construct a coherent hierarchy of knowledge based on the fundamental concepts and principles of physics, and be able to apply these concepts and principles to new, real-world situations in a logically consistent manner.	A story line is provided that concentrates on the fundamental concepts and principles of physics and situates students' learning in a real-world problem-solving framework. The lecturer explicitly models the process of constructing knowledge. Within the story-line, multiple situations and content topics are used to illustrate the fundamental concepts and principles. The fundamental concepts and principles are given on each exam -- they do not need to be memorized. All problems must be solved using only the fundamental concepts and principles given on the test.
Students tend to solve problems by memorizing sets of specific formulas to use in specific situations (novice strategy).	Students will learn a logical, general problem-solving strategy that they can use to solve real-world problems.	Students are taught a logical problem-solving strategy. The strategy is always modeled in its entirety in the lectures. Students are given context-rich problems that are too complex to solve with their situation-specific novice strategy. Students are provided with a supportive cooperative-group environment in which to practice using the strategy to solve context-rich word problems and concrete experimental problems. Students are provided with a booklet that describes the strategy, shows worked examples, and gives practice context-rich problems. They are also given problem-solving format sheets with procedural prompts. On tests, students are graded on the use of the strategy as well as for correct physics and mathematical procedures.

state to the desired final state of intellectual performance. Two types of teaching practices were designed -- those that support or reinforce the desired thought processes and learning behaviors, and those that discourage or prevent the continuation of initial thought processes and learning behaviors.

C. Changes in the operation of the lectures, discussion sections, and laboratories

In our introductory physics course, there are three 50-minute lectures, one 50 minute discussion section, and one 2-hour laboratory per week. To increase the effectiveness of the cooperative-group problem solving, discussion sections are scheduled to allow the same groups of students to work together with the same TA in both their discussion and laboratory sections. Each section typically has 18 students, or six groups of three students. Coordination between the lectures, discussion sections, and laboratories is maintained through a course team which consists of the lecturer and the TAs teaching those students. A course team typically meets biweekly to brief the TAs on the direction of the lectures, give feedback to the lecturer on the performance of the students, decide on the problem for the next discussion and the emphasis of that class, decide on the problems to be assigned for laboratory and the laboratory emphasis, discuss problems for the upcoming exam and the grading emphasis, and give feedback about student performance on each exam. The TAs work together to write lesson plans for each discussion section and laboratory class. These lesson plans are discussed and refined in the biweekly team meetings.

The operation of the lectures, discussion sections, and laboratories are described below. Table 2 summarizes how the operational changes in each component of the course were designed to either counteract students' initial expectations or to reinforce the desired active learning behaviors.

1. Lecture

The purposes of the lecture are to: (1) model some of the reasoning processes by which physicists construct new knowledge following the story-line; (2) introduce the fundamental concepts and principles necessary to the story line; and (3) explicitly model all steps and decision processes in problem solving. The majority of the lecture time is spent in the traditional manner with the lecturer talking, writing, giving demonstrations, and solving problems before a large number of students. Some peer guided practice, which involves students' active participation in the concept development, is accomplished using small ad-hoc cooperative groups of 2 or 3 students sitting near each other.

Informal cooperative group discussions are also used at other times during the lecture. When a new concept is introduced, the lecturer periodically stops and asks students to answer a question involving the new concept. This can be a planned question, or a spontaneous question inspired by the blank or puzzled looks on their faces. This small-group activity can be followed by a short question-and-answer period, which is now more focused because of the previous small group discussion. Occasionally, the predictions or answers to questions are written down and collected for grading. By grading the group outputs, the lecturer communicates that the students' active involvement in the construction of knowledge is an important component of the class.

2. Discussion Sections

A typical discussion session has three parts: introduction, a cooperative problem-solving task, and closure. First, the TA briefly describes the learning goals for the lesson. The TA then gives each student a sheet with the context-rich problem. The TA assigns students the roles of Manager, Recorder/Checker, and Skeptic to three students in each group. The students generally have about 30 minutes to complete the problem in their cooperative groups. The TA observes the groups,

Table 2
Reinforcement of Desired Student Behaviors and Barriers to Initial Behaviors in the Lecture, Recitation and Laboratories

Students' Initial Expectations of Learning Behavior	Desired Learning Behavior	Reinforcement of Desired Behaviors & Barriers to Initial Behaviors
Lectures:		
Some students attend lectures to clarify the reading in the textbook. They expect to sit passively and take notes on important facts and formulas that they will process (memorize) later. Some students attend the lectures to make sure they don't miss any important announcements and hints for the next test. They listen sporadically while reading the paper or studying for another course. They expect that everything they need to know is in the textbook. Some students do not attend the lectures. They expect to be able to read and memorize the important facts and formulas in the textbook just before an exam.	Students will actively process information, continually comparing their own intuitive ideas with those being developed by the lecturer. They will only take notes on issues they wish to think more about later.	Students are encouraged to talk softly to their neighbors during the lecture to check their understanding of the new concepts or problem-solving procedure. The lecturer occasionally stops talking and asks students to individually write down a prediction of the outcome of a demonstration, the answer of short qualitative question, or results for a step of a problem solution. Students participate in small ad hoc cooperative groups to compare their predictions about the outcome of a demonstration, their answers to a qualitative question, or their problem-solving procedure. Written predictions or answers to a question are occasionally collected for grading. The lecturer prepares overheads that are photocopied and available for students to purchase.

Table 2 (continued)

Students' Initial Expectations of Learning Behavior	Desired Learning Behavior	Reinforcement of Desired Behaviors & Barriers to Initial Behaviors
Recitation:		
Students expect TAs to answer specific questions about the solution of specific problems which they find difficult. After the first few sessions, most students stop attending because their questions are not addressed (there is insufficient time to answer 15 - 20 different questions).	Students will be actively engaged in refining their logical problem-solving techniques. As they try to solve written problems, students will recognize when their intuitive conceptions are incorrect.	Students are provided a supportive cooperative-group environment so they can solve context-rich problems. TAs circulate among the groups to provide coaching as needed. About three times a quarter, one of the cooperative group problems is turned in and counts as one test question. If a student is absent from the previous recitation session, he cannot take the group test problem and he receives a grade of zero for that question.
Laboratories:		
During labs, students expect to passively follow a clear step-by-step laboratory procedure to get a predetermined result. Students expect lab instructions to contain all necessary information so that they do need to prepare for a lab.	Students will prepare for each lab by reviewing the appropriate sections of the textbook and connecting the concepts of the lab to the appropriate lecture(s). During the lab, students will be actively engaged in using fundamental concepts and principles to solve concrete, experimental problems. Students will recognize when their intuitive concepts disagree with the way the world works.	Students must pass a short lab preparation test before they can participate in the lab. Students must make individual predictions of the behavior of the system under investigation before the lab. The TA checks predictions during the lab. The labs are designed so students must make many decisions: predict results; qualitatively explore the physical behavior of the system to check predictions and the range of the apparatus; and plan precise measurement and analysis procedures; Students are put in a supportive cooperative-group environment so they can compare their individual predictions and collectively make the required decisions. TAs circulate among the groups to focus students' attentions on the comparison of their results with their predictions and provide coaching as necessary.

diagnoses problems, and intervenes to coach a group only when he or she believes no progress is being made by the group or when students have drifted from their roles.

For closure, the TA conducts a short, whole class discussion. This discussion usually begins by randomly calling on one member from each group to draw or write something on the board. The similarities and differences are then discussed. Finally, the students are given about five minutes in their groups to discuss how well they worked together and what they could improve the next time they work together. Students are given a complete written solution to the problem at the end of the class.

3. Laboratories

The laboratories are coordinated with both the lectures and the discussion sections, always dealing with the same content at the same time as the other components of the course. The laboratory problems are designed to allow students to apply the problem-solving strategy to concrete situations and thus to help them confront their misconceptions. This emphasis on problem solving implies a laboratory with fewer specific directions, and more decisions left to the groups about what data to collect, how the data should be collected, and how the data should be analyzed to solve the experimental problem. To focus students' discussions in their groups on the physics of the situation, rather than on the quick collection of data, students are required to qualitatively analyze the situation and make group predictions about all measurements before data collection and quantitative analysis.

A given laboratory topic consists of a series of related problem and lasts two or three weeks to allow students to come back reexamine their apparatus and techniques if their measurements conflict with their predictions. Since the purpose of the laboratory is to develop students' understanding of the content of the course, different groups may, at the discretion of the TA, finish different numbers of problems in the time allotted for that topic. Before students can begin a laboratory, they must pass a short preparation test available on University computers. The tests consist of questions randomly selected from a large pool of similar questions about basic physics knowledge necessary to understand the laboratory problems. Students can take the test as many times as needed to answer successfully 75% of the questions.

The instructional structure of the laboratory is almost identical to that of the discussion section. The major difference is that the groups work on a set of concrete problems and have more than twice as much time per session. Again each session has a predetermined introduction, task, and closure with the function of the TA concentrated on coaching individual groups with specific weaknesses which s/he has observed either in the laboratory or discussion section.

IV. IMPLEMENTATION RESULTS

We believe that we have constructed one example of a conservative physics course that is effective in teaching both concepts and problem-solving skills. It is also appreciated by the students. We base this belief on the systematic collection of data over the past several years, including evaluations of students' problem solving skills and conceptual understanding of physics, observations of students working in cooperative groups, observations of TAs' interactions with students, evaluations of videotapes of students and TAs in recitation and laboratory settings, interviews of students and TAs, and written anonymous evaluations of the course by students and TAs. Some of this research has been reported elsewhere.[8,10,12,13] We found that group problem solutions, particularly the qualitative analysis of problems, were better than those produced by the best students in each group on matched individual problems. This result indicates that the cooperative groups function effectively. We also found that the individual problem solving performance of students improved over time at approximately the same rate for students of high, medium and low ability.

A comparisons with students taking a traditional section of the course indicated that students in the experimental section exhibited more expert-like problem solving. The course is equally effective for both men and women.

In addition, the course has been successfully implemented at both the University of Minnesota and Normandale Community College by faculty who were not involved in its development. Table 3 shows a sample of student opinions of the course taught at the University of Minnesota by a faculty member who, while skeptical of the content and structure, was willing to try it. The questionnaire was used during two successive years and the results for each year were consistent. By his own report, these were the most positive responses he had received from this class of students.

V. SUMMARY

There are three points we would like to emphasize about the Minnesota model for a large introductory physics course. First, the model is conservative because it retains the overall goals and structure of large university courses -- teaching physics with an emphasis on problem solving through lectures conducted by a professor and discussion sections and labs taught by graduate teaching assistants. Second, the model is minimal. It was arrived at step-by-step, making small changes to the existing course and testing the effectiveness of the changes by examining students' problem-solving performance. Consequently, we believe our model describes the minimal changes necessary to substantially improve the problem-solving performance of the majority of the students (not just the top 20%). We found that it was not effective to change one part of the course without simultaneously modifying the other parts of the course. For example, lectures which emphasized and modeled a logical and organized problem-solving strategy did not change students' novice problem-solving strategies. Students needed guided and supportive practice with context-rich problems and a rigorous grading policy to change their strategies. Finally, since the instructional model is minimal, there are many additional improvements that could be instituted as both the lecturer and graduate teaching assistants become more experienced and comfortable with non-traditional methods of teaching.

There are two major difficulties to consider in implementing the model. First, the model takes time on the part of the lecturer to manage and coordinate the TAs. Moreover, the TAs must be educated in (1) the story line for the course, (2) common student misconceptions and the importance of their use of language, (3) the problem-solving strategy, (4) cooperative grouping and their role as coaches, and (5) constructive grading practices. We have found that the TAs need about 30 hours of instruction before they begin to feel comfortable and be effective. During the course, the lecturer and TAs must operate as a team, meeting to discuss problems students are having understanding the material, and planning the upcoming discussion and laboratory sessions. We conducted two meetings per week, each lasting over one hour. The lecturer must also find time to visit the labs and discussion sections to observe both the TAs and the students. Meetings can then also serve to refine teachings skills as the TAs gain experience.

Second, the model requires a change in attitude and beliefs about teaching on the part of all the instructors of the course. It is very difficult to break the teach-as-taught cycle. There is a tendency on the part of the TAs to lecture students, since this is the only model of teaching they have from their past college experiences. The lecturer also has to break from tradition. Modeling the construction of knowledge through a story line requires changing not only the traditional sequence of content, but also how the content is presented. Explicitly modeling all steps and decision processes for solving typical introductory textbook problems is difficult because textbook problems are no longer real problems for an expert. The lecturer must reconstruct many problem-solving steps that he typically combines or does automatically. In addition, the lecturer must value the coaching function of the TAs as being of equal importance as the lectures. Another problem is

Table 3. Student Opinions of the Course Content and Structure

	1†	2	3	4	5	Mean
Lecture						
1. The instructor covered too little material in the course.	4* 2	13 5	20 24	45 52	18 17	3.6 3.8
2. The mixture of presenting new material and solving problems was about right.	17 12	63 67	9 10	10 11	0 1	2.1 2.2
3. Pausing in lecture to allow students to discuss the concepts with others was a good idea.	26 24	47 40	21 26	4 9	2 2	2.1 2.2
Recitation						
4. The recitation sessions were well coordinated with the lecture.	7 8	75 62	11 11	5 12	2 7	2.2 2.5
5. The discussions with my group helped me to understand the course material.	13 8	53 47	13 9	17 28	4 8	2.5 2.8
6. My group worked well together to complete problem solving activities.	14 4	59 53	18 17	7 21	2 5	2.2 2.7
Laboratory						
7. The laboratory activities were well coordinated with the lecture.	4 3	71 64	14 17	11 12	0 3	2.3 2.4
8. The laboratory experiments helped me to understand the concepts covered in class.	13 10	55 64	16 7	14 16	2 3	2.4 2.4
9. Working with the same group in laboratory and recitation sessions was useful.	22 16	54 64	17 18	3 1	3 2	2.1 2.1
10. Working with the same materials for at least two weeks helped me to understand the material.	21 15	65 64	10 16	3 3	1 3	2.0 2.2
Problem Solving Procedure						
11. The problem solving procedure taught in class makes sense	41 23	46 65	7 7	4 2	2 2	1.8 2.0
12. The instructor provided adequate examples of how to use the problem solving procedure.	53 31	40 58	3 4	3 6	1 1	1.6 1.9
13. Using the suggested problem solving format has helped me to solve problems more effectively.	37 22	31 44	15 13	7 14	9 7	2.2 2.4
14. The solution sheet format was a useful guide for problem solving.	25 22	39 55	25 10	10 10	1 4	2.2 2.3
15. Problems can be solved more effectively in a group than individually.	17 16	49 46	18 14	14 18	1 6	2.3 2.5
Testing and Grading						
16. The tests concentrated on important subjects presented in lectures.	21 26	72 65	5 5	2 3	0 2	1.9 1.9
17. Taking tests as a group helped me to understand the course material.	4 9	62 48	21 21	10 18	2 4	2.4 2.6

† The rating scale was: 1 = strongly agree, 2 = agree, 3 = no opinion, 4 = disagree, and 5 = strongly disagree.

* First row percentages are for the 1991 class (n = 99); second row percentages are for the 1992 class (n = 135).

that this type of instruction raises students' expectations for their own level of understanding of physics. Students in this course become very frustrated and vocally intolerant if parts of the course revert to the traditional style of fast-paced, superficial coverage of unmotivated topics.

At minimum, all the instructors of the course must develop an awareness of the content and form of the knowledge and thought processes beginning students bring to physics instruction. The structure of the course needs to present students with barriers to learning patterns and thought processes the instructor wants to discourage as well as clear rewards for the learning patterns and thought processes to be encouraged.

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