Project Description

Previous NSF Support: The PI (Meltzer) has received NSF support for two curriculum development projects during the past five years. One of these – the third in a series of related grants – supported the development of an elementary physics course based on guided-inquiry instructional methods, targeted at education majors and other non-technical students at Southeastern Louisiana University (SLU) (See Biography section for grant numbers and titles.) These projects very dramatically increased the number of education majors taking physics at SLU (from nearly zero, up to 21 during 1997-98). An independent study prepared for NSF's Division of Undergraduate Education described the first project in this series as "very successful."[44] In June of 2000, I (along with Co-P.I. Thomas Greenbowe) received a CCLI-EMD award for the development of active-learning curricular materials in thermodynamics. As part of this project we have carried out an extensive investigation of student learning of thermodynamic concepts in both chemistry and physics courses, publishing two papers to date[8,26] and making numerous conference and seminar presentations.[7,25] Based on that initial work, we have carried out preliminary development and testing of sample curricular materials, and are now drafting initial versions of the core materials themselves. In July 2002, Meltzer (PI) and Greenbowe (Co-PI) were awarded an NSF grant in the "Research On Learning and Education Program" to investigate the role of representational modes in student learning of physics and chemistry.

Outline of project: This is a project to adapt and develop curricular materials for the introductory physics course that are to be used in the context of a large lecture class, employing a variant of Mazur's "Peer Instruction" method.[16] Among the project goals will be to evaluate the effectiveness of the materials in the process of instruction, and to acquire baseline data regarding student performance that will be of value to other instructors who make use of the materials.

These curricular materials have the simultaneous functions of (a) providing formative assessment of student learning, thus guiding instructors to make necessary alterations and corrections to their instruction, and (b) forming an integral part of the instructional activities themselves. They are designed to allow real-time formative assessment by the instructor who may then make direct application of the results with literally no time delay at all. The materials are designed for use in the context of a class organized along "active-learning" lines, in a format to be described in detail below.

The curricular materials themselves consist of carefully sequenced sets of multiple-choice questions, each focused on a specific topic. The individual items are primarily conceptual questions that downplay algebraic manipulations, and instead make heavy use of diagrammatic, graphical, and pictorial elements; they are adaptations and modifications of Mazur's "ConcepTests." The materials are intended for use in large lecture classes, and they are specifically designed to allow for rapid and reliable assessment of student learning during the course of a single class. The instantaneous feedback they provide will allow instructors to make immediate alterations, as needed, in their presentation and planned instructional activities.

The curricular materials are designed to be integrated into a workbook which also includes non-multiple-choice (free-response) worksheets designed for students working in groups, and which contains as well a supporting set of "Lecture Notes." In fact, the major portion of such a workbook designed for the second semester of the algebra-based general physics course has already been written, and much of the material has been repeatedly class tested. The present proposal is intended to support the development and testing primarily of the multiple-choice assessment items. More specifically, about two-thirds of the items for the second-semester course have already been developed. This project is aimed at (1) developing and assessing questions for the remaining part of the second-semester course, (2) beginning development and testing of questions for the first-semester course, and (3) generating baseline data for students' responses to all developed questions.

General pedagogical issues: The motivation for the creation of these new materials is the now very extensive research base into student learning in introductory physics at the university level. An increasing body of evidence suggests that instruction utilizing ***only*** lecture classes and standard recitations and labs results in relatively small increases in ***most*** students' understanding of fundamental concepts.[9,11,32] It has been pointed out by many experienced researchers that complex scientific concepts are often not effectively communicated to students simply by lecturing about them – however clearly and logically the concepts may be presented.[1,17-19,31,42] In other words, students do not absorb physics concepts simply by being told (***or*** shown) that they are true. They must be guided continually to challenge their present state of understanding, and to resolve conceptual confusion through some process of "active engagement."

Pedagogical models that actively engage students in a process of investigation and discovery – often oriented around activities in the instructional laboratory – have been found to be effective in improving students' conceptual understanding of physical principles.[9,31,35-37] The targeted physical concepts are in general not "told" to the students before they have the opportunity to carry out investigations – or follow through chains of reasoning – that might lead them to synthesize the concept on their own. It has been especially challenging to develop effective active-learning materials that do not have the benefit of a simultaneous laboratory component to the instruction. Similarly, the environment of the large lecture class – where there may be 100, 200, or more students facing a single instructor – is an extremely challenging environment in which to establish active learning.

Other approaches to active-learning in large classes. A number of workers in recent years have explicitly addressed the challenge of the large-class learning environment. A pioneering figure has been Alan Van Heuvelen[40,41] who early on developed "Active-Learning Problem Sheets,"[38,39] consisting of free-response worksheets for use by students during class meetings in the lecture hall. Eric Mazur[16] has achieved spectacular success in popularizing "Peer Instruction,"[5] the method he developed for suspending a lecture at regular intervals with challenging conceptual questions posed to the whole class. Sokoloff and Thornton[35] have adapted their popular and effective Microcomputer-based Laboratory materials[36,37] originated in collaboration with Priscilla Laws,[14] for use in large lecture classes, in the form of "Interactive Lecture Demonstrations." Novak and collaborators[28] have developed "Just-In Time Teaching," which makes use of pre-class web-based computer warm-up exercises, and in-class group work by students using whiteboards. To some extent these incorporate similar methods used and promoted by Hestenes and his collaborators[10] who have developed "Modeling Instruction." The Physics Education Group at the University of Washington has experimented with modifications of their "Tutorials in Introductory Physics"[19,20] adapted for use in large lecture classes.[13] Textbooks and workbooks with a high "interactive" component that have been used in large classes include those by Chabay and Sherwood,[4] and Knight.[12] Other implementations of active learning in large classes using classroom communication systems have been described by Dufresne et al.,[6] Shapiro,[34] and Burnstein and Lederman.[3] The "Scale-Up" project at North Carolina State University[2] also makes use of technology-based systems with similar goals.

Distinctive elements of the current project. A detailed description of the materials proposed for this project will be given below. Here however I pause simply to highlight a number of the key distinctions between this work and those cited immediately above. The present project incorporates many of those ideas, with the following unique set of elements: (1) the items in this project are specifically targeted at the conceptual "entry level." That is, they are designed to be usable in *both* the algebra-based, as well as the calculus-based, general physics sequences. Moreover, they include a large proportion of items suitable for students in those courses with below-average preparation levels. (2) The items are designed with numerous multiple-choice responses suitable for use with the "flash card" response system (see below), or other similar systems. (3) The items are organized in discrete sets of tightly-structured sequences, each focused on a specific topic. They are intended to build on and feed off of each other by proceeding in an easy-to-hard conceptual sequence that incorporates different contexts and multiple forms of representation. (4) The conceptual "step size" between the items is relatively small, thereby increasing their utility for minute-by-minute assessment of learning and allowing multiple fine-turned course adjustments by the instructor during a single class. This also permits the use of a relatively large number of items during each individual class, in comparison with the other methods described above.

It is important to emphasize that materials of the type proposed here are *not* presently available in significant quantities elsewhere, whether in the test banks that accompany standard textbooks, or even in the very fine research-based curricular materials produced by other groups. Although individual questions on various topics may be found in a variety of sources, the multi-item sets of carefully sequenced, tightly focused multiple-choice questions employing small conceptual step sizes (necessary for use in "fully interactive" lectures) are not available outside of the *Workbook for Introductory Physics* by Meltzer and Manivannan.[23]

(It is appropriate to mention at this point that at Iowa State University, and probably at many other institutions, a majority of students in the second semester of the algebra-based general physics course are female, in striking distinction to the demographic composition of almost all other physics courses at the university. Most of these students are life-sciences majors, predominantly majors in biology, microbiology, and animal science. Many are pre-professional students who are planning to attend medical or veterinary school, or other health-science professions such as physical therapy, pharmacy, optometry, chiropractic, etc. For this reason the present project will have a disproportionately large immediate impact on females, a demographic group that is typically underrepresented in physics courses.)

The Challenge: Learning and assessment in a large lecture class. In the typical lecture class containing 50 or more students, only a very small proportion of the students ever speak out to respond to questions. How then does the instructor know whether the targeted concepts are actually being communicated to the students? What basis does the instructor have for determining whether modifications in the presentation are needed to improve student learning?

The premise of this project is there is an effective way to do assessment of student understanding in large lecture classes "real-time," and to implement necessary alterations and corrections right on the spot that can result in improved student learning. The methods I use incorporate modifications and adaptations of Mazur's Peer Instruction; the specific strategies were described in detail in a paper (with K. Manivannan) in the June 2002 issue of American Journal of Physics.[24] I have used these methods primarily in the second semester of the introductory general physics course, taught over the past six years at Southeastern Louisiana University and Iowa State University. Both institutions are typical in that their large student enrollments result in many large lecture courses.

The goal is the transformation of the lecture class, to the furthest extent possible, to the type of instructional environment that exists in an instructor's office. When physics instructors have one or two students in their office, they would likely speak for just a few minutes, solicit some feedback, then continue the discussion based on that feedback. In the office, instructors can get a sense of where students are conceptually and of how well they are following the discussion. It is possible to tailor one's presentation to the students' actual pace of understanding. The key issue is whether it is *practical* to do this in a room filled with 100 or more students.

We (and others) have found that it *is* practical to bring about this transformation to a very great extent. Success hinges on two key strategies: (1) students need to be guided in a deliberate, step-by-step process to think about, discuss, and then respond to a carefully designed sequence of questions and exercises; (2) there must be a system for the instructor to obtain *instantaneous* responses from *all* of the students in the class *simultaneously*. This system allows instructors to gauge their students' thinking and to rapidly modify their presentation, subsequent questioning, and discussion of students' ideas. Our methods are a variant of Peer Instruction,[5,16] and are similar to methods used at the University of Massachusetts[6,27,43] and at Eindhoven.[30]

The basic objective is to drastically increase the quantity and quality of interaction that occurs in class between the instructor and the students and among the students themselves. To this end, the instructor poses many questions. Students decide on an answer, discuss their ideas with each other, and provide their responses using a classroom communication system. The instructor makes immediate use of these responses by tailoring the succeeding questions and discussion to most effectively match the students' pace of understanding.

There are a number of student response systems available for use with interactive-lecture methods, including commercially available electronic systems. Our method employs flash cards on which oversize letters of the alphabet are printed. Flash cards are less expensive and easier to implement, although they lack useful features of the electronic systems such as instant graphical displays of responses.

With the use of the flash-card system, we are able to ask many questions during class and no longer have to wait for one daring individual to respond. Every student in the class has a pack of six large cards (5½″ × 8½″), each printed with one of the letters A, B, C, D, E, or F. Students bring the cards every day, and extra sets are always available. During class we repeatedly present multiple-choice questions. Often, the questions stress qualitative concepts involving comparison of magnitudes, directions, or trends (for example, *"Will it decrease, remain the same, or increase?"*). These questions are difficult to answer by plugging numbers into an equation. We give the students time to consider their response, 15 seconds to a minute depending on the difficulty. Then we ask them to signal their response by holding up one of the cards, everybody at once (see photo in Appendix). We can easily see all the cards from the front of the room. Immediately, we can tell whether most of the students have the answer we were seeking – or if, instead, there is a "split vote," that is, part of the class with one answer (e.g., "A"), part with another (e.g., "C") – or perhaps more than one other. (One of them, it is hoped, is the right answer!) One of the advantages of this system is that it allows the instructor to observe the students' body language. We can see whether the students held up their cards quickly, with confidence, or if instead they brought them up slowly, with confused looks on their faces.

If student opinion remains divided and a split vote persists despite the student discussion, we will often ask for an "A" supporter to present their argument, followed by a proponent of the "C" viewpoint. If necessary, we will eventually step in to alleviate the confusion. By this time, most of the students will have carefully thought through the problem. If they haven't already figured it out by themselves, they will now at least be in an excellent position to make sense out of any argument we offer to them. Before those minutes of hard thinking, we could have made the same argument and watched as almost every student in the class gave the wrong answer to some simple question. We know this to be true because we have tried it often enough.

As we work our way through a series of intermediate questions, at each step, we get a reading on our class: Do they respond quickly? With confidence? Mostly correctly? Then we comment briefly and move forward. Otherwise, we pause for a longer discussion. Instead of disposing of the entire topic in less than two minutes of traditional lecture, we now might take 10 to 15 minutes, struggling together with our students as they work their way through a conceptual minefield.

Curricular materials. This method is crucially dependent on having at one's disposal a large number of carefully constructed sequences of conceptual multiple-choice questions. The purpose of emphasizing non-numerical questions is to prevent students short-circuiting the thinking process by blindly plugging numbers into poorly understood equations. Although some collections of such problems exist in the literature[16,28] we have had to begin construction of our own set to meet part of the needs of a full one-semester course. It is the preparation and testing of such question sets that is among the most time-consuming prerequisites for this instruction. The question sets that we have created up until now are based, as much as possible, on the physics education research literature. The purpose of this present project is to complete the development of these items for the second semester of the algebra-based physics course, and begin development of items for the first-semester course. The topical areas intended for development are magnetism, light and electromagnetic waves, optics, modern physics, kinematics, dynamics, work and energy, torque and equilibrium, and oscillations and waves. It is important to point out that the materials may be used quite effectively by instructors in both the algebra-based and calculus-based sequences. This type of qualitative, conceptual assessment question is a valuable tool in any introductory physics course, and its utility is not at all restricted by the identity of their original target audience. Indeed, these materials can be used effectively by instructors at all types of institutions, including both two-year and four-year colleges, universities, and high schools.

The materials are designed with the premise that the solution of even very simple physics problems invariably hinges on a lengthy chain of concepts and reasoning, much of which is often glossed over, or which is simply unstated "tacit" knowledge gained through experience.[33] The question sequences guide the student to lay bare these chains of reasoning. They help students construct in-depth understanding of physical concepts through step-by-step confrontation with conceptual "sticking points" and counterintuitive ideas. One has to illuminate in a stark and glaring light, so to speak, the phases in the student's thought process where the concept is lacking, so that in the student's own mind the gap to be filled by the missing concept is clearly sensed. Then, the eventual synthesis of the concept by the student becomes ***dramatically*** apparent to them.

This is accomplished through carefully linked sequences of activities that first lead the student to confront the conceptual difficulties, and then to resolve them. This is, in essence, the strategy developed and employed by the Physics Education Group at the University of Washington.[17-19] The strategy is to break down complex physical problems into conceptual elements, allowing students to grapple with each one in turn, and then returning to synthesize a unifying perspective.

In the Appendix, sample excerpts from two sets of questions are shown. This includes parts of the sequence on electrical forces, and the sequence on currents. A number of items are omitted due to space limitations. (The entire electrical force sequence consists of 18 items, and each item in the sample shown carries its number from the original order.)

Results of class testing to date. The Workbook in its current form has been used for the past four years at Iowa State University. Although it has been under continuous development, the basic outline of materials has been in place for that whole time. Of course, since the multiple-choice items are merely one part of the entire curriculum project it is not possible to determine what part of the overall learning gains may be ascribable to them (or to any other separate part of the Workbook). Nonetheless it is relevant to cite some results.

Overall learning gains by the students are very high in relation to comparable courses nationwide. For the past five years I have given an abridged version of the "Conceptual Survey of Electricity"[29] (CSE), a diagnostic instrument that assesses qualitative understanding. 14 of the questions on that abridged CSE are also contained on the "Conceptual Survey of Electricity and Magnetism" (CSEM); national baseline data have recently been published for the CSEM.[15] My students' pretest scores (three-year average of 28%) are nearly identical to those reported in comparable algebra-based courses, and substantially lower than those in a nationwide sample of over 1500 students in calculus-based courses (37%). However, the average post-test score of my students over the past three years is 78%, while those of the nationwide sample range from 43% in the algebra-based course to 51% for students in the calculus-based classes.[15] Other assessment data are consistent with these results. On quantitative problems borrowed from exams given in the calculus-based class at ISU, students in my algebra-based course do equally well or better.

Plan of work and Assessment: There are two main phases to the present project: (1) Drafting and initial class testing of multiple-choice items for Chapter 10-14 of Vol. II, and for the initial chapters of Vol. I; (2) Acquiring a complete set of "baseline" data for all multiple-choice questions, by mean of automatic data logging using an electronic classroom response system. Ongoing assessment using the CSEM, as well as other assessment items for which we have already acquired baseline data, will aid in evaluation of the impact the new materials will have on student learning. Because essentially all other instructional materials are presently in place in near-final form, it is plausible that any additional learning gains of any significance may be due in sizeable part to the new materials to be developed with this project. Assessment of the materials developed in this project will be bolstered by three additional methods: (1) questions related to the newly developed materials will be drafted and placed on course quizzes and exams; these items will require students to provide *written explanations of their reasoning*. We and others have found that a relatively high proportion of correct explanations (>50%) is a useful indicator of probable effectiveness of instructional materials. (2) A number of one-on-one interviews with student volunteers will be carried out in which they work through the question sequences and solve them "out loud." This will aid significantly in detecting ambiguous or confusing wording, and ensuring that the thought process *intended* to be generated by the question sequence is *actually* one that is brought about in a "typical" student. (3) Pre- and post-testing with Force Concept Inventory and Mechanics Baseline Test[11] to assess *mechanics* topics.

Collection of baseline data. Although the flash card system is efficient and inexpensive, it does have one major drawback in the context of materials development: it does not allow for rapid and accurate recording of student responses. This is not normally a problem when considering solely the instructional function of the system. However, a major goal of this project is to record student responses to each of the assessment items, including those items already developed and class-tested, as well as the items that will first be developed as a result of the present project. For this reason I propose to purchase an electronic classroom communication system. This consists of individual handheld wireless keypads for each student which allow them to signal a response to a multiple-choice question. The signals are received, logged and tabulated by a central computer. ISU already owns such a system with 100 keypads, but this is insufficient for our largest lecture classes. Therefore I propose to purchase 100 additional keypads and the associated hardware and software.

The database to be created will have several very important uses: (a) It will provide a baseline for comparison when other instructors make use of the assessment materials. The student population enrolled in physics courses at Iowa State University is one that is very much characteristic of a large segment of physics students nationwide. A bank of typical student response rates to each assessment item will provide a useful benchmark for other instructors regarding the performance of their own students. (b) It will allow detailed analysis of the assessment items to help pinpoint any possible anomalies in the response patterns. These may indicate items that need revision or rewording, and may provide insights into student thinking that could generate additional questions that sharpen the focus of instruction and assessment.

Dissemination: In collaboration with K. Manivannan, I have already given four workshops at AAPT national meetings[22] in which other physics instructors were guided in the use of the instructional methods and materials described in this proposal. That initial cycle of workshops has now ended. As the complete version of the assessment items and other curricular materials is put into final form, it will be time to initiate a new cycle of workshops to begin the process of disseminating the materials and accompanying baseline data.

Several other instructors have already done initial testing of materials, and have expressed interest in continuing such in-class testing in the future. In addition, Prof. Kandiah Manivannan

(Southwest Missouri State University) has expressed a commitment to do extensive in-class testing of the new materials in the courses he teaches at SMSU. ***Please see section I for commitment letter from Dr. Manivannan.***

Since it will take some time for Volume I of this Workbook to be completed, this could lead to delays in publication. We have therefore adopted an interim dissemination method that is proving to be quite effective. The entirety of the preliminary version of the Workbook has been burned onto a CD-ROM, and copies are being distributed to physics instructors nationwide. Initially, both instructors who have specifically indicated an interest in the materials, as well as others who are known to use similar instructional methods, have been targeted to receive the preliminary version. The CD-ROM includes PDF files of every item, to insure faithful reproduction, but also includes Microsoft Word versions of most items. This ensures that individual instructors will be able to modify and adapt the materials to their own local circumstances. Because of the extremely low unit dissemination cost of the CD-ROM version, we have simply been mailing out free copies of the disc in order to promote widespread use and class testing (see "Institutional Commitment" below). We have placed an announcement on our web site inviting instructors to request a free copy of the CD-ROM. This method should be an extremely viable alternative for dissemination of the new materials to be created by this project, pending commercial publication. We are also exploring the possibility of posting selected portions of the materials on our web site, accessible via password to physics instructors. In addition, we may be able to post materials on the FLAG web site (i.e., the ("Field-tested Learning Assessment Guide") at http://www.wcer.wisc.edu/nise/CL1/flag/default.asp.

A tentative project timeline is shown on page 3 of "Supplementary Documentation."

Institutional Commitment: Iowa State University has already made substantial commitments to employ these instructional methods both at the Department level and beyond. Two other instructors in the general physics sequences (Profs. Craig Ogilvie and John Hill) are employing flash-card questions in their classes. At the University level, the PI has been named "ISU Center for Teaching Excellence [CTE] Teaching Scholar for 2002/2003," has published an invited paper in the CTE Newsletter promoting these methods [V. 15(2) at http://www.cte.iastate.edu/newsletter/] and has been scheduled to give faculty workshops regarding their use during Spring 2003. Moreover, CTE is funding the reproduction and national distribution of the *Workbook* CD-ROM.

Intellectual Merit: This project will make a unique contribution to the development of research-based, active-learning curricular materials for large-enrollment physics lecture classes. The carefully structured and strategically sequenced question sets described in this proposal represent specific modifications and adaptations of Mazur's "ConcepTests" that have only been available in substantial quantities from the previous work of the PI and his collaborators. The present project is an extension of previous work that has been extensively class tested and published.

Broader Impacts: As has been detailed above, this project has among its central goals (1) develop research-based educational materials and creation of a database (of student response frequencies) useful in teaching; (2) involve graduate researchers in undergraduate teaching activities; (3) participate in developing new approaches (e.g., use of interactive lecture instruction) to engage underserved individuals and groups (i.e., female physics students); (4) make data available in a timely manner by means such as CD-ROMs; (5) publish in diverse media (e.g., websites and CD-ROMs) to reach broad audiences; (6) integrate research (on teaching and learning) with education activities to order to communicate in a broader context, and (7) benefit society by increasing the effectiveness of undergraduate physics instruction.