Active Learning and Critical Thinking in Large-Enrollment Physics Courses: A Testing Ground for Improved Effectiveness in Undergraduate Instruction

This project focuses on improving student learning in large-enrollment introductory physics courses at ISU. The methods and materials to be developed through the project will be applicable to other subject areas beyond physics, particularly, but not exclusively, to mathematical and technical subjects. The primary means to accomplish this goal are (1) development and assessment of conceptual question sequences designed for use in interactive lectures with a student response system; (2) development and assessment of printed curricular materials, including active-learning worksheets, for small-group problem-solving activities during recitation sections; (3) training of graduate teaching assistants both to guide student learning while using the active-learning worksheets, and to participate in development and assessment of curricular materials.

I have already carried out extensive work along this theme previously at ISU and the results to date have been very encouraging. This work is described in detail in the paper "Transforming the lecture-hall environment: the fully interactive physics lecture" by David E. Meltzer and Kandiah Manivannan, *American Journal of Physics*, in press. I have also led four workshops devoted to these methods for other physics faculty at national meetings of the American Association of Physics Teachers. The purpose of this CTE Teaching Scholar project would be to extend this work to additional topics and courses in the physics curriculum, and to increase the number of graduate student teaching assistants who are familiar with and able to implement these pedagogical methods. Beyond that, a primary goal of the project will be to generalize the results to other fields initially including mathematics, physical and biological sciences, and engineering. It is through this generalization that the pedagogical methods to be developed will form part of the "Scholarship of Teaching and Learning" that can impact broad areas of instruction.

Beyond the impact this project will have on instruction in introductory physics courses at ISU, many of the techniques (and even some of the materials) would be applicable to other courses in mathematics and the sciences at Iowa State, and beyond. In particular, the method of developing and using conceptual multiple-choice question sequences in conjunction with student response systems has very broad applicability, and many of the specific principles used to design and test the question sequences are common to many subject areas. Moreover, the same can be said for the development and testing of the active-learning printed worksheets. In fact, work is ongoing in the Chemistry Department (by the Chemistry Education Research Group directed by Prof. Tom Greenbowe) along these lines.

1. **Question Sequences for Interactive Lectures.** I have been very successful in creating more effective student-student and student-faculty communication during large-enrollment physics lectures through the use of the "flash-card" response system ["Promoting interactivity in physics lecture classes," by David E. Meltzer and Kandiah Manivannan, *The Physics Teacher* **34**, 72 (1996)]. Students use sets of six large cards with the letters A-F printed on them to signal their responses to multiple-choice questions posed by the instructor. This method is entirely dependent on availability of many sets of closely linked sequences of conceptual questions in multiple-choice format. With my collaborator K. Manivannan, I have developed many of these question sequences (now available on the CD-ROM, "Workbook for Introductory Physics,") but the number available is still much less than necessary for the full introductory physics

curriculum. A key part of this project would be to develop and class-test additional question sequences. Assessment of effectiveness is carried out in part by use of standard diagnostic tests.

2. **Active-Learning Worksheets for Small-Group Learning.** One of the most successful methods for promoting students' critical thinking skills in the physics classroom has been the development of active-learning worksheets designed for use with "Socratic questioning" by instructors and teaching assistants. Students work in groups of three or four through conceptually oriented question sequences which are specifically designed to target well-known student learning difficulties. Instructors guide students not by lecturing, but by posing leading questions that aid students to construct their own understanding. I have developed and class-tested many of these worksheets at ISU (also available on the "Workbook for Introductory Physics" CD-ROM) and disseminated them to other physics faculty around the country. These are modeled after the carefully researched and tested "Tutorials in Introductory Physics" produced by Prof. Lillian C. McDermott and the Physics Education Group at the University of Washington. Although I have developed and assessed a large number of these worksheets, the number available is still far short of that required for the full introductory physics curriculum, and therefore it is still difficult for other faculty to fully adopt the materials for use in class. Part of this project will be to develop and assess additional worksheets, in particular for topics in mechanics that have not yet been addressed in the "Workbook for Introductory Physics."

3. **Training of Graduate Student Teaching Assistants.** An essential element to the successful use of active-learning curricular materials in introductory science courses is the preparation of graduate-student teaching assistants to utilize the materials effectively. Through supervision by the instructor and work with previously trained graduate teaching assistants, new graduate students learn to carry out the type of Socratic questioning that is needed to guide students in improving their critical thinking skills.

4. **Generalizing Methods and Materials to Other Subjects.** Although the primary focus of work will be in physics, the pedagogical techniques and types of curricular materials to be developed have immediate applicability to many other fields of instruction. For example, sequences of conceptually linked multiple-choice questions and active-learning worksheets could be developed and used in mathematics, science, and engineering courses with large enrollments. In order to initiate this extension and catalyze further work, I propose to (a) lead faculty workshops in which the methods and materials are discussed, and in which other subject-area faculty gain practice in developing and using the materials; (b) prepare articles [CTE Newsletter, etc.], perhaps in collaboration with other subject-area faculty, on how these techniques and materials may be applied in other fields; (c) lead faculty forums to discuss the implementation of these methods in broader contexts; (d) directly assist other subject-area faculty to initiate development of similar materials in their fields; model examples of the materials could then be distributed both in printed form, and through the worldwide web; (e) lead workshops, in collaboration with my experienced teaching assistants, for graduate student teaching assistants in other departments who express an interest in active-learning instructional techniques.

The specific outcomes to be produced through this project are as follows:

1. Sets of class-tested, conceptually linked multiple-choice question sequences for use in conjunction with student response systems. Most of these would be on physics topics, but at

least some samples for other subject areas will be produced through collaboration with other faculty, and in the course of the faculty workshops.

2. Class-tested active-learning worksheets designed for use in small-group problem solving sessions. These sessions will be guided by instructors and teaching assistants employing Socratic-questioning techniques. Most of these will be in physics, but sample materials will be generated in other fields through collaboration or during workshops with other faculty. Pre/post testing with widely used diagnostic instruments will aid in outcomes assessment.
3. Increased numbers of graduate student teaching assistants experienced and knowledgeable in the development and use of active-learning pedagogical materials in actual classroom settings.
4. Presentations and/or printed articles, perhaps in collaboration with other subject-area faculty, that detail the generalization of these pedagogical methods to other subject areas that impact undergraduate instruction.

Tentative Timeline

August-December 2002: Initiate development and class-testing of curricular materials, primarily in Physics 112 (non-calculus-based general physics); testing of multiple-choice question sequences during "large-room meetings" (i.e., lectures); guide graduate student teaching assistants as they employ materials in small-group learning during recitation sessions.

January-May 2003: Continued development of additional curricular materials in other topics (including fields besides physics), testing in selected recitation sections of other courses (with consent of course instructors); hold workshops for faculty and graduate student teaching assistants.

June 2003: Intensive work to complete writing, editing, and revising curricular materials, including question sequences and active-learning worksheets; analysis of assessment data resulting from class-testing of materials; preparation of articles and presentations on results of project.