PART II. RESEARCH METHODS AND ASSESSMENT: HOW DO WE DETERMINE WHAT STUDENTS ARE LEARNING?

Chapter 3. Overview of Methods in Physics Education Research

Part II of this dissertation is intended to help acquaint the reader with the methods and limitations of PER, in particular, the methods used in this investigation. This chapter provides a general overview of the models and methods of PER. The remaining chapters of Part II discuss in detail the specific research methods used in this dissertation.

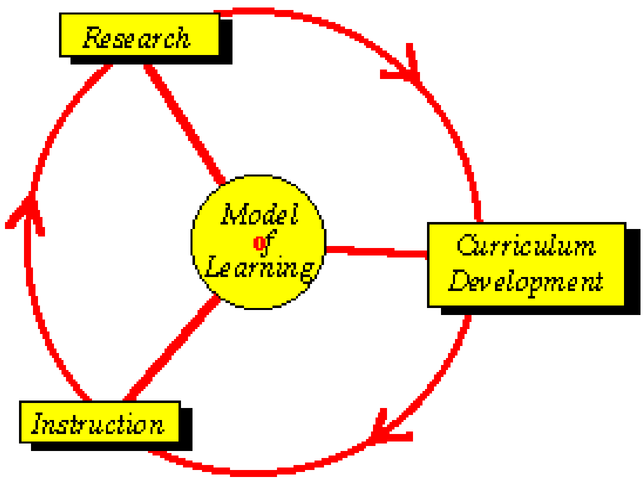
I. PHYSICS EDUCATION RESEARCH

PER involves research into the teaching and learning of physics, curriculum and software development, and innovative instruction. Lillian C. McDermott of the University of Washington Physics Education Group has broken the process in which her group uses research to guide curriculum development into three parts:[1]

1.) conducting systematic investigations of student understanding
2.) applying the results to the development of specific instructional strategies to address specific difficulties, and
3.) designing, testing, modifying, and revising the materials in a continuous cycle on the basis of classroom experience and systematic investigations with the target population.

This process is represented schematically as a cyclic process in Figure 3-1. This cycle represents an iterative approach where research leads to changes to curriculum which is then implemented in the classroom. Classroom instruction is then evaluated through research which leads to more changes in the curriculum. McDermott's research group went through several iterations of this cycle in the development of the materials for both

Figure 3-1. McDermott's iterative cycle of PER, curriculum development, and instruction with the Redish axle.[2]



the tutorial curriculum[3] to supplement calculus-based introductory physics lecture (discussed in chapter 8) and the *Physics by Inquiry* curriculum[4] to teach K-12 teacher science through discovery.

At University of Maryland, we have added an axle to McDermott's wheel to represent the model of how students think and learn. This highlights the importance of the model in all aspects of this cycle. The model both guides and is informed by the research and development cycle. Since, as we discussed in chapter 2, our model of student learning focuses on changes in the student, the basic problem in PER is then the transformation of a system S, i.e. the student, from an initial state S_i to a desired final state S_f where the student can do things they could not do before.[5] This suggests that student learning should be studied in a way analogous to the way physicists study physical processes; namely, measurements need to be made to determine the students' initial and final states to understand the transformation to help build and extend the model of student leaning. Intermediate measurements, if possible, are greatly desired to improve our understanding of the transformation and the model.

II. PHYSICS EDUCATION RESEARCH METHODS

In the past twenty years, physics education researchers have used a variety of techniques to evaluate what students know and what they are learning. These methods include the following:

1. Observing students in class and office hours
2. Measuring student and faculty habits, attitudes, and beliefs with a survey or questionnaire.
3. Measuring student learning using a multiple-choice test designed using the results of physics education research on commonly found errors to specify attractive distractors.
4. Measuring student learning using long-answer exam questions -- problems or open-expression questions in which students explain and discuss their answers.
5. Measuring student learning through recorded problem interviews.

Most instructors use observations of students to some degree. One of the key findings of physics education research is that one wants to understand student difficulties. It is important to not just listen to what the students are saying about the course material, but to draw out the students and see what they really think.[6] Classroom observations can be very helpful in this regard. However, it is difficult to make substantial observations on more than a small fraction of a class and the observations are dependent on available opportunities.

While surveys and questionnaires are the simplest and most commonly used method of evaluation by instructors in the form of typical course evaluations, it is important to distinguish between instruments that measure aspects of course satisfaction and instruments that deal with issues more directly related to student learning. Although both student and faculty satisfaction is important in motivating student work and presumably therefore student success, the link between satisfaction and learning is highly indirect. Indeed, students whose primary goal is a good grade may find higher satisfaction in a course that produces a good grade without improved learning, since improved learning often requires time and painful effort. However, several physics education researchers including the author have developed and used surveys to learn more about student habits, attitudes, and beliefs that have a more direct effect on how and what students learn. The survey developed for this dissertation is discussed in chapter 5.

Multiple-choice tests are easy to deliver, but building a useful and reliable instrument requires substantial effort. While the results can be highly suggestive, multiple choice tests can be difficult to interpret. They have a tendency to overestimate the student's learning since they can sometimes be answered correctly by means of incorrect reasoning or by "triggered" responses that fail to represent functional understanding. On the other hand, the use of common misconceptions as distractors produces "attractive nuisances" that challenges the students' understanding. Students that get the correct answer despite this challenge are likely to have a good understanding of the topic in question. We expect therefore that this method does give some indication of the robustness of a student's possession of and confidence in correct knowledge.

Long-answer problems are easy to deliver as part of a course quizzes and exams, but the analysis can be time consuming. Student answers must be read in detail and classified by the understanding displayed. Unlike instructors whose goal may be to certify student success and therefore focus on the student’s correct answers, researchers need to pay greater attention to student errors. The errors are often informative about how the students are thinking about physics. The functionality of student knowledge is rather well-tested by this approach since the student is being asked to produce the desired knowledge within the context of a problem and without the most common and automatic triggers. It has the defect that students occasionally give answers too incomplete or ambiguous to let instructors or researchers see what they are thinking.

The interview method is the most effective approach since it permits the researcher to observe in detail the functionality of the student's knowledge by the presentation of a variety of contexts. The researcher can follow up suggestive responses with more detailed and individually designed questions, but it is highly time consuming. In addition to the recording time (usually one or more hours per student), the recordings must be transcribed and analyzed. This approach is thus impractical for evaluating the distribution of student knowledge throughout a large class. However, because many students share a relatively small number of difficulties, a small number of interviews can usually reveal most of the common student problems in great detail.

Other evaluation methods used by physics education researchers include student journals, grades, and retention within the introductory sequence. Grades and retention are difficult measures to use unless proper controls are used to account for variations in population, instructors, and time. Student journals are becoming an increasingly common tool for physics education researchers in smaller classes. They can be very revealing for seeing how the students view both the course material and the course if the students are given proper guidelines. However, while journal entries can be a useful research tool, they can also be time consuming to read and analyze making them impractical for large classes.

III. OVERVIEW OF RESEARCH METHODS USED IN THIS STUDY

In order to evaluate the success of a particular research-based curriculum, we must decide what we mean by "success." This plays an important role in determining our approach to evaluation. What is meant by success is, in turn, determined by our model of student understanding and learning. As discussed in chapter 2, the critical element of our model for this application is to help students gain the knowledge and skills needed to improve their ability as problem solvers. In this study, I am evaluating the curricula in terms of student's conceptual understanding and their expectations or cognitive attitudes and beliefs.

In terms of conceptual understanding, the student may "have" an item of knowledge, that is, be able to recall it in response to a narrow range of triggers, but be unable to recall and apply it in a wide range of appropriate circumstances. Since our goal is help students achieve a robust functional understanding, this is what we want our evaluations to test for. Our evaluation of students' conceptual understanding with multiple-choice concept tests, open-ended conceptual problems, and interviews is presented in chapter 9.

As we saw in chapter 2, students' expectations can have a strong influence on what students take away from an introductory course. Here, a successful curriculum would be one that supports or encourages student expectations that are favorable for building a robust understanding of physics. Based on the studies of Perry and Belenky *et* *al*. and my own observations, student expectations can become more favorable over time. To measure this change, we need instruments that can recognize changes in expectations. While interviews are used to assess the expectations of a small sample of individual students, I have participated in the development of a survey instrument to determine the distribution of student expectation coming into the introductory class and to see how the distribution changes as the students progress through the sequence.[7] The Maryland Physics Expectation (MPEX) survey has been developed by members of the Physics Education Research Group at the University of Maryland over the past five years. Our evaluation of student expectations with the MPEX survey and interviews is presented in chapter 10.

The instruments and methods used in this study are described in detail in the next four chapters. Chapter 4 will discuss the Force Concept Inventory (FCI)[8] and the Force and Motion Concept Evaluation (FMCE)[9]. The development and validation of the MPEX survey is contained in chapter 5. A discussion of how exam and quiz problems can be used to evaluate instruction can be found in chapter 6. Our interview methods for studying students' expectations and conceptual understanding are described in chapter 7.

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