Iowa State University is New Entrant into Physics Education Research Community

David E. Meltzer

Last year the Department of Physics and Astronomy at Iowa State University inaugurated a new group devoted to physics education research. Thus ISU has joined about a dozen other physics departments around the country in which the new subfield of Physics Education joins more traditional fields as a legitimate area for scholarly research, and for training of graduate students. Department Chairman Douglas Finnemore said that "We want to put Physics Education on the same intellectual and competitive level as particle physics, nuclear physics, condensed matter physics, and astronomy."

The origins of physics education research (PER) lie in the strong desire of physics instructors to maximize the effectiveness of the teaching and learning of physics. It seems only natural that physicists are now applying their training and systematic analytical methods – so successfully used to understand the physical world – to explore the problems related to the learning of their subject. Within the past two decades, physicists in the colleges and universities have initiated intense efforts to study physics learning, particularly among undergraduate students. The efforts of PER to identify and address learning difficulties in physics should result in improved learning by both average students *and* high-performing students.

At Iowa State, in common with other PER groups, we engage in three distinct yet closely linked activities: (1) develop and assess more effective curricular materials; (2) implement and assess new instructional methods that make use of the improved curricula; (3) investigate learning difficulties, and carry out other basic research on the teaching and learning of physics. Our particular focus is on curriculum and instructional methods for large lecture classes.

Our objective is to address areas of pedagogical concern previously identified by physics education researchers. For instance, many if not most students in introductory courses develop weak *qualitative* understanding of concepts, even when they may be able to solve successfully certain types of quantitative problems. When lacking exact quantitative solutions, students often have difficulty in determining qualitative features such as comparison of magnitudes, determination of direction, and evaluation of trends.[1]

More broadly, students frequently lack a "functional" understanding of physics concepts, which would allow problem solving in a context *different* from the one in which the concept was originally learned. Students find it difficult to transfer an ability to solve standard textbook problems to situations involving actual, real-world physical objects and phenomena.[2] Moreover, there is a strong tendency to view phenomena and concepts as distinct, unrelated and highly dependent on context, rather than as comprehensible and derivable from just a few underlying universal principles.[3]

A number of factors have been identified as playing a role in these learning difficulties. For example, students enter introductory classes with their own ideas about the physical world that may strongly conflict with physicists' views.[4] Often called "misconceptions" or "alternative conceptions," these ideas are widely prevalent; there are some particular ideas that are almost universally held by beginning students. These ideas are often well-defined; they are not merely a "lack of understanding," but a very specific idea about what ***should*** be the case (but in fact is not). Examples of these ideas are that an object in motion *must* be experiencing a force, and that a given battery always produces the *same* current in *any* circuit. These ideas are often – usually – ***very*** tenacious and hard to dislodge.

Another important factor is that most students in introductory courses lack "active learning" skills, and need much guidance in scientific reasoning. Physics concepts are usually subtle, counterintuitive, and required extended chains of reasoning. Of course, ***some*** students learn efficiently. Highly successful physics students (e.g., future physics instructors) are active learners. They continuously probe their own understanding of a concept, for instance by posing their own questions and examining varied contexts. They are sensitive to areas of confusion, and have the confidence to confront those areas directly.

By contrast, the great majority of introductory students are unable to do efficient active learning on their own. They don't know "which questions they need to ask." They require considerable prodding by instructors (aided by appropriate curricular materials), and need frequent hints and confidence boosts.[3]

To address these problems, innovative pedagogical methods are being developed. To encourage active learning, students are led to engage in deeply thought-provoking activities requiring intense mental effort (so-called "Interactive Engagement"[5]). Students are frequently required to provide written or oral explanations of their reasoning process. Instruction recognizes – and deliberately elicits – students' preexisting "alternative conceptions," which are then made a focus of discussion. As much as possible, the ***process*** of science – exploration and discovery – is used as a means for ***learning*** science. Instructors avoid *telling* students that certain things are true, and instead students are guided to "figure it out for themselves," either in the instructional lab, or by step-by-step theoretical analysis.

We have been developing curricular materials along these themes for elementary topics in electricity and magnetism, and modern physics. Our "*Workbook for Introductory Physics*" (in collaboration with K. Manivannan) guides students to construct in-depth understanding through step-by-step confrontation with conceptual sticking points and counterintuitive ideas. Contexts are varied by heavy use of multiple representations – intermixing equations, word problems, pictures, diagrams, graphs and charts. In collaboration with ISU chemistry professor Tom Greenbowe – a long-time researcher in chemical education – we are developing similar materials for the thermodynamics curriculum. All materials undergo continuous testing and redesign through day-to-day class use and student assessment. Our curriculum development has been most strongly influenced by the pioneering work of Lillian McDermott and Alan Van Heuvelen.[6]

An active learning classroom is characterized by very high levels of interaction between students and instructor, and among the students themselves. There is usually collaborative group work, and students all engage in intensive learning activities far beyond passive listening and note copying. Students may be asked to make predictions of the outcome of experiments, and give written explanations of their reasoning. Instructors pose specific problems that are known to consistently trigger certain types of learning difficulties, and subsequent activities are then structured to confront these difficulties. Instructors avoid "telling" and instead provide leading questions. "Peer instruction" methods are employed in which students explain their reasoning to each other, and then critique each others' arguments.[7]

In the small-class environment, we have implemented active learning techniques in an NSF-supported elementary physics course targeted at elementary education majors.[8] For (some) large classes, we use the "Flash Card" response system to obtain instantaneous feedback on multiple-choice *Workbook* questions from all students simultaneously.[9] Students also spend a large fraction of class time working in groups on carefully structured free-response sequences in the *Workbook*. Recitations in selected courses are replaced by University-of-Washington-style "tutorials": students work in groups on *Workbook* materials while T.A.'s provide guidance through Socratic questioning.

We also carry out basic research to support curriculum development. Graduate student Jack Dostal has been investigating student understanding of gravitation, by developing and administering free-response diagnostics and conducting in-depth videotaped student interviews. He is developing and assessing curricular materials to address learning difficulties identified in his research. In other research, we are investigating the comparative effectiveness of different representational modes, i.e., the relationship between the ***form of representation*** of physics concepts, and efficiency of student learning. We are also exploring factors underlying individual differences in student learning: why do some students start (conceptually) at the same point, yet finish at different points? How can instruction most effectively target these diverse groups of students?

We view PER as a systematic, multi-faceted endeavor to expand the horizons of physics education for the new millenium. By building on past achievements and relentlessly exploring new instructional possibilities, we hope to significantly increase the impact that physics instructors worldwide will be able to have on their students' educational development.

More information about our work can be found on our website http://www.public.iastate.edu/~per or by contacting us directly.

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David E. Meltzer is Assistant Professor of Physics at Iowa State University, and is director of the ISU Physics Education Research Group.