Empowering Learners of Physics: Helping Instructors Use Physics Education Research

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Abstract

In recent decades physics education research has revealed various difficulties that many students have in learning physics. One of these difficulties is that many students do not link classroom material to their real-life experiences. Numerous solutions have been proposed. Textbook writers have steadily increased the numbers of real-life phenomena that they include. Further, several teams have proposed instructional approaches based on direct exposure to real-life material. Such treatments have been shown to lead to an improvement in student interest and understanding. However these innovations are not widely adopted by instructors (lecturers and teaching assistants). Many are still using the traditional teaching techniques. Interviews with students and instructors reveal some of the reasons for this. A professional development course was set up in the department to familiarize instructors with the issues in the physics education research literature. This measure was taken upon the recognition that we needed to motivate the teaching assistants to help us implement the reformed teaching approach. The impact of the program was apparent in the re-organization of first-year tutorials and the attitudes of those involved.

Introduction

The present generation of students can be considered as being different in many respects from their counterparts of a few decades ago. Students used to be independent and well-prepared when they embarked upon their study at the university. Current students, particularly first-year undergraduates, are generally less ready for college than their predecessors (Leamnson, 2001). Today's students have less real-life experience in their childhood. Games and entertainment are focussed around TV, videogames and shopping malls, rather than the outdoor experiences of the past. Modern appliances and toys tend to be "black-boxes" with their internal workings inaccessible. Modern students are less likely to see the relevance of their classroom activities. They are thus not motivated by the utility of their knowledge. This failure to link their classroom sciences to the real-world can be regarded as a total failure of the teaching process. Physics, as with all sciences, has as its overriding objective, the explanation of aspects of the real world, and many physics students never make the link. Students coming to introductory physics courses often bring ideas about how their world and the mechanics of their world operate. These ideas can be incompatible with the established concepts in the textbooks. These incompatible ideas are not easily eradicated by the so-called traditional instruction where the lecturers play the central role.

Numerous innovations in teaching methods have been proposed to remedy incorrect pre-conceptions and, more importantly, to help students learn physics more effectively. The literature on physics education research is abundant and instructional resources are commercially available. However, many lecturers are still conducting their teaching in the same old-fashioned way they used at the start of their teaching career. These lecturers, many of whom have long experience in teaching, are active researchers in other areas of physics. Some of these lecturers turn out to be unaware of students' difficulties mentioned above and unaware of the solutions proposed by physics education researchers.

This article presents our efforts to address this gap in the knowledge of university teachers. A formal, structured department programme attempting to bridge the gap will be described.

An Example of Innovation in Education

It has been widely acknowledged that the traditional teaching approach in introductory physics courses contributes to problems of misconception and unsatisfactory conceptual understanding. Beginning students usually perceive physics as a collection of unrelated formulas that are used to find numerical answers to quantitative problems. They have little understanding of the underlying principles behind the formulas. Physics is not viewed as the explanation of the working of the phenomena students come across in everyday life. In fact, they are often unable to relate the physical principles taught to their real-life experiences.

The problem has been recognized by a growing number of people in the physics education community. They have developed various instructional approaches and revised popular introductory textbooks in the attempt to help students to better learn physics. Among the many features of the teaching approaches and their supporting textbooks that are expected to make an improvement, the exposure to real-life phenomena in a variety of ways seems to play an important role. An examination of the progression of introductory textbooks such as Fundamentals of Physics (Halliday, Resnick & Walker, 1966, 1981, 1988, 1993, 1997, 2001) or University Physics (Sears, Zemansky & Young, 1957, 1978, 1982, 1987, 1996, 2000) reveals that later editions have an increasing number of explanations and questions describing real-life objects, events or applications throughout their pages.

Also various instructional approaches have been proposed to help students learn physics in more effective ways. Most of these efforts utilize the exposure of real-life material which can take shape from well designed demonstrations (Sokoloff & Thornton, 1997; Cummings, Marx, Thornton, & Kuhl, 1999; Steinberg & Donnelly, 2002), hands-on activities (Scherr, 2003; Thacker, Kim, Trefz, & Lea, 1994; McDermott, 2001; Steinberg & Donnelly, 2002; Sharma, Millar, & Seth, 1999; Laws, 1991; Laws, Rosborough, & Poodry, 1999) to student's analyses of phenomena videotaped by themselves (Beichner, 1996; Fuller, 1993; Zollman & Fuller, 1994; Zollman, 1996). Students treated with these reformed teaching techniques show improved comprehension of the concepts and better appreciation of the utility of the activities done in the class.

While many elements of the reformed approaches contribute to those results, the real-life exposure is argued to play a significant role in influencing students' perception of physics. The subsequently deeper engagement affects their understanding of the material. The real-life exposure helps in some ways to make abstraction become more concrete, or real, thus easier to grasp. The real-life exposure also demonstrates the relevance of physics to real world phenomena. Showing this relevance has been proved to attract students' interest, the expected result of which is their motivation to study more seriously. Activating stored knowledge and linking it with new concepts is facilitated by the real-life exposure. Students are found to be more stimulated to learn if they recognize that the materials are familiar to them. The activities usually accompanying the real-life exposure also encourage students to think through the situations and enable them to construct target concepts along the way. The instructors may provide guidance so that students are on the right track in the investigation, but it is the students themselves who build their own understanding through their learning.

The evidence for the advantages of using the real-life materials in improving student understanding is overwhelming. However instructors may have their own notions of the role of real-life phenomena in teaching physics. The instructors may have the view above, but how do they implement what they believe? How is physics actually perceived by the instructors? To what extend are instructors aware of the students' ideas of physics? More importantly, how do the students perceive the connection between physics and real-life phenomena? If students and instructors already have the perception of the connection between physics and real-life phenomena, can they be encouraged to include more real-life materials in teaching and learning by using some of the methods described in the physics education literature in order to achieve the optimum benefit?

A Case Study on Students' and Instructors' Perceptions

To answer the questions above, a case study was conducted at a physics department in a New Zealand university. The participants in the study were 6 lecturers and 5 tutors who have been teaching first year physics courses as well as 44 students who were taking one of two first-semester physics courses. They were interviewed to probe their perceptions on the connection between physics and real-life phenomena in teaching and learning.

The findings from the interviews show that students and instructors embrace the idea that physics has something to do with their real-life phenomena and experiences. While instructors have the intention of connecting physics and real-life phenomena in their teaching, they mostly lack the knowledge of innovative teaching approaches. The teaching methods that they use are largely traditional, whereby instructors try their best to transmit knowledge to their students: The real-life phenomena are presented in narratives or demonstrations. Because those activities are not central to the process of teaching and learning, many instructors are sceptical as to the benefit of real-life materials in improving student understanding.

The students, on the other hand, report enjoying the practice where real-life materials are presented, especially those in pictures displayed by the textbook or demonstrations in the lecture. These forms are more easily recognised than the real-life situations in the questions and problems of the text. Students also assert that real-life materials are helpful in improving their comprehension of the concepts. However they perceive that the emphasis is not so much on the connection between physics and real-life phenomena, but rather on the conventional view of the focus of learning in physics classes, such as formula, problem solving and well-structured lecture notes. This is in line with reports from other researchers which explain the reasons behind an inconsistency between students' perception of physics and their preference in doing physics (Prosser, Walker, & Miller, 1996; Haussler and Hoffmann, 2000; Elby, 1999).

Note the differences between the instructors' and the students' views on the usefulness of real-life exposure in teaching and learning. Students were convinced that the real-life materials help in their study because they can relate their experiences and the physics concepts, because the phenomena make them believe that the concepts work, and because they are simply interested in being shown such applications of physics. However, the instructors were less certain about the efficacy of real-life materials in helping students to learn. Their responses to the questions on the variety of approaches they adopt and their knowledge of other people implementing innovative approaches provide the reasons underlying their beliefs. Apart from the traditional method of delivering lecture in a one-way communication style, discussion involving students is the only other strategy that the instructors adopted. Their attempts to help students with conceptual difficulties are also conventional, namely the instructors try to make their explanation as clear as possible in a variety of ways including using analogies and contrasting situations. In our department, all instructors who were interviewed were aware of new teaching approaches and of people using new teaching approaches. Nevertheless, the teaching techniques they mention are traditional in nature, placing the instructor as the central figure in conveying all information. The instructors' doubts on the effectiveness of teaching approaches other their own are justified on the grounds that they are not familiar with those particular approaches nor with physics education research in general. Some may also find it hard to find time to reflect on their own teaching.

A Professional Development Course

In the attempts to improve the quality of undergraduate physics teaching in the department, a professional development course was set up (Cahyadi & Butler, 2005). The course "Introduction to Physics Education Research" is aimed at introducing issues in physics education research to teaching assistants (TAs). TAs are both tutors in tutorials and demonstrators in laboratories. In the light of the finding in the case study, all lecturers were also invited to participate in the course. On completion of the course, the participants are expected to:

- appreciate the scale of educational and cognitive research
- acknowledge the impact of this research on efforts to reform teaching
- be aware of typical students' preconceptions and state of understanding
- be sensitive to the skills and preconceptions of students in their class

Although the course was tailored for physics TAs, the objectives, design and evaluation could be adapted to suit any departmental TA development program. The class met weekly for 100 minutes to read and discuss various issues in physics education from journal articles and from a textbook (Redish, 2003). The latter contains a summary of research on cognitive development, curriculum design, student preconceptions and expectations, before offering guidance on using a variety of teaching tools. The participants were encouraged to interpret the reading material and to share their teaching experiences. The assessment consisted of contribution to weekly seminars, a short presentation on relevant topics and an essay extended from their presentation.

The majority of the participants were students working in their own thesis research in physics or astronomy. They were beginning their physical science research and thus were comfortable with its methodology. They were not familiar with the methodology of the social science research methodology, nor the findings of physics education research. It was inevitable that they had to struggle to make sense of the ideas involved in the readings. As the course progressed further, the participants grew more comfortable and better able to cope with the material discussed. The short presentations and essays submitted at the conclusion of the course examine a variety of topics, for instance a particular tutorial session, present tutorial practices, the condition of physics teaching and even the state of education in general. The participants made use of the reading material and discussion topics to base their suggestions for improving the situations they were focusing on. To provide convincing support for their arguments, most participants utilized other references outside the given articles. One of the desired aims of the course, to familiarize the participants with issues in physics education research, seems to have been accomplished.

As a follow-up of the course, the participants were invited to complete a questionnaire six months after the course finished. The survey results indicate that some of the course objectives have been met. The participants were able to assess the course itself in terms of organization, content and method of delivery. The course has made the participants appreciate the struggle of their students to understand physics. A lecturer reported that the tutors who had been on the course were more open to new ideas and willing to think critically about the teaching and learning taking place in a tutorial. Most responses revealed the participants' intention to apply what they learned in the course. One recommended the course to all academic staff in the department and suggested using that course as a model to other departments to develop a similar course.

Re-Organization of First Year Tutorials

In the year following the course, another outcome was realized in a departmental scale: All first-year tutorials were organized to have a uniform format. Prior to this, the tutorials were conducted by tutors who normally modelled the problem solutions on the board. Students just copied the solutions to their notes. Some tutors may throw questions or ask students to try on the board. Others tended to keep on talking and writing throughout the session. Students were not encouraged to have a discussion with their peers or do their own thinking. The lecturers arranged the meeting with the tutors only at the beginning of the semester. Very few lecturers maintained the contact with their tutors on a regular basis afterwards. Subsequent to being exposed to issues in physics education from the course described previously, there came a realization that such tutorial scheme did not help the students in understanding what they learned.

The new format of the tutorial is therefore designed to require an active involvement of the students in their own learning. Students are grouped in two or three to discuss the problems assigned as homework or exercise in the tutorial. The tutors no longer do the talking and writing for the class. They instead pose questions in a Socratic dialogue style (Hake, 1992) to guide the students to solve the problems on their own. Cognitive research has shown that students learn better if they can explain in their own words to others. On the part of the tutors, they were ready to change their tutorial instruction method to the new format. Two years prior to this course, an instructional reform was initiated in an introductory physics course (Cahyadi, 2004) which included tutorial sessions. It was observed that the tutors involved in the course had difficulties in interpreting their responsibilities associated with the teaching modification despite the weekly meetings to enlighten them about their tasks. Not only did they oppose the advice to less talk and write in front of the class, they also considered the student discussion as a waste of time. This attitude changed after they attended the professional development course. When they had been exposed to research on student preconceptions and other problems, they could appreciate why it is necessary to let students engage actively in their learning. They came to recognize there were many other ways of encouraging learning, some perhaps better than the way they were taught.

Linking Educational Research and Teaching

Education research supports the idea of students being the master of their own learning. In physics, there are many ways to provide a conducive environment to achieve this, including real-life exposure and active engagement in learning physics. Introductory physics textbooks have been developed to meet the market demand which indicates the preference for including more connection between physics and real-life phenomena or applications. Various reformed teaching techniques have been attested to enhance the student comprehension. However, the convincing findings may not guarantee their implementation in the classroom. Small educational projects such as conducting interviews or administering questionnaires can be used to bring to light some possible reasons. Many instructors were shown to be unfamiliar with the research. The instructors rarely come across relevant articles and reports or even come in contact with people doing research in education. As a result, they adopt the only teaching method they know, the way they were taught, which has been reported to contribute to persistent misconceptions in physics. The lack of detailed knowledge of other instruction techniques evokes doubts about the advantages of those techniques.

The first step towards linking education research and teaching seems to be acquiring the information itself. Our course aimed to first acquaint instructors with issues in education research. There are a number of other ways this could be accomplished. The information dissemination can be carried out through seminars in the department or university, short courses in a teaching and learning centre, or department-based professional development courses. Practical exercises can be done in workshops on various teaching techniques or by collaboration with more experienced colleagues in using certain techniques. A coordinated effort can be initiated, organizing activities promoting better practice in the departmental level. The department can also play an important role by establishing a policy which provides encouragement, material support, and rewards for those who endeavour to improve teaching and learning.

Conclusion

This article describes a journey towards realizing a scheme to help student learning. The accumulated research provides various suggestions and techniques to improve teaching. No matter how convincingly this wealth of research results is to the researchers, it is not beneficial if the instructors, whose research is not education related, are unaware of it. As instructors are normally fully involved in their own area of research, it is understandable that they are not able to appreciate the complexity of teaching and learning enterprise. They are also hesitant about their ability to implement a new teaching technique. This attitude is easily revealed in informal discussion or in a project-based interview. Familiarising the instructors with some outcomes of physics education research can be done in seminars, workshops or courses. The department should also provide support to promote the implementation of research-based teaching innovations.

References

Beichner, R. J. (1996). The impact of video motion analysis on kinematics graph interpretation skills. *American Journal of Physics, 64(10),* 1272-1277.

Cahyadi, V. (2004). Students' responses to a modification of the teaching approach in an introductory physics course, *Research and Development in Higher Education, 27,* 102-109.

Cahyadi, V. & Butler, P.H., (2005). Introducing discipline-specific education research: A professional development course for teaching assistants, *Research and Development in Higher Education, 28,* 79-85.

Cummings, K., Marx, J., Thornton, R., & Kuhl, D. (1999). Evaluating innovation in studio physics. *Physics Education Research, American Journal of Physics (Suppl.), 67(7),* S38-S44.

Elby, A. (1999). Another reason that physics students learn by rote. *Physics Education Research, American Journal of Physics (Suppl.), 67(7),* S52-S57.

Fuller, R. G. (1993). Millikan Lecture 1992: Hypermedia and the knowing of physics: Standing upon the shoulders of giants. *American Journal of Physics, 61(4),* 300-304.

Hake, R. R. (1992). Socratic pedagogy in the introductory physics laboratory. *Physics Teacher, 30(9),* 546-552.

Halliday, D. & Resnick, R.(1966). *Physics.* Combined edition. New York: Wiley.

Halliday, D. & Resnick, R.(1981). *Fundamentals of Physics.* 2nd edition. New York: Wiley.

Halliday, D. & Resnick, R.(1988). *Fundamentals of Physics.* 3rd edition. New York: Wiley.

Halliday, D., Resnick, R., & Walker, J. (1993). *Fundamentals of Physics.* 4th edition. New York: Wiley.

Halliday, D., Resnick, R., & Walker, J. (1997). *Fundamentals of Physics.* 5th edition. New York: Wiley.

Halliday, D., Resnick, R., & Walker, J. (2001). *Fundamentals of Physics.* 6th edition. New York: Wiley.

Häussler, P. & Hoffmann, L. (2000). A curricular frame for physics education: Development, comparison with students' interests, and impact on students' achievement and self-concept. *Science Education, 84(6),* 689-705.

Laws, P. W. (1991). Calculus-based physics without lecture. *Physics Today, 44(12),* 24-31.

Laws, P. W., Rosborough, P. J., & Poodry, F. J. (1999). Women's responses to an activity-based introductory physics program. *Physics Education Research, American Journal of Physics (Suppl.), 67(7),* S32-S37.

Leamnson, R. (2001). *Thinking about teaching and learning: Developing habits of learning with first year college and university students.* Sterling, Virginia: Stylus.

McDermott, M. C. (2001). Oersted Medal Lecture 2001: Physics education research – the key to student learning. *American Journal of Physics, 69(11),* 1127-1137.

Prosser, M., Walker, P., & Millar, R. (1996). Differences in students' perceptions of learning physics. *Physics Education, 31(1),* 43-48.

Redish, E.F. (2003). *Teaching physics with the physics suite.* New York: Wiley.

Scherr, R. E. (2003). An implementation of Physics by Inquiry in a large-enrollment class. *Physics Teacher, 41(2),* 113-118.

Sears, F.W. & Zemansky, M.W. (1957). *University Physics.* 2nd edition. Reading, Mass.: Addison-Wesley.

Sears, F.W., Zemansky, M.W., & Young, H.D. (1978). *University Physics.* 5th edition. Reading, Mass.: Addison-Wesley.

Sears, F.W., Zemansky, M.W., & Young, H.D. (1982). *University Physics.* 6th edition. Reading, Mass.: Addison-Wesley.

Sears, F.W., Zemansky, M.W., & Young, H.D. (1987). *University Physics.* 7th edition. Reading, Mass.: Addison-Wesley.

Sharma, M. D., Millar, R., & Seth, S. (1999). Workshop Tutorials: Accommodating student centred learning in large first year university physics courses. *International Journal of Science Education, 21(8),* 839-853.

Sokoloff, D. R. & Thornton, R. K. (1997). Using interactive lecture demonstrations to create an active learning environment. *Physics Teacher. 35(6),* 340-347.

Steinberg, R. N. & Donnelly, K. (2002). PER-based reform at a multicultural institution. *Physics Teacher, 40(2),* 108-114.

Thacker, B., Kim, E., Trefz, K., & Lea, S. M. (1994). Comparing problem solving performance of physics students in inquiry-based and traditional introductory physics courses. *American Journal of Physics, 62(7),* 627-633.

Young, H.D. & Freedman, R.A. (1996). *University Physics.* 9th edition. Reading, Mass.: Addison-Wesley.

Young, H.D. & Freedman, R.A. (2000). *University Physics.* 10th edition. Reading, Mass.: Addison-Wesley.

Zollman, D. (1996). Millikan Lecture 1995: Do they just sit there? Reflections on helping students learn physics. *American Journal of Physics, 64(2),* 114-119.

Zollman, K. D. & Fuller, R. G. (1994). Teaching and learning physics with interactive video. *Physics Today, 47(4),* 41-47.