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A Model for Reform in Teaching Physics: Large-Enrollment Physics Classes

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Abstract

Teachers at all levels require some knowledge of physics. A particularly large challenge is to provide appropriate higher education experiences for those future teachers who will be working with students in the first 6 to 7 years of their schooling. We have developed an activity-based course for these teachers. The activities involve both traditional short experiments and technology-based ones. The university course is somewhat unique because the design allows for one faculty member to work with a relatively large number of students and yet maintain a student-centered environment.

A Model for Reform in Teaching Physics: Large-Enrollment Physics Classes

Today's research in learning indicates that the most appropriate way for children of all ages to learn science is through hands-on activities. Yet many universities provide for future teachers science courses that are primarily in the lecture format. Thus, future teachers learn a model of teaching that is not appropriate for them to use.

The most common way to offer hands-on activities is in small classes. Yet, the economic constraints on our departments precluded offering a large number of small classes to future elementary school teachers. We needed to find a way that provided strong instruction in physics and an appropriate role model for the teaching of science. The course needed to be designed so that the faculty load was similar to a traditional lecture-laboratory course for about 100 students.

Concepts of Physics at Kansas State University is an introductory-level physics course which serves students who are preparing to teach in elementary school. Each year approximately 100 students, mostly second- and third-year university students, enroll in Concepts of Physics. Their goal is to obtain a sufficient background in physics so that they can teach at the elementary school level.

Review of Literature: Teaching Undergraduate Physics

A significant body of research on student learning of physics exists. Much of this research was reviewed by McDermott and Redish (1999) and Tiberghien, Jossem, and Barojas (1998). More recent information can be found in the proceedings of the annual Physics Education Research Conferences (Gordon Research Conferences, 2003). No similar review of recent curriculum reform at the undergraduate level exists. Reform based on physics education research has been an ongoing process dating back to the early

1980s (Laws, 1991; Manogue et al., 2001; McDermott, 1991; McDermott, 2001; Redish, 1994; Van Heuvelen, 1991; Wilson, 1994; Zollman, 1990).

A science instructional model used in a number of undergraduate institutions is the learning cycle. The learning cycle is derived from the intellectual development model of Jean Piaget and was first conceptualized as an instructional model in the early 1960s (Karplus, 1977). The learning cycle includes a sequence of three different types of activities (Zollman, 1997). The first activity, exploration, requires the student to explore a concept by performing a series of activities. Students are given a general goal, some equipment, and some general ideas about the concepts involved. They are asked to explore the concept experimentally, in as much detail as they can, and to relate it to other experiences they have had. The second phase of the learning cycle, concept introduction, provides a model or concept to explain observations of the exploration. Frequently, the concept-introduction stage is not an experimental activity but expository statement of concepts and principles. Following the concept introduction, the students move to concept application. Here, they use the concepts that were introduced and apply them to new situations. This application of the principles and concepts leads to further understanding of the theories and the models. The complete cycle has been used successfully to teach a wide variety of topics to students at all grade levels.

Course Design

The instructional model used in an introductory physics course at Kansas State University is the learning cycle that was originally developed by Robert Karplus. Because of the emphasis on student-centered activities, a learning cycle class at most universities usually has an enrollment of less than 30 students. However, the economics associated with small class size has limited adoption of this method at many universities. To overcome this difficulty, we have adapted the learning cycle for a class of about 100 students with one faculty member assigned to it. During the past 25 years the course has evolved into one with an emphasis on the nature of science and on learning science by doing scientific activities.

The course is constructed of 15 activity-based units, each of which is 1 week long. An activity-based unit is a learning experience that focuses on a series of 8 to 10 short experiments performed by all of the students in the class. Thus, students perform a large number of experiments and these activities form the backbone of the course.

Each unit involves hands-on activities and is based on the learning cycle format. To adapt the learning cycle for a large-enrollment course taught by a single faculty member, we use a combination of activities completed in an open laboratory environment and large class meetings. This adaptation utilizes an open laboratory that is available to the students about 30 hours per week. The three parts of the learning cycle are as follows:

1. Exploration. This part of the learning cycle is a series of hands-on activities. Instruction sheets guide the students through a series of short activities. Students working alone or in small groups perform most of the exploration.

2. Concept Introduction. One large class meeting each week is devoted to this phase. Students are asked to describe their exploration observations and any related experiences. Using these observations, the instructor guides the students toward a model or a theory that can be used to explain the observations.

3. Concept Application. The final phase of the cycle again involves hands-on activities. Using the model developed in the large class (concept-introduction phase), the

students make predictions for new situations. Their predictions are tested experimentally. As in the exploration phase, instruction sheets are available. Additional applications and summaries are discussed in a large class meeting.

The teaching assistants, frequently students who have taken the course in previous years, act as proctors who help with occasional conceptual or equipment difficulties rather than as instructors in the course.

Operation of the Course

Each learning cycle begins on a Monday. At that time, the equipment for the exploration is available in the open laboratory. Students must complete all exploration activities before the class on Wednesday. The concepts that were explored are introduced in a lecture-discussion format during a 50-min class on Wednesday.

To assure that the students stay involved in the large class we use a classroom response system such as ClassTalk (Better Education Inc., n.d.) or the Personal Response System (Center for Enhanced Learning and Teaching, Hong Kong University of Science and Technology, 2002). With these systems the instructor poses a question. The students are encouraged to discuss their answer with others and then enter a response into a small handheld device. By posing three to five questions per class the instructor receives immediate feedback on students' understanding, and the students are motivated to be attentive throughout the class.

Following this class meeting, the application equipment is available in the open laboratory until class time on Friday. The class meets on Friday to ask questions about the week's work. In addition, the concepts introduced on Wednesday are applied to situations that, usually, lead to questions not easily answered with present knowledge. These applications introduce the exploration of the next cycle.

Each exploration and application is composed of six to eight short experiments called activities. The equipment for each activity is placed in the open laboratory at marked stations. The students are told what equipment is located at each station and presented with questions to answer about it. For example, an application activity on electrostatics states,

At station EM-9 is a small Wimshurst Machine. By turning the crank you can charge the two spheres. A small aluminum ball is suspended between the spheres. Describe and explain the motion of the ball as you turn the crank.

The students are guided from station to station until they complete all activities (see Figure 1). For each activity they must write answers to all questions on their activity sheets). When they finish, the students leave the completed activity sheets in the laboratory.

To assure that students are adequately motivated to complete the activities, grades are assigned to each exploration and application. Explorations are graded on a satisfactory-unsatisfactory basis. To obtain a satisfactory, a student must try to answer each question. We do not grade on right or wrong answers—only attempts at exploring new phenomena.

The applications are graded on a scale of 0 to 8. In this case, grades are based on the students' abilities to use physics concepts in their explanations and to use those quantitative relationships presented in the class and text.

Insert Figure 1 about here

Sample Learning Cycle

As an example of a week's activity, consider the 1st of 5 weeks on the topic of energy. When students start the exploration, they have already studied kinematics, momentum, and forces. Thus, they begin by trying to explain the motion of a pendulum by using either conservation of momentum or Newton's laws. Then they look at several experiments involving motion and change of motion. (At this point the term energy has not been introduced.)

First, a toy car is rolled down an incline into an aluminum can. By releasing the car from several different locations on the incline, the students determine qualitatively the relationship between release location and damage to the can. The activity sheet then instructs the students to change the angle of the incline and repeat the experiments. (A similar experiment involves driving nails by dropping weights on them. They compare the distance the nail is driven for different release heights and different-sized weights.)

The exploration concludes with a station at which the cart and can are placed on a horizontal surface. The students are asked to make a dent in the can without lifting the cart or can from the table. Once they accomplish that, they are asked to do something to make a bigger dent. Most students decide to move the cart at a higher speed; a few think of adding mass to it.

After completing the exploration, the students express in writing any similarities they can see in the various observation activities. These statements will be in their own language since we have not yet introduced the vocabulary of energy-related concepts.

The concept introduction begins with a discussion of the difficulties involved in describing the motion of the pendulum and with the “exchange of something” that causes the pendulum to move fast at the bottom and slow at the top of its swing. The discussion is partially student centered. The instructor leads off with a question, but the students do most of the talking. The discussion motivates a reason for introducing a new concept.

The general concepts of energy and gravitational potential energy are introduced. Students, by referring to their observations during the exploration, provide a list of variables upon which the potential energy depends. By recalling the nail-driving activities, they can also state the functional dependence of gravitational potential energy on mass and height.

A similar discussion occurs for kinetic energy. Most students will state that kinetic energy depends on speed. (However, none of the activities have enabled them to determine the functional dependence.) A few students will have discovered that adding mass to the cart will have an effect. Thus, with guidance from the instructor and frequent reference to their exploration activities, the students help construct the basic ideas of mechanical energy.

To conclude the introduction, we return to the pendulum and develop the idea of conservation of energy. With this material, the students are ready to begin the concept application.

The beginning of the application is simply a check to determine if the students can plug numbers correctly into the equations. After measuring their masses and walking speeds, they calculate their kinetic energies while walking and their change in gravitational potential energies when they move from the first to second floor of the physics building. For the next activity, they return to the nail driver, calculate its potential energy at several heights, and use conservation of energy to state its kinetic energy just before it hits the nail. Even though they have “learned” conservation of energy, many students reach a state of disequilibrium here. “How can I determine kinetic energy when I don’t know the speed?” is a frequent question. Without the application, the students would not have noticed this problem in their learning until the next test. With this concrete example, they are able to address it at once.

A toy car with a loop-the-loop track is the equipment for the next activity. The students are asked to measure the height of the loop and predict the kinetic energy needed for a car to go through it. Using a photocell timer, the students determine the speed and calculate the kinetic energy at the bottom of the loop. When they compare the actual kinetic energy with their prediction, they find a significant discrepancy. The students are asked to speculate about the reason for differences between these two numbers and told that we will discuss it during Friday’s class.

Next, the students drop a feather and a BB from the same height. The two objects have equal mass so they begin with the same potential energy (which the students calculate). Without making any measurements, all students notice that the two objects have different kinetic energies as they reach the floor. Again, they speculate about these differences.

Finally a two-hill “roller coaster” track is used. The students are asked to predict, and then experimentally determine, the point on the higher hill from which a steel ball must be released to roll over the lower hill. The experiment is repeated with a cork-covered ball of the same mass. They discuss the differences between these results and the results predicted by conservation of potential and kinetic energy.

After answering questions during Friday's class meeting, we continue looking at situations wherein the sum of kinetic and gravitation potential energies is not conserved. Particular attention is paid to the differences between the BB and the feather and between the bare steel and cork-covered balls. Because the students have studied friction, they speculate that it must be involved. A discussion of work by a frictional force prepares the students for the next activity: exploring thermal energy.

In this example of our adapted learning cycle, students used traditional laboratory equipment to perform all observations and measurements. However, other cycles include activities based on contemporary technology.

Interactive Multimedia in Explorations and Applications

In an exploration that introduces impulse, students are asked to view a short video sequence that shows a mannequin in a car that collides with a fixed wall (see Figure 2). Another mannequin would be in an identical collision but would have an airbag in the car. Students are asked to describe similarities and differences in the two events and what is different, and to speculate on why the airbag makes a difference in the amount of damage done to the mannequin. In general, students would make comments such as "the airbag is softer than the windshield" or "the mannequin sinks into the airbag but it bounces off the windshield." Their wording would not be in terms of Newton's laws of motion or impulse that are the concepts to be studied after this exploration.

This same video sequence could be used for an application activity. After the students have been introduced to the concepts of impulse and Newton's second law, they can be asked to look at the two video scenes and describe in terms of these concepts why the mannequin which is protected by the airbag receives less damage than the one which is not. Thus, an identical video sequence can be used in both an application and an exploration.

Video scenes such as these can also be used in situations where the students need to apply their knowledge of physics but for which there is no right answer. One of the favorites in this category is a video sequence from the second Mohammed Ali-Sonny Liston prizefight. In this sequence, Ali swings at Liston and Liston falls down. A voice-over narrator says that this punch was very controversial, and some people do not believe that Liston was actually hit. The students are asked to watch the video one frame at a time and try to determine if Liston was hit. However, they cannot just say, “Yes, I think so,” or “No”; they must state their reasoning in terms of conservation of momentum, which is the concept being applied. Thus, they must talk about the momentum of Ali’s fist before the interaction as well as the momentum of Liston’s head. They must then look at the momenta of these two objects after the collision and come to some conclusion. However, because the camera angle does not allow for extremely careful measurement, no definitive answer can be determined. Thus, the students are required to come to their own conclusions and defend their conclusions based on the laws of physics. They are told that either yes or no is correct but that their reasoning is what really counts.

In other scenes careful measurement can be completed. Students are asked to apply the principle of conservation of energy to a pole-vaulter on the videodisc Physics of Sports (Zollman & Noble, 1988). They step through a pole vault sequence one frame at a time. Using VideoPoint software (Luetzelschwab & Laws, 2001) they measure the distance that the vaulter is moving during each frame before he leaves the ground. With this information they can calculate the vaulter's speed and then his kinetic energy. They then move to the frame at which he is highest above the ground and measure the distance to which he has ascended. Now, they can calculate the gravitational potential energy of the vaulter. The students must then determine if all of the gravitational potential energy that the vaulter obtained came from his kinetic energy when he was running on the ground. If not, they must speculate on where the remaining energy may have come from. Thus, this application is also an exploration for the next concept: the many forms of energy in addition to kinetic and gravitational potential energy.

Another example, which is partially quantitative and partially qualitative, involves the students analyzing the forces on a diver as she goes from a 3-m board into the water. The students are asked to look at the scene and then to go to several frames that have been preselected by the instructor. For each of these frames they are to state all of the forces acting on the diver and then the net force on the diver. This activity is particularly useful in bringing out some of the students' conceptions that are not consistent with the accepted way in which Newton's laws are applied. In particular, many students will state that as the diver is ascending, she must have a force in the up direction acting on her. The reason that the students give is she is moving up therefore there must be a force acting up. By the time the students come to this interactive video activity, they have already learned that a force does not necessarily need to be in the direction of motion. However, this idea is very firmly held by most students when they enter a physics class and is difficult to change. Thus, a "real-life" example helps bring it out so that the instructor can discuss it further. These and other similar activities are particularly helpful in this respect because they apply to real events with which the student can identify.

Insert Figure 2 about here

Multimedia in the Large-Class Setting

The lecture response system allows the instructor to pose questions to the entire class during the large-class meetings, which are for the concept introduction and part of the applications. When the students respond, the responses are collected by the instructor's computer and sorted. Thus, the instructor and students can interact regularly even though the class is rather large.

An example of a large class meeting in which both multimedia and the classroom response system are used in combination is one in which students summarize work on the transfer of thermal energy. To begin the activity the class watches a scene from the film Wizard of Oz in which Dorothy throws water on the Wicked Witch of the West, and the witch melts. The instructor states that, because the witch melted, we should be able to determine the latent heat of fusion for her. The students are then asked if they have a sufficient amount of information to calculate this particular variable. The majority will answer that they do not, so they are asked to enter into their computers the variables that we need to know to make the calculation. From the students' responses the instructor can make a list of variables that the class will either need to estimate or measure. The instructor can also address variables that are listed by the students but are not necessary in this situation. Thus, the interactive system enables the instructor to uncover student misconceptions and address them in real time. For each of the variables that are needed the students are asked to enter in their computers an estimate based on the information on the screen. Thus, they estimate the mass of the witch, the temperature in the castle, the change in the water temperature, and the amount of water that struck the witch.

The estimates are made by looking at individual pictures in the film. The students can request any picture. For each variable the students enter an estimate into their computers. The instructor uses the values that were entered to determine an approximate average value for each variable. These averages are then used in the determination of the latent heat of fusion of the Wicked Witch of the West.

While on the surface this activity is a calculation of one number, the process that the students go through reviews most of the concepts related to thermal energy transfer. Further, the process shows students how we can use estimation as part of the scientific process. The students will also raise questions about thermal energy that we cannot account. For example, “steam” rises from the witch. That would indicate that she did not simply melt. Then, we must estimate if these contributions are significant. Thus, the overall result of the activity is an interactive discussion, which takes almost a full class period and includes a variety of topics related to the process of science as well as the concepts that are studied. The combination of interactive video and a class response system provides motivation and assures that all students are involved.

In all parts of the course, the multimedia and interactive classroom activities are not separated from other hands-on activities. Students move quickly and easily from an experiment involving standard laboratory materials to an interactive video station and then back to lab apparatus within a single class period. Likewise, in the large-class activities the instructor uses computer modeling, interactive video, and physics demonstrations together with the response system. Thus, the interactive media component of the course is fully integrated with all other aspects and provides a model for including these types of activities in their future teaching.

Outcomes of Learning Cycle in the Physics Course

During the past 25 years, Concepts of Physics has been the primary course in physics for future elementary teachers at Kansas State University. When the course was first introduced, a study indicated that students in the course learned the content better than in a traditional mode. More recent studies have focused on the use of technology in the course. (Escalada & Zollman, 1997) The studies show that the students' attitudes toward physics and toward the methods of learning as well as their learning of the content are very positive.

We find that students who complete the course frequently make statements such as, "I could not have succeeded in physics without the activities." Further, when they become student teachers or teachers, they return to borrow equipment or discuss how to teach certain topics. Thus, the goal to provide an appropriate role model for teaching science has been achieved.

Summary: Recommendations for the Development of an Effective Course in Physics

When this course began, it was based rather tightly on the learning cycle model. In the past 25 years, research has modified some underlying principles about ways to teach science (Erickson, 2000). Simultaneously, research in physics teaching and learning has vastly increased our knowledge of conceptions that students bring to a physics class and how to build on and modify those conceptions. This newly acquired knowledge about teaching and learning has been introduced into the basic structure of the course in a rather seamless manner. For example, explorations now frequently provide the beginnings for students to see how their naïve conceptions may not be generalized. Applications will offer students the opportunity to investigate the value of newly acquired knowledge in a variety of different contexts and to transfer knowledge from one component of the course to another. Each of these additions to the course represents research that has developed since the course was begun.

We are able to modify the learning experiences to account for up-to-date research because the foundation for the course is very solid. The learning cycle was initially based on Piaget's model of intellectual development and provides a good classroom environment for any constructivist approach to teaching and learning. Because it has a solid base, the course structure was flexible enough to be able to be changed as knowledge about teaching and learning improved.

The primary conclusion is that a course of this nature needs to have a solid foundation based on contemporary ideas of teaching and learning. With that foundation an instructor can be in a position to make changes as needed and yet not need to modify the underlying operation of the course.

Transferability to other faculty is also a critical part of success. A good structure must survive the "enthusiasm curve" of the developer. In our case, the course was designed and implemented by the author of this chapter. A challenge was to convert the course from "Zollman's Course" to one which other faculty would feel comfortable teaching. This process began about seven years ago. Since then two other faculty, whose research areas are not physics education, have taught Concepts of Physics while the originator acted as his mentor. The transfer has been successful.

Implications for Reform in Undergraduate Physics and Future Research

Reform in undergraduate physics teaching and learning will continue to be based on physics education research and on intuition of physics faculty. Both the research and the intuition are necessary components of this type of development. The research informs us of models for student thinking and applications to instruction. Intuition based on experience can help improve the process in areas where the research base is not yet developed.

Physics education research has broadened greatly in recent years. We have a solid body of research that helps us understand the naïve conceptions that students bring to a physics class and a good understanding of which of these conceptions are most resistant to change by instruction. Now the research is looking at underlying models that students use, how those models are cued by the contexts in which they are used and how information and thinking processes transfer within a physics course and from one course to another. This research should be able to feed back into the conceptual change work and perhaps lower the resistance to some of that change. Thus, future research will build on but go far beyond the conceptual change research that has served us so well.

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Author Note

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Figure Captions

Figure 1. Traditional hands-on activities as well as interactive multimedia are used in the explorations and applications.

Figure 2. A scene from Physics and Automobile Collisions that is used to explore Newton's laws.

Figure 2