Appendix E

Poster Abstracts

Abstracts for several posters from PERC98 are presented in the following pages:

Matter and Interactions: A New Curriculum and Textbook for Mechanics and Thermal Physics
Ruth Chabay, Bruce Sherwood, Tom Foster (Carnegie Mellon University)

“Hidden Variables” in Conceptual Diagnostic Pretest Data?
David E. Meltzer (Iowa State University)

Investigating Students’ Concepts of Surface Phenomena
Kastro Hamed and Dean A. Zollman (Kansas State University)

Students’ Understanding of Quantum Phenomena
N. Sanjay Rebello and Dean A. Zollman (Kansas State University)

Integrating Research and Education
Michael Thoresen and Dean A. Zollman (Kansas State University)

Research on the Teaching and Learning of Radiation and Radioactivity
Edward E. Prather (University of Maine)

Individual Student Use of Multiple Models to Guide Reasoning in Physics: An Example from Mechanical Waves*
Michael Wittmann (University of Maryland)

The Connection Students make Between Qualitative and Quantitative Physics Knowledge
Physics Education Research Group (University of Maryland)

Jose Mestre (University of Massachusetts)

Computerizing Undergraduate Laboratories - Initial Results
Laura McCullough (University of Minnesota)

Computer Intensive Physics: Module Development
Rebecca Lindell Adrian, Cecilia A. Hernández and Tom Koch (University of Nebraska – Lincoln)

A Qualitative Investigation of College Students' Understanding of the Effects of Apparent Celestial Motions
Rebecca Lindell Adrian (University of Nebraska-Lincoln)

The Ohio State University–Physics Education Research Group
Poster #1: Conceptual Understanding
Poster #2: Problem-Solving
Poster #3: Lab Development, based on Research

RESEARCH AND DEVELOPMENT PROJECTS WE ARE NOW DOING
Kandiah Manivannan (Southeastern Louisiana University)

Matter and Interactions: A New Curriculum and Textbook for Mechanics and Thermal Physics

Ruth Chabay, Bruce Sherwood, Tom Foster (Carnegie Mellon University)

This past semester (Fall 1997) we offered an alternative Physics 1 course to one section of volunteers who were entering freshmen majoring in science, math, or computer science at Carnegie Mellon University. A primary goal was to engage students in modeling physical systems, including using computer modeling. An equally important goal was to offer a Physics 1 course that would be intrinsically more interesting because it had a more modern flavor, and did not appear to the students as a repetition of what they had already done in high school. We wrote a new textbook, *Matter and Interactions*, to support the approach. A list of textbook chapters and topics was included on the poster and is available from the authors.

We judge the course to have been quite successful. Certainly the content was significantly more modern than usual and students reported learning much more in this course than in other courses they were taking.

Computer modeling

An integral component of the course was computer modeling, to enable students to analyze complex systems and to carry out progressive refinements of models (such as adding air resistance). During the semester students wrote computer programs in the cT language to model and visualize various physical systems, including a voyage to the Moon, planetary orbits, projectile motion with and without air resistance, a mass on a spring, energy conservation in all of these systems, trajectories and momentum in the Rutherford experiment (an alpha particle incident on a gold nucleus), the angular momentum of a comet about two different origins, and thermal properties of an Einstein solid. Computer modeling of air resistance and the harmonic oscillator was connected to experiments performed by the students on falling coffee filters and a mass on a spring.

While we had the students use cT because of our familiarity with it, other computing tools could be used, such as a spreadsheet or a math package (such as Mathematica or Maple). We should however comment that there are some significant advantages to using a programming language. While graphs of functions are easy to create in a math package, animations of moving systems may be difficult.

Concerns expressed about the course

Three major were concerns expressed by our physics colleagues. Here is how these concerns worked out in practice:

The course attempts to cover way too much. We were able to introduce a wealth of new material, and engage students in physical modeling including computer modeling, in part by minimising time spent on vectors and kinematics justifiably assuming that the students had already studied this in high school (though we did do just-in-time review of these concepts as needed).

Computer programming will be a stumbling block and detract from the physics. We devised an efficient way to introduce cT programming in a physics context that took about 2 hours to complete. Programming was definitely not a problem and added critical support to physical modeling.

The level of sophistication is too high. This does remain a question mark, although the level of sophistication was generally within reach of our volunteer students. One year of high school physics is an admission requirement for our students. This alternative Physics 1 therefore is built on the assumption that students know some basic mechanics, which is true of a large fraction of the students. We should mention that most of our volunteer students had quite strong physics backgrounds, and many even had two years of high school physics. They didn't place out of Physics 1 for various reasons (no AP course available, or didn't take the AP test, or didn't get a 5 on the test). Yet it would have been quite inappropriate for them to take the regular Physics 1 course, given their knowledge of mechanics. However, students whose high school physics preparation is very weak are unlikely to be able to cope with the alternative course. We will continue exploring this issue over the duration of this project.

Future plans

We plan to teach the course again in Fall 1998 to a somewhat larger group. In the spring and summer of 1998 we will make significant revisions to the textbook and course structure, to improve instruction in areas identified as problematic, and to make it possible to scale up the course and run it in a traditional 3 lecture, 2 recitation format. We will also continue the formative evaluation by assessing course goal achievement, student attitudes, student preparation, student background, and overall student performance.

"Hidden Variables" in Conceptual Diagnostic Pretest Data?

David E. Meltzer (Iowa State University)

"Normalized Learning Gain" [Hake's "*g*"] on the Force Concept Inventory (FCI) is generally considered to be correlated only with instructional method. [g = (posttest score – pretest score)/(maximum possible score – pretest score).] Hake (1998) has found that *g* was ***not*** correlated with class-averaged FCI pretest score, but ***was*** consistently higher for courses in which "Interactive Engagement" methods of instruction were used. We have confirmed (Meltzer, 1997) that ***individual*** student *g* does not appear to be correlated with students' pretest score, either on the FCI or on the Conceptual Survey of Electricity (CSE) (O'Kuma et al., 1998).

However, many studies in the literature assert that there is a correlation between students' mathematical ability, and their performance in physics courses. Is it possible that such a correlation might also be reflected in learning gains as measured by *g* on the FCI, CSE, or similar conceptual diagnostic exams?

If normalized learning gain *g* could be shown to be correlated with ***any*** precourse measure (such as mathematical ability), then this would have to be taken into account when analyzing comparative FCI data. It could no longer be assumed that equal FCI pretest scores in courses that use identical instructional methods imply equal probability of attaining specified posttest scores. **Other, "hidden" variables would be required to fully characterize a student's preinstruction "mental" state function.**

Zeroth Order Analysis: **Are students' ACT Math scores correlated with their normalized learning gain *g* as measured by the Conceptual Survey in Electricity (CSE)?**

We have examined two separate samples of data to explore the possibility of this correlation. Both samples were drawn from students enrolled in the second semester of the algebra-based introductory courses at Southeastern Louisiana University. All students were included for whom both ACT Math score, and pre/posttest scores on the (abridged) CSE were available.

RESULTS: The results of the preliminary study were ambiguous, and indicate a need for further investigation. *FALL 1997: Correlation analysis was performed for individual students' ACT Math score and their normalized gain* ***g****; N = 46; correlation coefficient = 0.22 and is* ***not significant*** *at the p= 0.05 level. However, if one outlier is removed, then the correlation coefficient = 0.38, p < 0.01, and the correlation is significant.*

SPRING 1998: Identical analysis was performed for this data set. N = 37; correlation coefficient = 0.12, p = 0.49, correlation is ***not significant****.*

Hake, Richard R. (1998), American Journal of Physics **66**, 64.

Meltzer, David E. (1997), AAPT Announcer **27(4)**, 89.

O'Kuma, Tom L., Curtis J. Hieggelke, Dave Maloney, and Alan Van Heuvelen (1998), AAPT Announcer **28(2)**, 81.

Investigating Students' Concepts of Surface Phenomena
Kastro Hamed and Dean A. Zollman (Kansas State University)

My research endeavor is part of the Integration of Education and Research project at Kansas State University. I am interested in probing into the students' understanding of the particulate nature of matter, the students' ability to relate macroscopic phenomena to the microscopic molecular behavior. The probing procedure utilizes a semi- focused interview approach. The findings of this part of the research will be used as a guide in developing instructional materials. Of particular interest in my effort is introducing the students to contemporary research in surface physics. To accomplish this goal, a combination of Molecular Dynamics animations, interactive computer simulations, and hands on activities will be utilized.

Students' Understanding of Quantum Phenomena
N. Sanjay Rebello and Dean A. Zollman (Kansas State University)

The Visual Quantum Mechanics (VQM) project teaches some basic ideas of quantum mechanics to high school and introductory college students by integrating hands-on activities and computer visualization, rather than higher level mathematics. We have field-tested these materials in high schools and colleges. During field tests of the materials we obtained data concerning student understanding of some quantum concepts including potential energy diagrams, energy levels and spectra in atoms, energy bands in solids, wave functions and probability, and quantum tunneling. Often we will compare student responses before and after they completed a specific section of the materials or used a specific computer program. Data were collected from written responses of students and structured interviews. The overall results indicate that although misconceptions may exist, students seem to have acquired a good general understanding of some important concepts that are traditionally not taught at the introductory level.

Integrating Research and Education
Michael Thoresen and Dean A. Zollman (Kansas State University)

Kansas State University was one of ten universities to receive a Recognition Award for Integrating Research and Education from NSF. This award was based upon three previous projects, which incorporated scientific research results and methods with educational materials. Previous projects developed materials on genetics for continuing education of middle and high school teachers, quantum mechanics for use by preservice teachers and in high schools, and a program for elementary education teacher preparation in mathematics, science and technology.

A unique feature of the KSU efforts is that all projects used research in science education to guide the development of instructional materials. The current project will use research on education to develop instructional materials which incorporate hands-on, research-type activities in the learning process. Additionally, efforts are underway to provide science research opportunities for undergraduate education majors. This will enable our future science teachers to have a first hand knowledge of what scientists do.

Research on the Teaching and Learning of Radiation and Radioactivity

Edward E. Prather (University of Maine)

Researchers from the Laboratory for Research in Physics Education (LRPE) are involved in a project to identify student conceptual and reasoning difficulties related to the concepts of radiation and radioactivity. This project has involved participants from a wide range of science backgrounds. The results of initial individual demonstration interviews and open response concept tests were used to guide our initial instructional goals and drive the development of laboratory and tutorial activities. These activities are being designed to help students gain a better understanding of the concepts of ionizing radiation, radioactivity, irradiation and contamination through hands-on inquiry based activities.

Individual Student Use of Multiple Models to Guide Reasoning in Physics: An Example from Mechanical Waves*

Michael Wittmann (University of Maryland)

The Physics Education Research Group at the University of Maryland, College Park, (UMd) has been investigating student understanding of waves in an ongoing project to improve student learning in our classroom. We have used a variety of research probes to investigate our student's understanding of physics, including videotaped and transcribed individual interviews and written examinations. This poster presents student use of multiple models of wave physics on a pre- and post-instruction diagnostic test on waves.

Classroom instruction consisted of UW-style tutorials developed at UMd that made use of videos filmed at Dickinson College of wave motion and medium motion due to waves. In tutorials, students working in groups participate in an active learning setting where they make predictions based on their models of the physical situation, compare predictions to observations, revise any incorrect predictions, and apply their new reasoning to new physical situations. The principle of *elicit - confront - resolve* guides the classroom learning of the students.

In the tutorial materials, students are confronted with common difficulties that have been found through our previous research into student understanding of waves. The research questions used to develop the tutorials have been combined into a single diagnostic test that was administered in the Fall, 1997 semester to calculus based engineering students at UMd. A total of 137 students answered the question before and after instruction.

When analyzing student responses, we find that students use one of two models in their reasoning. At the beginning of the semester, few use the correct model of wave physics that we teach at the introductory physics level. Instead, they make use of what we call the Particle Pulses Mental Model. A mental model describes the analogies or patterns of association that students use to guide their reasoning. In this case, the analogy is to Newtonian particle mechanics. Students often describe wavepulses (i.e. finite length waves, e.g. Gaussian shaped waves) by only one point (the peak of the pulse), describe making faster waves by "putting more force" into their creation (like throwing a ball harder), and describe the effects of sound waves to be that they push the medium (air) in front of them (like a surfer riding an ocean wave). At the end of the semester, after specially designed instruction, many still use the Particle Pulses Mental Model, though many more make use of the correct model. These results allow us to gain insight into how students come to make sense of physics in our classrooms and provide an opportunity to discuss what is meant by the term “misconceptions” when discussing student difficulties.

The Connection Students make Between Qualitative and Quantitative Physics Knowledge

Physics Education Research Group (University of Maryland)

A physics problem is composed of qualitative and quantitative parts. In order for the student to solve challenging problems, the student must have both a qualitative understanding and a quantitative understanding and be able to connect and integrate the two. de Jong and Ferguson-Hessler state that having the knowledge is not sufficient. The knowledge must be organized in a useful manner. This organization separates the novice and expert problem solvers. The Physics Education Research Group at the University of Maryland has been investigating some of these issues. The poster will show three specific examples of difficulties students have in linking qualitative understanding to quantitative problem solving.

Jose Mestre (University of Massachusetts)

Assessing To Learn Project (A2L)

A2L is a four-year, newly funded NSF project to develop and evaluate formative assessment materials (assessments that the teacher uses to make decisions about subsequent instruction) for high school physics. The materials will fully integrate assessment and instruction, a goal that will be achieved with the use of classroom communication technologies.

Research on Effective Use of Classroom Communication Systems (CCS)

For the past five years we have been investigating strategies aimed at promoting active learning in large college introductory courses using the Classtalk CCS. We are currently investigating whether or not an interactive instructional approach improves learning in large introductory courses. More specifically, we are focusing on measures of conceptual understanding and problem solving to determine whether students exhibit differential performance as a function of whether they are taught via lectures or interactively through small group activities and class-wide discussions. We are also investigating whether or not active learning strategies improve students' attitudes toward learning physics and class attendance.

Minds-On Physics (MOP)

MOP is a full year high school curriculum that stresses conceptual understanding and problem solving through collaborative learning activities during which the teacher plays the role of coach. MOP is designed to be consonant with findings from different strands of educational and cognitive research—misconceptions research, expert-novice research, studies of cognitive load associated with problem solving, research on problem solving, and studies on active learning and cooperative group learning. MOP activities are designed to help students learn to use physics concepts to analyze and solve problems, and to curb students' proclivity toward rote learning and formula manipulation. Attention has also been paid to helping students organize their physics knowledge in ways that are efficient for recall and application. The MOP curriculum is available through Kendall / Hunt Publishing Co.

Fundamental Research on Learning and Assessment

We are investigating what multiple choice questions tell us about students' knowledge, and how multiple choice questions can be used effectively for formative assessment. Our initial study examines students' answers on a select set of three multiple choice questions from the Force Concept Inventory (FCI). By asking additional multiple choice questions, and by asking the FCI questions in a variety of different formats, we are attempting to determine the factors leading to false-positive and false-negative responses on these three questions. By giving the questions to large groups of students we hope to get a realistic measure of the size of these effects.

Computerizing Undergraduate Laboratories - Initial Results

Laura McCullough (University of Minnesota)

We recently tested a new computerized version of the problem-solving labs developed at the University of Minnesota. Data were collected from both the non-computerized labs and the computerized labs. Conceptual development, cooperative group functioning, time spent on task, and student beliefs about physics were all analyzed in order to enhance the laboratory design. Representative results from our studies will be shown.

Computer Intensive Physics: Module Development

Rebecca Lindell Adrian, Cecilia A. Hernández and Tom Koch (University of Nebraska – Lincoln)

During the spring semester of 1998, the University of Nebraska—Lincoln offered a computer intensive physics course as an alternative to the traditional calculus-based introductory physics. The course was taught in a laboratory classroom environment. The students worked in small teams to learn physics principles through interactive multimedia tasks, such as micro-computer based laboratories, computer algebra systems and interactive videos. This posters shows three of the modules prepared for the course— Simple Harmonic Motion, Traveling Waves and Heat & Temperature.

Funding for this project was provided by NSF grants #DUE-9555404, #DUE-9551515 and #GRT-9452801.

A Qualitative Investigation of College Students' Understanding of the Effects of Apparent Celestial Motions

Rebecca Lindell Adrian (University of Nebraska-Lincoln)

At the University of Nebraska-Lincoln, we are in the process of designing multimedia astronomy instruction based on the Karplus learning cycle[1]. Before effective instruction can be designed, a qualitative study investigating college students' understanding of astronomical concepts is needed. To this end, extensive qualitative interviews were administered to University of Nebraska-Lincoln students planning to take the introductory astronomy course during the following semester. These interviews were designed to determine college students' explanations of common astronomical phenomena and to determine their understandings of the effects of apparent celestial motion. The interview protocol consisted of a hypothetical observing session with an inner city child interested in astronomy, participation in a simulated observation of the night sky, and discussion of actual photographs of the phases of the moon, of the apparent motion of the stars, moon and sun and of lunar and solar eclipses. Students' alternate explanations of common astronomical phenomena will be discussed, as well as their understanding of apparent celestial motion. Instructional activities to help students develop mature astronomical understandings will be suggested.

Partially sponsored by NSF Grant #GRT-9452801

[1] Karplus, R. , Science Teaching and Development of Reasoning, ***Journal of Research in Science Teaching***, 14, (2), 169-175, 1977.

The Ohio State University–Physics Education Research Group
Poster #1: Conceptual Understanding

We are currently investigating students' conceptual understanding of various content areas, including: the photon and quantization, work-energy processes and internal energy, and electromagnetic induction (Faraday's and Lenz's laws). We are also continually monitoring students' conceptual understanding of broader content areas such as kinematics, dynamics, electricity, and magnetism using multiple choice survey tests. We have been analyzing the difficulty and discrimination of questions on these tests using Item Analysis. The following paragraphs will describe these efforts in more detail.

Student Conceptions of Quantization and the Photon: **(Gordon Aubrecht, Tom Kassebaum, David May, and Jim Stith)** What is a Photon? Many students of physics bring with them preconceptions about the photon. These preconceptions may affect student learning of modern physics. We have interviewed students, teachers, and physicists about photons in order to gain insight into their conceptions of quantization, a fundamental concept in modern physics. Our analysis of these interviews is being used to develop a pencil/paper survey intended to determine the extent to which these conceptions exist in the general public.

We are experimenting with different computer software packages to aid in the transcription and analysis of the interviews, including the latest voice-recognition software and qualitative data analysis software.

Each interview includes questions about the nature and properties of photons and the subject's mental image of a photon. Preliminary analysis shows that students and faculty alike struggle with a wide variety of mental images of the photon, although faculty and graduate students typically have more elaborate images.

Work-Energy Processes and Internal Energy: **(Xueli Zou and Alan Van Heuvelen)**: Based on Uri Ganiel's paper in The Physics Teacher (1992) and our interview results, a pair of special carts have been developed to help students visualize internal energy during a partially inelastic collision. This demonstration, along with corresponding worksheets, was shown in a calculus-based class. From the results of a written quiz administered to the class, we found that students who finished the questions on the worksheets did much better than those students who had not seen the demos or had not answered the worksheet questions. Also, we found that many students have alternative concepts about internal energy during collisions; for example, that it is transferred to friction, internal forces, or heat.

Electromagnetic Induction: (Leith Allen and Alan Van Heuvelen) Among other measures, lab activities are being used to probe students' understanding of concepts related to electromagnetic induction. Prior to any formal instruction on electromagnetic induction, 172 students in an introductory calculus-based course were asked to describe if it would be possible to light a bulb using only a bar magnet and a coil of wire. Preliminary results showed that 30% of the responses were satisfactory, 26% were incomplete. 28% indicated that they would need a battery, and almost 14% drew a circuit in which the magnet acted as a battery connected to the bulb. One described this last process as "…the + charge in the north end will flow towards the – charge in the S end and vice versa, lighting the bulb."

During an Experiment Problem lab (described on the lab poster), 91 of these same students were asked to predict the shape of a graph of induced voltage across a solenoid as a function of time as a magnet travelled down and incline and through the solenoid. Results showed that students' generated a wide variety of predicted shapes. Students' descriptions included ideas that EMF is proportional to magnetic field, magnetic flux, or velocity. There also seemed to be the idea that induced EMF is not transient. When asked to predict changes in the graph if the magnet was initially released from half the original height, all but 7 students predicted that the peak value would be less. However, 31% predicted it would now be half its previous value. 31% correctly predicted it would be less by a factor of $1/\sqrt{(2)}$. For this activity, students worked in groups, but made individual predictions.

Systemic Change: Many of the tools described on these posters and developed by members of the OSU Physics Education Research Group have been and are being integrated into the (honors and regular) introductory calculus-based physics course and into the second-year course for physics majors. At present, most work has been done for the calculus-based physics honors course which is part of the College of Engineering Gateway Program for first-year engineering students (about 70 students per year). The course involves: considerable group work, interactive multimedia simulation activities, open-ended labs involving considerable design work, contextually interesting complex problems and other innovations. In the fall of 1998, these students scored 86 percent on the FCI posttest and 77 percent on the MB posttest. With the experience in this course, we are now ready to implement these strategies in the large calculus-based physics course for engineers (about 1000 students per year) and in the second-year course for physics majors. This is part of an NSF Course and Curriculum Development project involving all of the OSU Physics Education Research Group plus Professor Richard Furnstahl, postdoc Mike Strickland, and graduate student Brent Allen from the Nuclear Theory Group.

Item Analysis: **(Xueli Zou, Leith Allen)** We have analyzed student responses on a conceptual survey of electricity and magnetism. An example is given of a question that was found to have a moderate difficulty and good discrimination. A second example is given of a question that may have had an unintentional ambiguity due to its location on a page following a series of questions that referred to a specific diagram. The diagram--not intended for use with this question--may have reinforced a misconception for some of the stronger students.

The Ohio State University –Physics Education Research Group
Poster #2: Problem-Solving

We are currently studying the following aspects of students’ problem-solving abilities. How well are students able to break down multi-part problems based on underlying physics concepts? How does the number of steps they see compare to that seen by experts? How much does the perception of “math” versus “physics” affect students’ ability to solve problems? How well can students use multiple representations to solve problems? How much does students’ conceptual and qualitative understanding influence their approach to and success in solving quantitative problems? How well do students’ interpersonal and problem-solving skills develop when they are periodically asked to rate themselves and their group members on them?

Problem Decomposition Diagnostic (PDD) (for Mechanics): **(Dave Van Domelen)**: In the course of other research on problem-solving, including the Toys In Motion laboratory course, it was realized that there wasn't a reliable way to test for student ability to break a complex problem down into simpler pieces. This project is currently in the preliminary stages, attempting to create a test that is as objective as it can be made without loss of validity. When complete, the PDD will hopefully measure three things:

1) Student ability to identify the parts of a problem.
2) Student ability to classify these parts by what kind of problem they are.
3) Specific weaknesses tied to particular types of problem, such as consistently failing to recognize a collision as being a separate part of a problem.

Multiple Representations (e.g., in the context of Work-Energy): **(Xueli Zou and Alan Van Heuvelen)**: Work is being done to help students develop functional understanding about work and energy by explicitly learning to represent a work-energy process in multiple ways---words, picture or diagrams, bar charts, and math equations. An energy bar chart, as a physical representation, especially plays the role of a bridge between verbal and mathematical representations. The bar charts as visual aids foster students’ understanding of the problems, and help students move in smaller, easier steps from words to equations. A survey was administered to about 70 honors engineering freshmen who learned this method. It shows that 92% of the students thought that this approach was very helpful for them to understand concepts of work and energy, and to set up correct equations to solve problems.

Math/Physics: **(Kathy Andre)** A short interview protocol containing two math problems and a physics problem was developed to probe relations between student solutions to math and physics problems. These problems were given to students, as well as some physicists, in think-aloud interviews. Initial analysis indicates that, at a basic level, the difficulties observed in solving physics problems are not due to poor math skills. Also, the wordiness of physics problems does not appear to be the root of the difficulties. The novice-expert comparisons show that novices tend to identify more solution steps than experts, and that experts have greater agreement than novices about what constitutes a step.

Quantitative vs. Qualitative Ability (in the context of Faraday's law): **(Leith Allen)** Among other measures, data from a final exam problem involving electromagnetic induction was studied for students in the introductory calculus-based physics course. A scatterplot of quantitative versus qualitative physics scores on this problem shows these students fill the whole phase space of ability, including strong quantitative but weak qualitative ability and vice versa. Students' mathematical scores were not included in the above analysis.

Outcome-Driven Assessment: **(Kathy Andre and Alan Van Heuvelen)** In outcome-driven assessment, course objectives and student learning outcomes are first clearly identified. For example, an objective might be to provide students with the opportunity to learn and practice working in teams to solve ill-defined contextually interesting multi-part problems. Desired student outcomes would be to demonstrate an ability to actively participate, listen, and cooperate with other team members while working such problems. The assessment method includes a group member's evaluation of their own abilities to perform specified tasks needed to solve such problems, as well as a peer review of the individual by team members regarding these same skills. This feedback from team members, when compared with the student's self assessment, leads the student to focus on weaknesses in his or her team skills. The feedback to the professor by the students also indicates if the students are achieving the desired outcomes. A web tool is being developed by the OSU Physics Education Research Group to conveniently use outcome driven assessment in large classes.

The Ohio State University –Physics Education Research Group
Poster #3: Lab Development, based on Research

We are continuing the iterative process of revising and assessing various lab activities in the introductory calculus-based physics sequence. Those described here include a "Toys in Motion" series, examples of "Experiment Problems" in the context of work-energy processes and electromagnetic induction, and a series of Concept Construction Labs.

Toys in Motion (TIM): **(Dave Van Domelen)** The Toys In Motion lab course was designed to emphasize problem-solving skills and design work while using simple equipment, mainly toys. Rather than working through a lab manual, students are given a task such as "Design an experiment to find the acceleration of gravity," and then they work in groups to design their own labs. The course includes a number of tasks that are deliberately designed to avoid commonly-derived textbook results (such as the range equation).

The aspects of problem-solving which TIM is expected to help with are:

- *Design*: students are expected to work out their own lab exercises to meet a particular requirement.
- *Breaking complex problems into simple parts*: later labs present students with tasks that cannot be performed in a single step.
- *Approximation and estimation*: because of the nature of the equipment used, students are not able to get data out to three or more significant digits, so they have to learn to accept rough data. Also, some tasks are not solvable analytically, and mathematical approximations need to be made.

Experiment Problems: Students use the concepts of physics to make predictions about the outcomes of more complex multi-part problems that involve experimental apparatus. They then perform the experiment to test their predictions. To solve an Experiment Problem, a student must do one or more of the following:

- Divide the problem in parts, solve the parts and reassemble the parts to answer the big question.
- Define a poorly-defined problem.
- Design an experiment.
- Choose the best concept to solve the problem.
- Choose the important variables and determine their values.
- Decide if approximations are appropriate.
- Determine how something works.

Group members are studying effective ways to help students learn to solve such problems. About thirty Experiment Problems will soon be available at www.physics.ohio-state.edu/exppro.html. This is part of a National Science Foundation curriculum development project involving the OSU Physics Education Research Group.

Pendulum Box Bash: (Xueli Zou and Alan Van Heuvelen) A pendulum swings down and collides with a box, which is at the bottom in the path of the pendulum. After the collision, the box slides on the surface of the table. Students are asked to use this experimental setup to determine the coefficient of friction between the box and the table. Students first individually break the problem into smaller and simpler parts. They then make a group plan. Before students do any measurements, they must decide what physics equations should be used for each part and what variables should be measured. After students finish measurements and calculations, there are follow up questions to help students think more about the lab problem. For example, they are asked if kinetic energy is conserved during the collision, and why or why not. Finally, students design an independent experiment to evaluate their previous experimental result.

Magnetic Toy Cars: (Leith Allen and Alan Van Heuvelen) In this lab, students are asked to estimate the maximum voltage that will be induced across a solenoid as a cow magnet, taped to a Hot Wheels™ car, travels down an incline and then through the solenoid. The students must break this problem into parts, make simplifying assumptions, and decide what to measure. Students are also asked to qualitatively predict the shape of the graph of induced voltage versus time for this situation. Afterwards, a computer, using an MPLI interface and voltage probe attachment, acts as a digital oscilloscope to allow students to test their predictions. Further, students predict and observe the affect of varying different experimental parameters. For example, releasing the car backwards reverses the two peaks, and releasing the car from half the original height reduces the maximum voltage by a factor of $\sqrt{2}$. Students are also encouraged to perform experiments of their own design to test the affect of other variables. Finally, students can be given graphs of voltage versus time and asked to sketch physical situations that may have been used to generate the graphs. As always, afterwards they can test their predictions.

Concept Construction Labs: (Alan Van Heuvelen) Students perform a set of guided inquiry experimental activities that lead to the "invention" of one of the important concepts of physics. Many of these labs end with a series of puzzles in which students use the concepts to make predictions about the outcome of an experiment or simulation question. Students test a prediction by completing the experiment or by running a different version of the simulation. In three different evaluations by different investigators, the labs have produced statistically significant improvements in the Force Concept Inventory Test. This is part of a National Science Foundation curriculum development project involving the OSU Physics Education Research Group.

RESEARCH AND DEVELOPMENT PROJECTS WE ARE NOW DOING

Kandiah Manivannan (Southeastern Louisiana University)

We have been engaged in a number of projects directed at increasing active student participation in the classroom learning environment. These include (1) new instructional methods for large-enrollment classes; (2) development of new curricular materials for large-enrollment classes; (3) development of a new elementary physics course based on guided inquiry, targeted at education majors and other non-technical students. (These projects have all been carried out in collaboration with David Meltzer at Iowa State University.)

In large lecture classes, we maintain an extremely interactive setting in which we do not deliver a formal lecture. Instead we will present material for several minutes, usually ten minutes or less. At this point we will pause and present either a problem or a question for the students to work on and discuss with each other. Then we will either solicit individual responses on multiple-choice questions through the use of flash cards, or walk among them and look at the written responses of each group of neighboring students. (Each student is given a set of six large cards labeled A, B, C, D, E, and F, which can be held up facing the instructor to signal their answer to a question.)

(2) In order to support new instructional methods for large lecture classes, described above, we have been developing new curricular materials. These include *conceptual dissections*, which take fairly traditional physics problems and break them down into conceptual elements. Each of the conceptual elements may then be converted into a multiple-choice question with which flash cards may be used. Other multiple-choice questions include *linked conceptual sequences*, in which a series of closely related questions—usually qualitative—explore a particular concept in depth. The Workbook for Introductory Physics (by David E. Meltzer and Kandiah Manivannan) is our major curriculum development project, and it includes these types of questions. Also included in the Workbook are non-multiple choice exercises which are designed for students to work on during class, and which may be easily and quickly checked by the instructor while the students are at work.

(3) We have been engaged in ongoing development of an inquiry-based elementary physics course targeted at education majors and other non-technical students. In this course, issues related to student preconceptions (as determined by pre-testing) are investigated by students through guided mini-research projects. These projects are carried out by the students working cooperatively in small groups. Discussions centered around each group's results lead to a systematic summing up by the instructor to provide perspective. During course delivery, ongoing testing and other assessment guide the pacing and depth of the topical coverage. Among the issues we have investigated is the question of just how severely the breadth of topical coverage has to be reduced from conventional levels in order to ensure student mastery of the targeted concepts.