Chapter 8

Graduate Students and Post Doctoral Students Discuss Their Thesis Research

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Mel Sabella, *University of Maryland*
Jeff Saul, *University of Maryland*
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Aaron Titus, *North Carolina State University*
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Chair: Thomas Koch, *University of Nebraska-Lincoln*

Each presenter prepared a short document for the proceedings. Parts of the following pages are adapted from overhead transparencies used in the discussion.

Kastro Hamed, *Kansas State University*

This research endeavor is part of the Integration of Research and Education project at Kansas State University (I.R.E.). We are interested in probing into the students' understanding of the particulate nature of matter, the students' ability to relate macroscopic phenomena to microscopic molecular behavior. The probing procedure utilizes a focused interview protocol, and a written instrument is also being developed. The findings of this part of the research will be used as a guide in developing instructional materials. Of particular interest in this 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.

Research on the Teaching and Learning of Radiation and Radioactivity

Edward E. Prather and Prof. Randal R. Harrington, *University of Maine*

Researchers at the University of Maine are currently involved in a project to identify student conceptual and reasoning difficulties related to radiation and radioactivity and then to develop effective instructional strategies to address these difficulties. This work builds on previous work with middle school level children published by Robin Millar.[1] This project has involved participants from a wide range of backgrounds and grade levels including middle school science students, high school physics and chemistry students, introductory college level physics and chemistry students, pre-service and in-service teachers and undergraduate physics majors. The primary research methods used are descriptive in nature with the largest source of data coming from individual interviews, written questionnaires and classroom observations.

Based on the results from the initial individual demonstration interviews and open response concept tests we identified three common alternative concepts: (1) most students do not differentiate between the concepts of radiation and contamination (i.e. they believe that an object exposed to radiation results in the object becoming radioactive), (2) some students use shell or valence electrons to account for radioactive phenomena and (3) students' concepts of half-life often involve changing a material's bulk properties (mass and volume) by half. These findings were used as the foundation for creating our initial instructional goals and helped to guide 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 laboratory experiments. The results from both formative and summative assessments of these materials as they are used in the classroom form the basis for on-going revisions to both the specific activities and the overall instructional approach.

[1] R. Millar, "School students' understanding of key ideas about radioactivity and ionizing radiation," Pub. Understand. Sci. 3, 53-70 (1994)

Student Models in Learning Modern Topics of Physics

Lei Bao, Edward F. Redish, *University of Maryland*

- Student models in understanding conductivity
  - The microscopic models of current
  - The concept of shared carriers
  - Band structure for different materials
  - Relations between band structure and the electric properties of different materials (the model of resistivity)
- Student difficulties in understanding conductivity
  - Electrons are bounded to the individual atoms in conductor
  - Incorrect model of band structure for resistor
  - Incorrect microscopic models for current
- Student models in learning quantum mechanics
  - The classical prerequisites
    - Energy diagram
    - Probability
  - Fundamental QM concepts
    - Relations between the energy and the shape of quantum wavefunction

  - Student intuitive models in thinking quantum problems

- Student difficulties in learning quantum mechanics
  - Incorrect interpretations of energy diagrams – especially potential energy diagrams
  - Insufficient background knowledge in understanding probability even at a classical level
  - Incorrect interpretations of quantum wavefunction
  - Using classical intuitive models to think about quantum problems
  - Holding inconsistent models at the same time

Based on our research results, we developed several University of Washington style tutorials to help the students with their conceptual difficulties.
- Potential Energy Diagrams and Potential Well
- Classical Probability
- Energy Band in LED's

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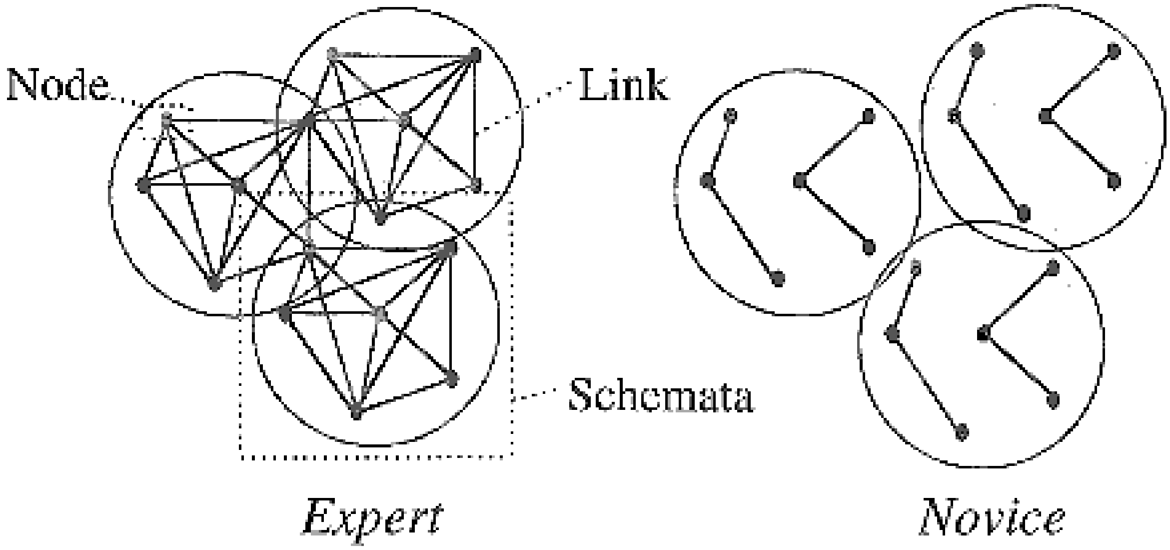
Linking Students' Fragmented Knowledge

Mel Sabella, *University of Maryland*

Students have difficulty making connections in many different physics contexts such as:
- Connecting qualitative understanding to quantitative problem solving.
- Connecting different physical concepts and principles.
- Connecting the local and global aspects of a challenging problem.
- Connecting the real world to the physics world.

Links in physics are extremely important at both the introductory level and the advanced level.

These graphs show the difference between novice and expert knowledge.



Jeff Saul, *University of Maryland*

A large number of innovative approaches have been developed based on Physics Education Research (PER) to address student difficulties introductory physics instruction. Yet, there are currently few widely accepted assessment methods for determining the effectiveness of these methods. My dissertation research compares the effectiveness of traditional calculus-based instruction with University of Washington's Tutorials, University of Minnesota's Group Problem Solving & Problem Solving Labs, and Dickinson College's Workshop Physics. Implementations of these curricula were studied at ten undergraduate institutions. The research methods used include the Force Concept Inventory (FCI), the Maryland Physics Expectation (MPEX) survey, specially designed exam problems, and interviews with student volunteers. The MPEX survey is a new diagnostic instrument developed specifically for this study.

Instructors often have learning goals for their students that go beyond having them demonstrate mastery of physics through typical end-of-chapter problems on exams and homeworks. Because these goals are often not stated explicitly nor adequately reinforced through grading and testing, we refer to this kind of learning goal as part of the course's "hidden curriculum." In this study, we evaluate two aspects of student learning from this hidden curriculum in the introductory physics sequence: conceptual understanding and expectations (cognitive beliefs that affect how students think about and learn physics).

We find two main results. First, the exam problems and the pre/post FCI results on students conceptual understanding showed that the three research-based curricula were more effective than traditional instruction for helping students learn velocity graphs, Newtonian concepts of force and motion, harmonic oscillator motion, and interference. Second, although the distribution of students' expectations vary for different student populations, the overall distributions differ considerably from what expert physics instructors would like them to have and differ even more by the end of the first year. Only students from two of the research-based sequences showed any improvement in their expectations.

Student Use of Multiple Models When Making Sense of Physics: An Example From Mechanical Waves*

Michael C. Wittmann, *University of Maryland*
Advisor: Edward F. “Joe” Redish

My dissertation as part of the Physics Education Research Group (PERG) at the University of Maryland grew out of the simple assignment to investigate and come to an understanding of student misconceptions with wave physics. In the process of studying how students make sense of wave physics, we saw that students were not being consistent in their functional descriptions of waves. We found that our investigations presented an opportunity to discuss the term "misconceptions" as it has been used in the PER community. As part of the investigation, many questions were raised about how students come to an understanding of the material we teach in our classes, how they make use of the knowledge that they bring to our classrooms, and how we can affect their understanding through the use of effective curriculum materials developed to address student needs.

We have found that many students, both before and after instruction, make use of what we call the Particle Pulses Mental Model (PM). By mental model, we mean a pattern of association or analogy that students use to guide their reasoning on a topic. The PM is based on an analogy to Newtonian particle mechanics. Students using the PM functionally describe a wavepulse (e.g. Gaussian lineshape) as a single point, describe changes to the wave speed in terms of the force exerted while creating the wave (like throwing a ball harder), and often describe the permanent effects of superposition as in terms of collisions between massive objects (such as gliders on air tracks).

My dissertation has focused on coming to an understanding of the guiding analogies that students use and how they come to use them while developing and evaluating curriculum materials to help students overcome difficulties with the material. We have developed a diagnostic test (based on a set of research questions each individually investigated) that allows us to observe student use of mental models before and after instruction. We find that students use primarily the naive PM to describe wave physics before any instruction, indicating that they are making analogies based on previous material they have learned (an encouraging result, though they apply the analogies incorrectly). We also find that they learn the correct understanding in our modified classroom, where we have developed video-based UW-style tutorials that are designed to address student difficulties with the material. We find that the PM still plays a large role in student understanding of waves after instruction, indicating that our curriculum materials are not as effective as we would like. We are using our results to organize how we see students come to an understanding of waves and how this can inform our teaching in other areas of physics.

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The Development of Students' Problem-Solving Skill from Instruction Emphasizing Qualitative Problem-Solving

Tom Foster, *University of Minnesota*

- Research questions:
  1. In what way do students' problem-solving skills develop in a physics course taught by an instructor who emphasizes the Minnesota Strategy?
  2. In what way do students' problem-solving skills develop in a physics course taught by an instructor who does not emphasize a problem-solving strategy?

- Research design:
    - Two cases composed of 25 matched students each.
    - Collect identical exam solutions from all students.
    - Code solutions based on problem-solving performance.
    - Collect triangulation data such as grades, and m/c tests.
- Story telling:
    - Examine student development data and classify by their story.
    - Do RQ(1) case first to limit bias, then do RQ(2) case.
- Limitations:
    - Size: 25 students is small, but matching adds strength to study.
    - Instructor effects: unavoidable in a timely study due to instructor expertise.

What is the Effect of Introducing Computers into Introductory Physics Problem-solving Laboratories?

Laura McCullough, *University of Minnesota*

At the University of Minnesota, we have recently introduced computers as a tool in our problem-solving laboratories. Part of this implementation process included an evaluation of these new labs. The evaluation was divided into three parts.

The first part was designed to determine the effect of the labs on student performance. Introducing new technology often leads to a decrease in student performance, since time spent learning the new technology means less time-on-task. Student grades and student performance on conceptual exams and problem-solving exams were examined.

The second part of the evaluation examined student and TA attitudes towards the new labs.

The evaluation’s third part was an investigation of what actually happened in the labs. Careful observations were made of student behavior in the labs.

The results of the evaluation will be used to revise the laboratory design and implementation, in order to increase the value and effectiveness of the new labs.

Our goal for the new laboratories is to incorporate the advantages of the computer while retaining the advantages of the problem-solving laboratories.

Understanding Group Harmony: Examining Small-Group Interactions in an Inquiry-based Introductory Physics Course

Master's Thesis Abstract

Meredith J. Wills, *Montana State University*

As inquiry-based physics courses become more popular, a new emphasis is being placed on small-group collaborative learning. In this study, we examined student behavior within a series of collaborative learning groups in an inquiry-based physics course for pre-service teachers. Out of nineteen students, we interviewed nine, whose experiences covered a total of fourteen groups. Our interviews focused on group dynamics and hierarchy, with an emphasis on group harmony and positive learning environment. We found that students' behavior changed from group to group. We also found that only five of the fourteen groups produced a decidedly positive learning experience while seven produced a negative learning experience. This suggests that the current format is not serving students as well as we would hope.

In examining student interviews, we classified five major categories of students based on their group behavior: previously knowledgeable, aggressive-confident, cooperative-confident, cooperative-uncertain, and passive-uncertain. The first category encompasses students with a relatively strong physics background, regardless of personality, while the last four categories focus on varying degrees of self-confidence and assertiveness.

We found that most group difficulties stemmed from the presence of a previously-knowledgeable student; previously-knowledgeable students did not appear to profit from the group experience nor did group members benefit from their presence. The remaining group difficulties arose from extreme group heterogeneity—aggressive-confident students conflicted with passive-uncertain students. Successful groups repeatedly demonstrated limited heterogeneity and an absence of previously-knowledgeable students.

Based on our results, we have formulated an interview schema for initial student categorization. The hope is that this might lead to the formation of a greater number of successful groups.

Using Conceptual Multimedia Instruction to Improve Non-Science Major College Students' Understanding of Celestial Motion

Rebecca Lindell Adrian, *University of Nebraska-Lincoln*

For my dissertation research I am conducting a multi-phase research study investigating non-science major college students' understanding of celestial motion and ways that this understanding can be improved. In the first phase, non-science college students' understanding of celestial motion was qualitatively investigated through open-ended structured interviews. Once students' difficulties are uncovered, the second phase of the research will focus on developing inquiry-based instruction designed to promote conceptual change. Also during the second phase of the research a celestial motion concept test will be developed. In the third phase of the research, the effectiveness of the instruction in promoting conceptual change will be investigated.

Web-based Assessment and Testing Systems

Scott Bonham, *North Carolina State University*

Foundations
- Strengths and Weaknesses
- Types of studies that could benefit

First year of WebAssign
- Factors that affect students' use of the system
- Learning how to use this research tool

Future
- Homework patterns of successful students
- Use of Java applets in the classroom

Integrating Video and Animation with Physics Problem Solving Exercises on the World Wide Web

Aaron Patrick Titus, *North Carolina State University*
(Under the direction of Robert J. Beichner)

Problem solving is of paramount importance in teaching and learning physics. An important step in solving a problem is visualization. To help students visualize a problem, we included video clips with homework questions delivered via the World Wide Web. Although including video with physics problems has a positive effect with some problems, we found that this may not be the best way to integrate multimedia with physics problems since improving visualization is probably not as helpful as changing students' approach.

To challenge how students solve problems and to help them develop a more expert-like approach, we developed a type of physics exercise called a *multimedia-focused problem* where students take data from an animation in order to solve a problem. Because numbers suggestive of a solution are not given in the text of the question, students have to consider the problem conceptually before analyzing it mathematically. As a result, we found that students had difficulty solving such problems compared to traditional textbook-like problems. Students' survey responses showed that students indeed had difficulty determining what was needed to solve a problem when it was not explicitly given to them in the text of the question. Analyzing think-aloud interviews where students verbalized their thoughts while solving problems, we found that multimedia-focused problems indeed required solid conceptual understanding in order for them to be solved correctly.

As a result, we believe that when integrated with instruction, multimedia-focused problems can be a valuable tool in helping students develop better conceptual understanding and more expert-like problem solving skills by challenging novice beliefs and problem solving approaches. Multimedia-focused problems may also be useful for diagnosing conceptual understanding and problem skills.

Physics Education Group at the University of Washington

All students in the Physics Education Group participate in most of the research, curriculum development, and instructional projects of the group. The graduate students teach in the tutorials associated with the introductory calculus-based course, in tutorials for upper-level physics courses, in special courses for preservice and inservice teachers, and in seminars and workshops for present and future faculty. All students contribute to the development of *Physics by Inquiry* and *Tutorials in Introductory Physics,* the instructional materials produced by the group. The abstracts below, which summarize the dissertation projects of the graduate students, represent only a part of the research that they to fulfill the requirements for the Ph.D. in physics.

Bradley S. Ambrose

Ph.D. February 1999

My research is part of an ongoing investigation of student learning of the wave-like properties of light and matter. The research was conducted in the context of a broad range of physics courses, including courses for introductory students, advanced undergraduate majors, and graduate students. The initial emphasis was to strengthen the current research base on student understanding of physical optics. The scope of the investigation was later expanded to probe the ability of students to interpret the interference and diffraction of matter in terms of a wave model. The findings led us to extend the research to include student understanding of the de Broglie wavelength and some basic concepts in quantum mechanics. The results have guided the design of supplementary instructional materials that have been shown to address specific difficulties identified in the research.

Christopher T. Border

I am working to extend the research of our group in the area of student understanding of physical optics and quantum mechanics. Current topics we are examining include student understanding of interference, diffraction and de Broglie wavelength. In addition we are beginning to investigate student understanding of polarization, wavefunctions in simple square wells, simple tunneling and scattering states, and quantum observables. Results will guide the design of instructional materials, the effectiveness of which will be assessed and modified in an ongoing cycle of research, curriculum development, and instruction.

Andrew Boudreaux

I am conducting research on student understanding of mechanics in the context of Galilean and special relativity. Topics include relative motion in one- and two-dimensions, reference frames, and conservation of momentum. A preliminary result is that student difficulties with advanced topics can often be traced to difficulties with related, more basic material. For example, some student difficulties with the application of momentum concepts to relativistic collisions have their roots in difficulties with conservation of momentum in the context of Galilean relativity. Results of the investigation are being used to guide the design of instructional materials for use with students in introductory physics courses, in sophomore and junior level courses, and in special courses for the preparation of teachers.

Christian H. Kautz

My research project is part of an ongoing investigation of student understanding of hydrostatics and thermal physics. The research is being conducted in the context of a broad range of physics courses, including algebra- and calculus-based introductory courses and sophomore-level courses. In my dissertation, which focuses on student understanding of gases, I identify conceptual difficulties interpreting and applying the ideal gas law. Other aspects of my research include identifying reasoning difficulties with multi-variable equations and examining the interplay of student reasoning about processes at the microscopic and macroscopic levels. The results are being used to guide the design of instructional materials on various topics in hydrostatics and thermal physics.

Stephen Kanim

Ph.D. April 1999

My research has concentrated on examining some of the difficulties that students have in solving traditional quantitative problems. The context has been selected topics in electrostatics and electric circuits. We have found that many errors result from specific conceptual and reasoning difficulties. In other cases, students understand the concepts but cannot apply them appropriately. We have developed tutorials and tutorial homework that address specific difficulties and that explicitly help students make a connection between the concepts and the mathematical formalism used in solving physics problems.

Michael E. Loverude

Ph.D. May 1999

My research has concentrated on student understanding of hydrostatics and thermal physics. In particular, I have investigated the ability of students to apply Newtonian mechanics to problems in these new contexts. Many student difficulties with hydrostatics and with thermal physics can be traced to underlying difficulties with concepts from mechanics, including forces, Newton’s second law, and work. We have developed instructional materials to help students apply the tools of mechanics correctly in these new contexts. These materials have been tested in large lecture classes, in small-group tutorials, and in special courses for teachers.

Luanna G. Ortiz

My research has concentrated on student understanding of rigid-body dynamics and static equilibrium. We have identified student difficulties in extending the fundamental principles of mechanics to rigid bodies. In particular, many students cannot correctly account for the translational and rotational motion of rigid bodies using the concepts of force, torque, and center of mass. On the basis of detailed knowledge of difficulties among college science and engineering majors, we are developing instructional materials for use in small-group tutorials in the introductory physics sequence. We are also developing laboratory-based instructional materials for use in courses that prepare precollege (K-12) teachers to teach physics and physical science.

Rachel Scherr

My research has concentrated on student understanding of special relativity. Many student difficulties with special relativity can be traced to a lack of understanding of important basic concepts in Galilean relativity and measurement, such as the inherently local nature of measurement, appropriate measurement processes for quantities such as length, and the relationship of measurements made in one frame to those made in another. We have developed instructional materials to help students understand these key concepts and apply them correctly in special relativistic contexts. These materials have been tested in large lecture classes, in small-group tutorials, and in special courses for teachers.