SUMMARY OF CURRENT RESEARCH ACTIVITIES: 2003

My research this past year has been associated with three ongoing NSF-funded projects:

- "CAREER: Research on Students' Mental Models, Learning and Transfer as a Guide to Application-Based Curriculum Development and Instruction in Physics" (P.I. Sanjay Rebello)
- "Technology & Model-Based Conceptual Assessment: Research on Students' Applications of Models in Physics & Mathematics" (P.I. Dean Zollman)
- "ASA: Assessing Student Transfer and Retention of Learning in Mathematics, Physics and Engineering Courses"(P.I. Andrew Bennett -- Mathematics)

My ongoing research efforts in these areas are described below.

"CAREER: Research on Students' Mental Models, Learning and Transfer as a Guide to Application-Based Curriculum Development and Instruction in Physics" (P.I. Sanjay Rebello)

The overarching goals of this project are to:

GOAL 1. investigate the mental models that students have developed through interactions with everyday devices and how they apply these mental models in various contexts.

GOAL 2. develop, based on the above research results, application-oriented curricula for introductory undergraduates.

GOAL 3. pilot-test these curricula in introductory physics courses and investigate the impact of these materials on students' mental models and how they transfer these models from one context to another.

This year we expanded our work toward GOAL 1 of the project and also began work pertaining to GOALS 2 and 3.

GOAL 1: Last year we began our work on exploring students' ideas of two real-world applications: the bicycle and electrical appliances. This year we concluded our work on students' understanding of the bicycle and expanded as well as completed our study of students' understanding of electrical appliances. There were no significant changes from the protocol from last year when they were initially done. Both the light bulb and bicycle interviews that we did this year followed the same protocol as last year. Our main objective was to increase the numbers from last year. The only true difference was that we combined the bicycle protocol into one activity and did the entire protocol in one sitting as the earlier interviews were rather short. We also did the light bulb interviews over the course of a week for both interviews. We also began explorations of student understanding in another area: musical instruments and sound. Here we describe some of our activities in each of these areas.

Light bulb: We focused specifically on the light bulb and electric circuits. Our student participants included three groups: non-science majors, most of whom have had no physics course in the past and are currently enrolled in a conceptual physics course, life-science majors, about half of whom have had high school physics and are currently enrolled in an algebra-based physics course and finally physical-science majors, almost all of whom have had a year of physics in high school and are currently enrolled in a calculus-based physics course. Previous researchers have asked students to make a bulb light up using a single wire and a battery. A vast majority of students are unable to successfully complete this task and researchers have concluded that students do not understand the concept of a complete circuit. Our research activities included interviews with a few students as

well as surveys in large-enrollment classes. Our research findings (described below) are somewhat different from those of previous researchers. We have presented our research findings in a conference talk as well as in a journal article that is currently in press.

Musical Instruments: Musical instruments are an interesting real-world context because almost all students have heard musical instruments. A few students have played musical instruments themselves. Also sound and musical instruments are often addressed in most introductory undergraduate physics courses. Our semi-structured research protocols (See Teaching Experiment below) explored students' understanding of sound waves as well as how sound was produced in string, wind and percussion instruments. Some of the musical instruments explored included the violin, cello, drums, organ pipes, etc. Our research findings in this area were presented at a conference talk. Protocols used for the teaching experiments are attached in the "Activities File."

Friction: We began some preliminary work in establishing a framework in which to explore students' ideas of friction. Friction is a real-world phenomenon that all students experience. It is also a topic that is covered quite extensively in almost all introductory physics course. The phenomenon also has significant applications in the field of nanotechnology. In this regard, we chose to explore students' microscopic models of friction. We conducted a literature search on scientists' microscopic models of friction. These models are not generally publicized in introductory physics texts although they appear to be straightforward analogs of macroscopic friction. The models also can help explain some of the anomalies that students sometimes encounter when they test their macroscopic models with real-world experiences. We have just begun work in this area and will spend a significant portion of our time in the next year exploring this interesting area of students' microscopic modeling of friction.

GOAL 2: Based on our research findings on students' understanding of the bicycle and the light bulb, we developed instructional materials that would enable students to build on their understanding of these devices.

Bicycle: Our findings from last year's research indicated that most students have a clear conception of how the bicycle works. They are able to describe how the force is transmitted from the bike pedals through the rear-wheels and gears. One principal finding last year was that most students intuitively use force to explain the working of the bicycle, rather than energy concepts. They do so even when the question asked specifically cues them toward energy. We believe that the bicycle can be a useful tool to enable students to understand the concept of energy conservation. Therefore, we designed a set of activities to help students learn about the energy concepts using the bike as a context.

Light bulb: Based on our research findings (described above we designed a set of activities to help students construct a model of the internal wiring of the light bulb. The activities were loosely structured around the Learning Cycle model of instruction proposed by Karplus and involved processes in which students actively confronted their existing models.

GOAL 3: We pilot-tested the activities that we had developed in the following areas.

Bicycle: Our bicycle activities were pilot-tested with non-science students enrolled in a conceptually-based physics class as well as life-science students enrolled in an algebra-based physics class. There were two formats in which we pilot-tested these activities. First, we pilot-tested the activity with a group of three students at a time, outside of class. This afforded us the opportunity to closely observe the students working on the activity and learn about what worked and what did not work. Then we pilot-tested the activity with an entire laboratory section in an algebra-based physics course. This activity afforded us the opportunity to learn about some of the same issues, but also helped us learn more about how this activity may work in a real instructional setting, and some of

the logistical issues involved. We have yet to complete a detailed analysis of the pilot-tests of the bicycle activities. Our initial impressions are described in the Research Findings section below.

Light bulb: Our light bulb activities were pilot-tested with several audiences. We pilot-tested the activities with high-school seniors in a physics class. We also pilot-tested the activities with students enrolled in a conceptually-based physics class and with students in an algebra-based physics class at Kansas State University.

OTHER ACTIVITIES

In addition to activities directly tied to the three goals listed above, the project also completed work in the following areas:

Teaching Interview Methodology: The teaching experiment methodology has been used by previous researchers in mathematics education. A few physics education researchers have used this methodology as well, but most researchers in this area have used the more traditional clinical interview methodology. Based on our experience, we found that the clinical interview methodology has some limitations for our research. Most students have seldom given any prior thought to how some of the devices that they encounter in their everyday life work. Therefore, when these students are asked about the working of these devices in a clinical interview, they often respond by stating that they do not know the answer and resort to bits of knowledge that they may have heard. The teaching experiment gives us the opportunity to learn how students construct knowledge when provided with certain resources such as hands-on experiences, information from the instructor, etc. Therefore, it provides a rich context in which to explore students' knowledge construction. The Teaching Interview (or Experiment) also forms a useful bridge between clinical research and curriculum development, i.e. it provides a bridge between GOAL 1 and GOAL 2 of our project.

Analytical Framework: As stated before, when students are asked questions in a clinical interview, particularly questions about real-world devices that they may not have given prior thought to, they often make up their responses on the spot. We worked synergistically with researchers in another NSF-funded REC project in the ROLE program (REC-0087788) to develop an analytical framework that helps characterize student responses in an interview.

"Technology & Model-Based Conceptual Assessment: Research in Students' Applications of Models in Physics & Mathematics" (P.I. Dean Zollman)

Developing an Analytical Framework

We have developed an analytical framework to characterize the processes of student reasoning during an interview and discuss implications of the framework. The interviews on which this framework is based were conducted by several researchers in our group, each with different research goals. The research participants are enrolled in various introductory physics courses at KSU.

From our interview transcripts we have constructed a framework involving four aspects: [1] External Inputs (e.g. questions asked, verbal, graphic and other cues) from the interviewer and interview environment; [2] Tools (e.g. memorized and familiar formulae, laws and definitions, prior experiences) that the student brings to the interview; [3] Workbench encompassing mental processes (e.g. induction, accommodation) that incorporate the aforementioned inputs and tools and [4] Answer given by the student.

We have used a coding scheme to map out reasoning paths through the four aspects of our framework. Our analysis finds remarkable commonality between students' reasoning paths in different contexts as well as interesting patterns depending upon the question type, topical area, etc. Based on these

observed patterns we discuss the implications of our framework to elucidate the dynamics of student reasoning and its potential to inform the construction of interview protocols

The Effect of Order on Student Performance

In the previous year we investigated the effect of question order on student performance on surveys. This year we extended that research to include the order of interview questions. The questions were picked from the Force Concept Inventory. We created pairs of questions which were related to each other in terms of their concepts, but had several distinguishing surface features. Students were first asked one question (without being shown the other). Then they were asked the other question. They were also asked whether they would like to go back and change the answer to the previous question, and whether their answer to the second question would be affected by the first question. Students were also asked to enumerate the similarities and differences between the two questions in each pair.

We found in several cases that question order did have an impact on how students answered the questions. In one of the pairs, when the questions were asked in a particular order all of the students got one of the questions correct. When they were asked in the opposite order only significantly fewer students got the same question correct. Although students changed their answers to questions based on the second question asked, they were often able to clearly articulate the similarities and differences between the two questions. The similarities that they pointed out were not as deep as the conceptual similarities perceived by the instructor. The differences tended to focus on surface features.

We are continuing to analyze the data from this study. The study will result in a Masters Thesis by Kara Gray who plans to complete her Masters in May 2004.

"ASA: Assessing Student Transfer and Retention of Learning in Mathematics, Physics and Engineering Courses."(P.I. Andrew Bennett -- Mathematics)

Our goal in this project is to design assessment tools that are capable of answering the following research questions:

- What specific materials have the students learned in core engineering science courses in mathematics and physics?
- What understanding do the students have of the material they have learned? Is it just disconnected facts and procedures, a broad conceptual picture informed by careful understanding of the details or something in between? If it is something in between, can we describe exactly what understanding they have gained?
- How much (and what type of) knowledge do the students retain after specific classes have ended.
- Can the students use the material they have learned in new situations in their professional courses? How consistently do they use the understanding developed in core engineering science courses when encountering these ideas in new contexts? More specifically...
    - Is it easier for students to transfer certain mathematical concepts (and skills) than others to a given physical context?
    - Is it easier for students to transfer their mathematical concepts (and skills) to certain physical concepts than others?

- Can we devise an instrument that can predict the extent to which Mathematics and Engineering Physics students will be able to transfer what they have learned to contexts that they may encounter in their core engineering courses?

This study is in collaboration with faculty members in the Mathematics Dept. and the College of Engineering. This past year we focused our efforts on understanding how students transfer their knowledge from Trigonometry to General Physics.

There are three levels of representations of trigonometry concepts that are typically utilized in introductory physics:

Level 1: Geometric representation in right triangles: Students relate the ratios of the lengths of the side to the trigonometric functions. This representation is typically used in vector analysis, e.g. in projectile motion, relative velocity problems, resolution of forces, etc. It is perhaps the most widely used representation in introductory physics.

Level 2: Unit circle representation: This is also a geometric representation, but one of the points of the right triangle moves along the surface of a circle whose radius is unity and the other point lies at the center of the circle. This representation is often used in relating simple harmonic motion to circular motion.

Level 3: Functional representation: This is a purely mathematical representation using sines and cosines. In introductory physics it is most used in describing wave motion.

We have identified a cohort group of about 50 students who took Trigonometry in the last three years at K-State and are currently enrolled in General Physics. We are utilizing three kinds of data in the study:

1. Online homework data from Dr. Bennett's Online Homework System used in Trigonometry and WebAssign used in General Physics. We will compare students' responses on paired Trigonometry and General Physics problems.
2. Trigonometry-Physics survey consisting of two types of questions
    a. Questions where the trigonometry concepts are embedded in the physics.
    b. Questions where the trigonometry concepts are *not* embedded in physics, i.e. purely mathematics questions

    We will vary the order of three questions of the two types. Each of the three levels of representations discussed above are also addressed in the survey. Therefore, the survey has six categories of questions in all. Two of each type above x Three of the levels described above.

    The survey was given out on the first day of class as a diagnostic. Additionally, relevant parts of the survey were administered after students had covered material pertaining to the three levels of trigonometry described above.
3. Clinical Think Aloud Interviews: These were conducted after students had completed three of the four exams that they took in the General Physics I class. The purpose of the interviews was whether students could be provided scaffolding that would enable them to transfer their knowledge learned in trigonometry to solve physics problems or vice versa. Again, the order of questions of the two types 2a and 2b was relevant in the interviews.

We are currently in the process of analyzing this data. This research will result in a Masters Dissertation by Darryl Ozimek.