SUMMARY OF CURRENT RESEARCH ACTIVITIES: 2002

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 in 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:

1. investigate the mental models that students have developed through interactions with everyday devices and how they apply these mental models in various contexts.
2. develop, based on the above research results, application-oriented curricula for introductory undergraduates.
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.

In connection with these goals we have focused on two real-world applications so far:

The Bicycle

The bicycle is an effective real-world context in which to explore students' mental models and how they relate to physics, because almost all students are familiar with a bicycle. Also, unlike some other more complicated real-world applications (e.g. automobile) the physical mechanism of the bicycle is in clear view of the students. It is therefore possible to ask students in the context of an interview to investigate various aspects of a bicycle.

Our research instruments at this point involve primarily semi-structured demonstration interviews. We interview students in a conceptual physics class before instruction and after instruction. The instruction, of course, was not focused on a bicycle but was rather covered conventional topics (force, work, energy etc.).

Our results indicate that even before any formal instruction students appear to have a coherent, well-conceived mental model of how the bicycle works. They are able to describe in some detail how the motion is transferred from the pedals to the rear wheel. They can also explain why the rear wheel turns many more times than the pedal, based on the relative sizes of the two sprockets. However, they do seem to have difficulty in explaining multi-speed bicycles. In all of their explanations, students appear to use physics terminology, but this is often terminology that is also used in everyday language (force, power, work etc.) Students, however do not use these terms in the same way as experts would. They rather use some of the terms quite interchangeably.

After instruction, we queried students with a view to investigate the extent to which they would apply the physics learned in class to the bicycle. We find that students do seem to refer to physics concepts, but they prefer to apply some physics concepts more than others in their explanations. For instance, students prefer to use force reasoning to explain why it is harder to go uphill vs. downhill rather than energy reasoning.

Students are able to transfer their knowledge of a bicycle to other applications and explain what features of these other applications relate functionally to that of the bicycle. For instance, when prompted they correctly associate the tread and wheels on a toy tank to a single bicycle wheel, rather than to the sprocket-chain assembly. They are also able to relate the bicycle to other real-world applications e.g. egg-beater etc.

Our next step in this project is to design curriculum that would utilize the bicycle as a pedagogical vehicle to teach physics concepts. Clearly, it appears that students seem to associate the bicycle more intuitively with some concepts than with others. We plan to capitalize on this association. We plan to pilot-test the curriculum with conceptual physics students and compare its effectiveness with that of other more traditional curricula that address the same topics.

The Flashlight, Battery and Simple Electric Circuits

Students encounter electricity and use electrical appliances everyday. Therefore some of these appliances may serve as an interesting context to investigate student reasoning patterns. We selected an array of electrical appliances that students may encounter. The ones that we focused most on were the battery and the flashlight.

We compared students reasoning about how these appliances worked with their reasoning about more contrived context that are typically used in a physics classroom such as a lemon battery or simple DC circuit with two batteries and a bulb.

We found that students' mental models seemed to be more complete and coherent when explaining contexts in which the physical connections between various elements were in clear view of the observer. For instance students did not seem to have a clear model about a D-cell. However, when shown a lemon battery they were able to explain its working more effectively.

We also investigated changing the order in which these examples were presented. We found, that when students are first presented with the example in which the electrical connections are in clear view, they are more likely to come up with a coherent mental model for the other application. Therefore the order in which these applications (real-world or contrived) are presented to the students is important.

Our initial conclusions lead us to believe that we must think carefully about the real-world context in which to introduce physics concepts. Familiar real-world contexts that may students may find interesting may not necessarily be pedagogically beneficial if the physical mechanism is not in clear view of the students. These examples could in fact be more confusing to students and could potentially pose a barrier to learning of the underlying concepts, because students are invariably more cued toward focusing on the details of the device rather than on the physical mechanism.

We will continue our work on electrical appliances into the next semester. Additionally we also plan to explore other real-world devices:

- Musical instruments: dealing with sound creation and propagation.
- Lenses, magnifying glasses, rear-view mirrors: dealing with light and geometrical optics.

- Thermos, heating pads etc. dealing with thermodynamics.

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

Students Mental Models and their Applications in Newton's II Law

We decided to investigate the extent to which students' transfer their understanding of Newton's II Law

- Case study interview of a group of students three times during the semester.
- Short multiple-choice survey questions to be give to the students a three times during the semester. The questions were created based on the responses in the interviews.

The goal of the interview was to find out the extent to which students applied Newton's II Law in contexts in electricity and magnetism

We found that students' responses are consistent with two principal mental models (Newtonian and Aristotelian) in Newton's II Law contexts spanning the topical areas of mechanics, electrostatics and magnetism. Some students might use conceptions from both models depending upon the context, i.e. they are in a mixed model state. Students' responses tended to be more Newtonian–like after instruction, but not all of them remain "Newtonian thinkers" through different contexts. In the second semester most students' responses are consistent with the Newtonian model even when the concepts of study are more abstract than on the first semester. Therefore, thinking while responding to physics questions is dependent both on the instruction as well as on the context of the question.

The Effect of Order on Student Performance

For years physics education researchers have used surveys and other investigative tools to learn what physics students know and how they think. These researchers often assume that the order of questions does not affect student responses. For as long as teachers have been giving tests, students have been looking for strategies and "tricks" to improve their performance on exams. These methods include "test taking strategies" often taught in high school and some college orientation classes. A common strategy includes looking for the answer or helpful hints in other problems when answering an unfamiliar question. Thus, students' performance may be influenced by their test taking skills or ability to "learn" the physics as they take the test. There is no reason to believe that students forget this skill when they are taking physics education research surveys as opposed to graded exams. This is a serious problem for researchers who are attempting to understand how students think about a series of problems or situations.

The purpose of our research is to test the aforementioned assumption that the order of questions in a test does not affect student responses to individual questions on the test. The results of our study suggest that the order of questions does have an effect on students' responses to multiple-choice questions, including the frequency of correct responses and responses based on common misconceptions. Our research is intended to draw attention to a basic assumption of most research and to initiate a discussion on the validity of this assumption.

Our research shows that the order of questions and the inclusion of an unrelated question can have a statistically significant effect on student responses. We used two Newton's III Law questions in our survey, one in which the objects were accelerating and another in which they were moving at a constant speed. The results of our study are statistically significant, albeit marginally. Therefore, in our ongoing efforts we will retest our results with another group of students enrolled in a different semester. Based on our present results however, we can state that the assumption that the order of questions is irrelevant should no longer be accepted as simple fact. Instead there is reason to believe that the effect of question order on student response merits further careful investigation and should be considered in the design of survey instruments.

"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 material 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 Mathematics Dept. and the College of Engineering. This past semester we focused our efforts on investigating student transfer and retention from Engineering Physics I and II and two sets of courses in the College of Engineering. Our efforts can be broadly categorized as follows

- Retention from *Engineering Physics I* to *Statics* (Civil Engg.) and *Statics & Dynamics* (Mech. Engg). We lumped these two courses together because in terms of concepts these two courses cover the same area -- mechanics that is covered in *Engineering Physics I.*
- Transfer and retention from *Engineering Physics II* to *Electromagnetic Theory* (Electrical Engg.).

Our research instruments included open-ended questionnaires to faculty members in engineering as well as multiple-choice surveys followed by more in-depth, semi-structured interviews.

We began by surveying engineering faculty members about the topics and concepts that they feel students should be familiar with after they have taken a physics course and just as they enter the engineering courses mentioned above.

Responses from engineering faculty were predictable: they mentioned several of the topics that are in fact covered in the *Engineering Physics* sequence of courses. Therefore, in an ideal situation, one would like these students to be rather well prepared as they enter their engineering courses.

Based on these responses, we constructed surveys that addressed these topics. We drew from research-based instruments that are already being used elsewhere, but found that no one instrument would address the topics listed by the engineering faculty members. Therefore, we had to combine questions from different existing instruments. We constructed one survey covering the mechanics topics and another for the E&M topics.

These surveys were administered in the respective engineering courses in the first week of class. We also administered these surveys to *Engineering Physics* students in the last week of class. Therefore, comparison of performance on these two sets of surveys would give some indication of the level of retention of the concepts learned in *Engineering Physics*. Responses on these surveys indicated that students had difficulties very similar to those that hey have in physics courses. We are currently in the process of doing a more detailed analysis of these surveys.

We also interviewed a cohort group of students enrolled in *Electromagnetic Theory*. Each of these students was interviewed once after each major exam in the course. The interview questions focused on asking students which question they found easiest and hardest on the exams and which questions were most related or least related to material learned in a previous course (most often *Engineering Physics II*).

We also interviewed physics faculty members who had taught or were currently teaching *Engineering Physics* and asked them what questions on those quizzes and exams they felt were most related to material covered in *Engineering Physics*.

We found, in general, that faculty often tend to see more commonalities between the questions on the *Electromagnetic Theory* exams and material covered in *Engineering Physics* than the students do. Students cite several aspects that are different between their previous physics course and the current engineering course. Especially, they point to different notation used in the two subjects as well as the type of examples. As expected, the examples in the engineering courses are more tied to the real-world than in a physics course where they are more contrived, although the underlying concepts in both cases are the same.

What is also interesting is that while faculty members may not view these differences as posing difficult learning barriers to students, the students in fact do see these differences as being important and potential barriers to their learning.

At least one of the students pointed to the different culture in the two courses as being a major difference that influenced his performance. While engineering courses (which he was currently taking) emphasized group learning and collaboration, physics courses appeared to expect more individualized work. He also mentioned that most students taking *Engineering Physics* were sophomores or freshmen/women. At that time in their academic career they may not have been as well socialized about college life and would not be as prepared to collaborate with others. Therefore, this socialization, or the lack of it, seemed to pose a significant barrier to learning the material.

We are continuing to analyze the data described above and also extend our study to include other engineering courses that would apply physics concepts. Additionally we are also interested in investigating the extent to which students in a trigonometry class are able to transfer that knowledge to their introductory physics class, and later to engineering courses.