

**Annual Report of Faculty Activities
(January 2004 – December 2004)**

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APPENDIX D: SUMMARY OF RESEARCH ACTIVITIES

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

- “CAREER/PECASE: 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/PECASE: 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 focused on GOAL 1 and expanded our activities toward this goal into two different areas.

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. Thus, friction qualified as an interesting real world phenomenon about which to explore student understanding.

Although friction is a commonly encountered everyday phenomenon, not many students have previously thought about friction at a microscopic level. In fact, most of the time friction is covered in mechanics course and explained as a macroscopic phenomenon. Therefore, simply asking students to explain their ideas (or mental model) of friction at a microscopic level would not yield useful results. We devised a two-phase protocol to achieve our goal of understanding students' mental models, and also finding out what we would need to do to change models toward the more scientifically accepted models.

In Phase I we conducted clinical interviews to explore students' ideas about friction, particularly their ideas about friction at a microscopic level. We focused on three groups of undergraduates: Non-science students, most of whom have had no high school physics; Life-science students, about half of whom have had high school physics; Engineering-Physics students, almost all of whom have had physics in high school. Our findings are described in the “Findings” section of this report. Clinical interview protocols are included in the attached “Activities” file.

In Phase II we conducted what we call ‘teaching interviews’. Teaching interviews are different from clinical interviews in that the goal here is to find out the kinds of inputs –hints and cues that would

be necessary to change students' ideas, rather than simply explore the ideas that students bring with them (or construct on the spot). We employ techniques that are commonly used in constructivist methods of teaching such as creating cognitive dissonance through discrepant events and Socratic dialog with students. The researcher i.e. the interviewer also takes on the role of a teacher in that s/he aims to change students' ideas in a deliberate way, and determine whether students can apply these ideas in different contexts. Also, teaching interviews are also conducted with groups of students to gauge the impact of student-student interaction in the model building process. We found the 'teaching interview' methodology rather useful in our work. We summarize our results with using teaching interview in the "Findings" section of this report. Teaching interview protocols are included in the attached "Activities" file.

In addition to exploring students' ideas about friction, we conducted a literature search on scientists' microscopic models of friction. We also talked with faculty experts in the area. These models are not generally publicized in introductory physics texts, and are not necessarily universally accepted. We are continuing to talk with experts with a goal toward determining an appropriate 'target' model that we would aim for students to have after they have completed their teaching interview. A protocol for interaction with experts is included with the "Activities" file.

After completing the teaching interviews this coming year we will develop teaching materials (GOAL 2) and pilot-test these materials (GOAL 3).

Physics in Movies: In addition to their experiences with everyday devices and phenomena (e.g. friction), most students also experience physical phenomena through popular media, especially movies. Action movie sequences often contain motion based on questionable physics. To reach the goal of creating a scientifically literate and informed citizenry of tomorrow, students must be able to apply their physics knowledge to discern whether what they see in movies is physically possible or an artifact of the production.

In this study we investigated whether students would transfer their classroom knowledge as well as everyday experiences to explain the physical motion seen in an action movie clip and then determine whether or not this motion would be physically possible or impossible. We also intended to compare students' ideas about these movie clips with those of experts – physics graduate students, researchers and faculty.

To achieve our above goal, we conducted individual clinical interviews with two groups of students: Non-science students with no prior background in physics and engineering physics students almost all of whom had and physics in high school. We had two rounds of interviews. The first round of exploratory interviews used eight short action movie clips. We asked students to what they found interesting from a physics point of view, what the underlying physical were, and whether or not the motion shown was physically possible or an artifact of movie making. Students were also asked what concepts covered in class they could associate with each of the clips and describe how they might relate the clip to any personal experiences in their life. Next we also interviewed a group of experts to determine their views about the clips.

Based on the first round of pilot-interviews with students and experts we were able to narrow down the initial list of eight action movie clips to four action movie clips. The criterion used was what movie clips found the interview participants – both students and experts found most interesting in terms of the underlying physics. Also based on our experiences with the first round of interviews we decided

that in addition to showing the participants the clips, it might be worthwhile to provide them with props such as toys and hands-on demonstrations that they could use while they talk about the action movie sequences. In the second round, we again interviewed both the experts and the students. As expected, the experts seldom relied on the hands-on props while talking about the action sequence; however the students did find the props useful when they talked about the clips. We will summarize the results from our interview in the “Findings” section of this report. The interview protocols used are in the attached “Activities” file.

General Comments: The following aspects of our activities are common to both of the studies described above.

Theoretical Framework: We have spent considerable efforts over the past year toward honing a theoretical framework to characterize dynamic transfer of learning. We have found this framework particularly useful in analyzing our data in both the ‘friction’ and ‘movie physics’ studies described above. Our framework is consistent with the current paradigms on the transfer of learning and models of thinking used in cognitive science research. This year we completed the publication of a book chapter that describes the framework and its applications. The manuscript is in the “Findings” section of the project report.

Research Methodology: We have found that research on student understanding of some everyday devices poses some unique challenges. Unlike deeply rooted misconceptions that students may have acquired over time through instruction or experiences, students often have not given prior thought to the internal working or the physical principles underlying everyday devices, many of which are impenetrable black boxes or microscopic phenomena that are invisible to the eye. Therefore, when students are asked to describe their understanding in a clinical interview we find that students often make up answers to their questions on the spot. We have found the ‘teaching interview’ to yield more useful data about the process by which students construct their answers or build their mental model. By putting these two together along with action research on completed curricular materials used in a classroom setting, we have constructed a three stage methodology that involves both grounded theory and phenomenographic approaches. The methodology is described in the “Findings” section of this project report.

Data Collection: All interviews (clinical and teaching) were videotaped and audio taped. In some cases, two video cameras were used. While one camera focused on what the student was writing, the other focused on the hands-on activities. In the “Physics in Movies” project, one camera was often focused on the movie clip that was shown to the students on a laptop screen, while the other was focused on the hands-on activities and gestures that the student was engaged in during the interview.

In accordance with University Institutional Review Board we obtained written permission from each of the participants for use of their data in our research. All participants signed a consent form based on a template provided by the University IRB. Participants were either compensated for their participation at the rate of \$10 per hour for the interviews. Some of the participants were offered extra credit in the physics courses that they were enrolled in that semester. No specific attempts were made to ascertain whether the participants were a statistically representative sample of the overall student population at KSU.

Data Analysis: The video tapes were analyzed using software called DIVER (Digital Interactive Video Exploration & Reflection) which is currently under development at Stanford (<http://scil.stanford.edu/research/projects/diver.html>). The software allows us to blend several (in our case two) video streams of data so that you can play them back in sync and focus on any one of them.

The software also allows us to stop a particular frame and comment on it or record a segment of the video with both streams and comment on it, so that it can be played back on demand. We found this software particularly useful in the ‘Physics in Movies’ study because one video camera was focused on the movie clip that the student was watching and the other was focused on the student’s gestures and hands-on activities. Both data streams were needed to gain insights into how students made sense of the physics underlying the action movie clips that they saw.

“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.

This study resulted in a MS in Physics by Kara Gray who successfully defended her MS thesis in May 2004. The Graduate School has selected Kara Gray’s MS Thesis to represent KSU for the 2005 Distinguished Thesis Award sponsored by the Midwestern Council of Graduate Schools.

“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.

This study resulted in a MS in Physics by Darryl J. Ozimek who successfully defended his MS thesis in July 2004.