Technology & Model-Based Conceptual Assessment:
Research in Students' Applications of Models in Physics & Mathematics

NSF Grant Number 0087788

Responses to Annual Survey of
NSF Division of Research, Evaluation and Communication

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1. If you would like to update your award abstract, copy from the previous text into the box, then make any update or changes. This will not change your original NSF award abstract however.

No changes

2. What is/are your primary research question(s)?

General research questions

a. Can we measure and trace students' states of understanding and changes in those states during instruction for time periods ranging from a single class session to several weeks of instruction,

b. What role does real-time feedback play in the state of student conceptual understanding during an individual class period and/or between two consecutive class sessions?

c. Which tools, technological or procedural, will promote research in ongoing classes (sometimes called action research) among instructors with interests in learning more about their students' states of understanding and in using that knowledge to improve their teaching?

d. Can these tools be created so that they can be used effectively in classes ranging from small seminars to large lectures?

e. How do students transfer knowledge between physics and mathematics?

f. How do students and instructors interact with a new teaching environment that enables rapid feedback on the level of student understanding and transfer?

g. Can we better understand how students construct knowledge through doing homework?

h. Can we better understand how to use online homework to enhance student learning?

Components of this last question are

(i) How does speed at which students complete homework correlate to eventual success in the class?

(ii) What features of an assignment (number of problems, positive/negative feedback, amount of feedback) lead students to continue struggling with difficult concepts until they succeed and what features contribute to students giving up without success?

(iii) What is the relative importance of student effort vs. initial abilities in determining student success?

(iv) What signifiers identify students who will succeed with more practice and what signifiers identify students who need intervention to succeed?

3 a) What is/are your research method(s)?

A primary component of our research is to understand the students' state of understanding. The method of studying the students' states is Model Analysis. This Analysis begins with our knowledge of student learning that is obtained from research and experience. We know that for any different physical concept students are likely to apply several different models. These models may be consistent with the accepted physical model and they may not.

We then select a scenario for which the models can be applied. Each physical model or mathematical concept will have several components to be probed. For example, what is the relation between motion and mass, force, acceleration or shape of object? With these components we design a model-based multiple-choice test, which is validated by research and can be easily implemented in large classes. The key elements in the creation process of this method include the following:

1. Based on previous research and additional student interviews (if necessary), common student models are identified and validated.
2. Multiple-choice questions that are designed to measure how student models are developed. The effectiveness of the questions is validated through research.
3. The full responses (including the wrong answers) and the context in which they were given are analyzed. The results provide explicit information on the students' state of understanding.

Model Analysis is based on both qualitative and quantitative methods. The qualitative research identifies the students' models that reflect the majority of different types of student understandings. Quantitative methods are used to analyze the multiple-choice instruments. Thus, we use interviews to identify the students' actual reasoning that is common to a large population and research-based multiple-choice instruments to measure the students' use of this popular reasoning in learning.

We are also using data mining techniques on a database of student responses to an online homework system used regularly in a large lecture course in trigonometry by about 180 students. As we gain confidence in our system, we anticipate extending this system to additional classes.

b) Why did you select them and how do they relate to your research questions?

In problem-solving situations, students are found to use their models in a variety of ways, some of which can be inconsistent. Previous research on college-level physics and mathematics learning has not looked carefully at these inconsistencies or the underlying reason for them. In our preliminary work we saw many examples of students with a mixed state understanding, when one student applies different models to problems that would seem to require identical models to explain. We wished to investigate this situation and Model Analysis coupled with the technology of on-line homework, large class-response systems and data mining provides an appropriate mechanism.

c) Did you consciously choose to not use certain research methods?

No

d) Why?
Not applicable

4. What changes have you made in the original research proposal, if any, and why have you made these changes?

We are planning to expand to include collaborations with a research group in Germany because of a large overlap in their work and ours and the opportunity to look at similar issues in two cultures.

5. What are the principal discoveries or findings from your research project? (Please feel free to identify, where appropriate, expected findings.)

Because we began the project in January, 2001, we have no significant findings to report at this time. We expect within the next few months to have established a research protocol for investigating the context dependence of students' performance on physics problems. Shortly after that we should have some preliminary findings on that topic. Likewise, we are preparing to look at the transfer of knowledge from trigonometry to an algebra-based physics course. Based on preliminary indications we expect to find that students find the transfer relatively easy when they consider trigonometric functions as related to triangles. However, one may need to consider the trig functions as mathematical functions the transfer is somewhat more difficult. We also have some preliminary results on student mental models concerning Newton's Third Law. Here, the model seems to be different depending on whether the objects involved in a collision are animate or inanimate. The context of the question thus seems to bring out a different model in the students.

We are continuing to study this context dependence of learning, especially the effects of different contextual settings on student understanding of physics. We have identified many cases in several major areas of physics where context seems to be important in students' responses. This investigation is continuing to identify more examples and to cover more specific topics. These results will allow us to develop a comprehensive understanding on how different context settings of specific physics knowledge used in teaching can affect student learning and how to improve instruction by explicit emphasis of the context settings that can cause problems.

For the mathematics study we have insufficient data to have confidence in our findings at this point. Our analysis of our initial data suggests that students who have little success within their first three attempts on an assignment need outside intervention to succeed. Students with substantial success within three attempts usually only need more practice to succeed. Fifteen to twenty questions is the optimal length for an online homework assignment (that may be attempted several times). "A" students are more likely to continue to work when they have a poor or average initial score, while F students are likely to quit if they receive either a poor or above average initial score but to continue to work when they receive a slightly below average score.

6. Has your research project resulted in methodological advances? If so, please characterize.

While we are anticipating some methodological advances in both assessing and representing student mental models, we have not yet achieved those advances. The primary advance will be in the implementation of Model Analysis as the quantitative analysis method. This method will go beyond existing score-based assessment tools in characterizing student understand and difficulties.

This is the first project we are aware of to apply data mining techniques to online homework system responses. We are developing an understanding of what are the important items to measure and are working to develop means of analyzing student responses to understand the underlying student models (but this is still in development and is not yet an *advance*).

7. a) What would you identify as the most important recent discoveries or findings in the field of your research project, that is, excluding your project?

In the field directly related to our research recent work on students' mental models of abstract ideas in physics and chemistry are somewhat valuable. The work of Treagust and his co-workers on students' views of atoms and orbitals will be valuable to us. Some of the recent conceptual inventories, particularly those on topics related to light and electricity and magnetism will form a basis on which we can build. The preliminary work on a possible gender bias in inventories such as the force concept inventory could prove to be quite useful if these initial findings hold up under further experimentation.

b) Which researcher(s) do you draw upon most heavily. With whom do you most collaborate?

We rely significantly on the work of Andrew DiSessa, his work on p-prims and his paper, "What Changes During Conceptual Change," provide useful background for us. Likewise, the work of Minstrell on Facets of Learning is research which we use frequently. In addition, a number of recent papers on the context dependence of student performance may prove valuable.

We are collaborating with Manfred Euler at the Institut für die Pädagogik der Naturwissenschaften in Kiel, Germany.

8. a) Please suggest a summary of the contribution of your research to NSF's possible report to Congress on this goal.

Teachers frequently notice what seems to be an inconsistency in their students' performance. Sometimes the students will be able to apply a scientific principle to a new problem or situation quite easily. Other times, even though the teacher thinks the problem is almost identical, the students have significant difficulty applying the principles. This lack of consistency is in reality part of the process of change as students learn new material. It is a result of students holding more than one view of how the natural world works. These views may be conflicting and thus the students seem to be inconsistent in their knowledge. Our research is investigating situations in which students do hold more than one view for particular scientific principles. We are developing problems and questions which will help us and other teachers understand better the situations in which students correctly and incorrectly apply scientific principles. We expect to find that the context in which the problem is stated has an important effect. By learning which contexts are the best starting points, we will be able to develop some instructional strategies which gradually move the students from the situations in which they are most able to apply the correct picture of nature to those which give them more trouble. By organizing the problems and questions in this manner we anticipate that we will make the learning situation for the students somewhat easier.

The use of the World Wide Web to access information online is reshaping many different activities. This project is studying the affects of such a transformation on educational practices and has the potential to use instant feedback, unlimited practice, and time flexibility to improve student learning.

b) Would you be comfortable positioning your project on a "research-to-practice" continuum?

Yes, the purpose of this project is to implement advanced research methods and results in practical applications in teaching.

c) If so, where would you position it? (Please feel free to comment on a concept of such a continuum.)

Our project seems to lie somewhere in the middle of the research to practice continuum. We are developing some basic research tools which we expect to be able to be applied, with minor modification, by practicing teachers.

9. What would facilitate the transfer of your research to practice ?

Part of the transfer from research to practice is built into our project. Near the end of the project we intend to have a few workshops to introduce teachers to the techniques that we have used and their value for classroom teaching. Because the way in which we are looking at the data collected by conceptual inventories is quite different from current practice among physics teachers, additional workshops on how to use it in the classroom and handbooks could best move it to practice. Web sites on how to use the materials in classrooms could also be useful if they are constructed carefully. Publication, once we have sufficient data to be confident of our results, followed by commercial systems adopting whatever data collection and analysis strategies prove most effective for reporting feedback both to students and instructors.

10. Describe any influence (accomplished or anticipated) on improved achievement in mathematics and science abilities due to your research project.

At this time all of the improvements in science and mathematics learning are anticipated because we are near the beginning of our project. We expect to be able to suggest to teachers scenarios or sequences of events which can lead students from problems in which the context helps the students understand the physical principles and how to apply it to ones which traditionally give them more difficulty. By isolating the components of the context that provide the greatest difficulty, we will be able to suggest to teachers that they delay introduction of those components until the students have demonstrated an understanding of the ones that give them less trouble. Then by gradually adding the components which have traditionally caused the most difficulty, the teacher will be able to help develop the conceptual understanding in a gradual way.

A similar approach is being undertaken in the study of the transfer of knowledge from mathematics to physics. By learning more about the specific difficulties that students have when they apply (or are unable to apply) their knowledge of trigonometry in a physics course, we will isolate the components that give the students the greatest difficulty. Again, by suggesting strategies and sequences of instruction we should be able to help teachers facilitate the transfer of previously leaned information to the physics course.

Within 10 years, it seems extremely likely that online homework systems will be the standard technique for handling homework in mathematics. A clear understanding of how to use such systems effectively would greatly enhance all students' abilities to learn mathematics.

11. a) How has your research been connected with on-going efforts of NSF to reform mathematics and science education in the United States?

Our project is part of an ongoing effort by the physics education research community to understand better the difficulties that students have in learning and applying the concepts of physics. Early work in this area collected a large amount of data on the concepts which give students difficulties and some instructional strategies on how to alleviate some of those difficulties. Thus we have learned much about the lack of conceptual change in students taking traditional physics instruction and some specific strategies for enhancing that change. Our research will take this effort somewhat further by looking at some of the details of students' mental models during the conceptual change process. By doing so we will be able to learn about specific components of different physical principles that represent the primary barrier to conceptual change. At the same time, we will build a representation of the change process so that teachers will be able to follow the progress of their classes.

b) With which projects have you most exchanged ideas and information?

Our primary exchange has been with a similar project at Institut für die Pädagogik der Naturwissenschaften in Kiel, Germany.

12. Please provide a list of publications, conference proceedings, book chapters, technical reports, etc., that may be attributed wholly or in significant part to this project.

Papers have been submitted (see below) but none have been accepted for publication yet.

13. Presentations at Conferences

Bao, L. (2001). "Context-Explicit Modeling of Conceptual Learning Process: Theory, Assessment, and Instruction," AAPT Winter Meeting, San Diego, CA (2001).

Dean Zollman & Kirsten Hogg "Attitudes of Future Teachers to Teaching and Learning", AAPT Winter Meeting, San Diego, CA (2001).

N. Sanjay Rebello & Dean Zollman "The Effect of Distracters on Student Performance on the Force Concept Inventory," AAPT Winter Meeting, San Diego, CA (2001).

Online Homework, A Preliminary Report, Andrew G. Bennett and Fedor Andreev, Mathematics Technology Expo, Kansas City, MO, October 2000 (This talk took place before project funding began, but was based on the research we did to write the initial proposal to receive funding).

Mathematics Teaching and the World Wide Web, Andrew G. Bennett (plus others from outside this project), Joint Meeting of the AMS/MAA, New Orleans, LA, January 2001

14. Identify any honors, awards or other recognition associated with your project activities.

The principal investigator, Dean Zollman, has recently been named a University Distinguished Professor by Kansas State University. This recognition is a direct result of his research on the learning and teaching of physics.

Co-PI Andrew Bennett is a 2001 recipient of the KSU Commerce Bank Outstanding Undergraduate Teaching Award. While this award is recognition for teaching, it is related to the project because the research that he does on this project informs his teaching.

15. Is your project structured to train or apprentice new investigators? Please provide details.

This project involves both graduate students and postdoctoral research associates. At Kansas State University the project will support one postdoctoral research associate in physics education and another in mathematics education. Fedor Andreev, who did much of the preliminary work in mathematics education for this project, is currently supported and has made one presentation and is preparing a paper for publication. Dr. Andreev has accepted a tenure-track position in Illinois, though he intends to continue to collaborate online. Kirsten Hogg, who worked on early stages of the project as a post-doc in physics education, is returning to teaching in Australia. We have hired a physics education post-doc who will begin in July and are currently hiring a mathematics replacement post-doc. In both cases the people selected for these positions were educated in a traditional research area and have made commitments to changing to physics or mathematics education research. Kansas State University has two graduate students working on the project. One is completed MS thesis research while the other is completing a PhD dissertation in physics education research. At Ohio State University two graduate students are working on PhD dissertations related to this project.

16. Project Methodology (from check boxes)
Action Research, Quasi-experiment, Design Experiment

17. Grade Level Addressed by the Project:
Main Emphasis: Undergraduate, Secondary Emphasis: K-12

18. Measures and Instrumentation for Subjects
Short Answer Tests, Performance Assessment, Demonstration (Live or Presentation), Multiple-choice Tests

19. Data Collection Procedures
Testing, Non Participant Observation, Group Interviews, Sample Survey or

Questionnaire, Clinical Interviews, Other (Describe): On-line and response system assessment

20. Working papers not yet presented/published:

Lei Bao "Understanding probabilistic interpretations of physical systems: a pre-requisite to learning quantum mechanics," submitted to Am. J. Phys.

N. Sanjay Rebello & Dean Zollman: "The Effect Of Distracters On Student Performance On The Force Concept Inventory" Submitted the *American Journal of Physics,* (2001)

Lei Bao, Dean Zollman & Kirsten Hogg "Model Analysis of Fine Structures of Student Models: An Example with Newton's Third Law" Submitted the *American Journal of Physics,* (2001)

Student Reactions to an Online Homework System, by Andrew G. Bennett and Fedor Andreev (in preparation)

21. **Keywords**

Physics

Mathematics

Context dependence

Conceptual Understanding

Student Difficulties

Mental models

Large class response systems

On-line homework

22. **Related Funding Awards, Granted After NSF Issued This Grant Or As A Result Of NSF Issuing This Grant**
None

(Check all of the following characteristics that relate to your project)

23. ☑ Applies ideas, approaches, media, materials, or technology in new ways.

24. ☑ Applied or problem-based research.

25. ☐ Basic or case theory-based research.

26. ☑ Descriptive research, to examine and explain a phenomenon.

27. ☑ Multidisciplinary project focus.

28. ☑ Multidisciplinary project team.

29. ☐ Teacher professional development.

30. ☐ Curriculum development.

31. ☑ Instructional practices, in a specific instructional domain.

32. ☐ Changes in society's perspectives or understanding of the value of math and science.
33. ☑ Student achievement.
34. ☑ Teaching strategies, broadly defined.
35. ☑ International focus
36. ☐ Scientific visualization.
37. ☑ Modeling and simulation.
38. ☑ Constructivism.
39. ☐ Educational reform
40. ☑ Multiple research organization participation.

(Check all of the following characteristics that relate to your project)

41. ☐ Conference and meetings.
42. ☑ Surveys.
43. ☐ Women's education.
44. ☐ Minority education.
45. ☐ Special education.
46. ☑ Science or science education.
47. ☑ Mathematics or mathematics education.
48. ☑ Computer software use, including networking.
49. ☑ Software development.
50. ☑ Computer hardware use, including networking.
51. ☐ Hardware development, including peripherals and interfaces for special equipment.
52. ☐ Technology use, other than computers.
53. ☐ Technology development, other than computers.
54. ☑ Media use, including printer, audio, video, and multimedia.
55. ☑ Media development, including printer, audio, video, and multimedia.
56. ☑ Assessment of project and its effects on SMET teaching or learning.

57. **General comments, including recommendations for EHR research directions**:
    None