Chapter 1: Introduction and Background

Chapter 1: Introduction and Overview

What do we mean by coherent physics knowledge?

Many physics education researchers have stated that students possess a fragmented knowledge of physics consisting of isolated facts and formulas.[1] In this dissertation we use the context of problem solving to show that calculus-based physics students as well as advanced physics majors exhibit a local coherence but not a global coherence in their physics knowledge. When a student is presented a problem-solving task the student often activates a coherent set of knowledge called a *schema* to solve the problem. This schema consists of strongly related knowledge and procedures that are used to accomplish the goal of the problem.

The schemas students develop in the physics course for solving problems are usually sufficient for success in the class. Unfortunately these schemas are often insufficient to solve complex problems. *Complex problems* require that students have a deep conceptual understanding; *deep conceptual understanding* means that students have integrated their qualitative knowledge with their quantitative knowledge and have integrated related physics topics. We will show that the knowledge our students possess is often incorrect and is often inconsistent with their other knowledge. In addition, activated schemas consist of a small amount of knowledge and these schemas are often isolated from other schemas.

As an example, in this dissertation we analyze student responses to a problem involving the topics of dynamics and work-energy. Many students employed a schema consisting only of knowledge from dynamics, which was insufficient to solve the problem. Because students' schemas are isolated from one another it was difficult for them to activate the relevant schema. For these students, the concepts of dynamics and work-energy were only weakly linked.

This problem also illustrates that the responses students gave to the qualitative questions sometimes contradicted their answers to the quantitative questions. This suggests that students possess schemas for qualitative knowledge and schemas for quantitative knowledge. Again we see that the task activates a particular schema (either qualitative or quantitative) which is isolated from the other. For expert problem-solvers, a novel problem would tend to activate both qualitative and quantitative knowledge that they would use to solve the problem. Schema theory can therefore be used to help us make sense of the following issues about physics problem solving:

(1) Success on traditional quantitative problems tells us little about qualitative understanding and
(2) Success on qualitative questions tells us little about quantitative problem solving skills.

Physics Education Research (PER) has provided many useful results about students understanding of physics. One particular research result is that students often lack a deep understanding of the underlying principles and concepts even though they can succeed in the course.[2] PER has also shown that the problem solving skills many of our students possess are very different than those of expert problem solvers.[3]

Evaluating students in the introductory physics course usually involves performance on traditional quantitative problems, like the ones found at the end of the chapter in a physics textbook. In the introductory physics course it is often the case that students are rewarded with good grades by applying formulas and facts without a deep understanding. Acquiring a fragmented knowledge consisting of unrelated facts and formulas becomes an efficient way for students to succeed in the course. But when students are presented with novel problems we often see them attempt to apply formulas and patterns of solution that are inappropriate.

David Hammer examined the role coherence plays in student understanding.[4] He interviewed two students who, at the beginning of an introductory physics course for pre-medical students, had very different ideas about how to approach the course. Liza relied heavily on memorization and pattern matching, while Ellen tried to build a deep understanding of the material and reconcile her in-class experience with her intuition. Despite having expert-like qualities, Ellen was forced to abandon these qualities in favor of a more fragmented knowledge focusing on formulas and facts in order to succeed in the course.[5]

Results showing that students have a poor qualitative understanding of the material has led many physics instructors and physics education researchers to address the quality of conceptual knowledge. Physics education researchers have shown that through research based curriculum, students can develop better qualitative understanding.[6] Results from this dissertation will show that improving qualitative understanding does not always transfer to quantitative problem solving.

Motivation

If students are to solve novel problems such as problems they may encounter in research, or problems they may encounter later in their careers, in school or in work, they will need to be able to apply an integrated set of knowledge. Different principles and concepts must be linked together and the qualitative aspects of a problem must be linked to the quantitative aspects of a problem. This integration is an important characteristic of physics understanding. To accomplish this, the traditional introductory course requires a new set of paradigms. We believe that expert-like analytic reasoning requires that students integrate their qualitative knowledge and their quantitative knowledge. Reif and Heller state that teaching problem solving skills and concepts are not sufficient; the two must be integrated.[7]

We believe that students leaving our physics courses must possess an integrated set of knowledge that can be used in solving research problems. Without coherent knowledge students will be unable to adapt to new situations. Therefore, integrating physics knowledge should be a major goal of physics instruction. In addition, the evaluation of coherence is an important component in the assessment of student understanding. Traditional exams and homework assignments give us a very limited understanding of our students' knowledge and how our students are integrating aspects the course. For this reason, the University of Maryland Physics Education Research Group has begun to develop and implement measures that can evaluate whether our students are developing coherent physics knowledge. The context of physics problem-solving provides the physics community with effective ways to evaluate coherence. This dissertation will provide the physics education researcher, as well as the physics instructor, with a number of tools that can be used to evaluate coherence.

Dissertation overview

Schema Theory and Previous Research in Student Problem-Solving

Ideas from education and cognitive science play an important role in our discussion of the coherence in student knowledge and problem-solving ability. In particular, schema theory will serve as the theoretical framework for the results of this study. We therefore provide the reader with a detailed background on schema theory and how it relates to problem solving.

There is currently a substantial body of work dedicated to student problem solving, covering many diverse topics. We will discuss the research done in how students solve problems in physics. Much of this research focuses on the differences between expert and novice problem-solvers.

Physics Education Research: Methods and Context

After providing a background on schema theory and the existing research in student problem-solving we will discuss the background for the research presented in this dissertation. For the benefit of those unfamiliar with PER we provide a description of some of the goals of PER and some of the methods researchers use to accomplish these goals.

The methods used in this dissertation to evaluate the coherence of student knowledge in the context of problem-solving involves specific applications of the general methods of PER that include one-on-one interviews, open-ended exam questions, and multiple-choice questions. Most of the research in this dissertation focuses on written responses to open-ended exam questions.

The research is conducted with two different populations of students. The first population is the undergraduate engineering majors, enrolled in the introductory physics sequence (Physics 161, 262, 263) at the University of Maryland. The second population is advanced physics majors, all of whom are enrolled in graduate level courses at the University of Maryland.

Results: Students use locally coherent knowledge in problem-solving contexts.

We first show that the schemas students activate to answer questions and solve problems strongly depends on the context of the problem. Exam problems and multiple-choice questions that test the same physics concepts were given to undergraduate engineering majors. Even though the corresponding exam questions and multiple-choice questions would be considered essentially identical by physicists, students often answered inconsistently. This is a clear example of the context triggering a particular way to respond to a question.

In the next section, we present results showing that specific principles and concepts that are closely integrated in an experts' knowledge are distinct in our students' knowledge. In a problem involving dynamics and work-energy we observed that students had difficulty applying both concepts to the problem. Most students focused on using ideas from dynamics to solve the problem. When they found that their knowledge from dynamics was not enough many were unable to activate the relevant schemas for solving the problem. In another example, we show that many students view the work done by a piston in a thermodynamic process as either the area under the *PV* curve or $\int Pdv$. These two procedures for calculating work are seen as distinct methods.

We also observe that students possess schemas for qualitative knowledge and quantitative knowledge, which tend to be isolated from one another. We analyze responses to different problem-solving tasks that were given by students in each part of the three semester, calculus-based, introductory physics course, at the University of Maryland. We demonstrate that our students can have qualitative knowledge and quantitative knowledge that sometimes contradict one another. Our results show that students can solve traditional questions correctly without a basic conceptual understanding of the material. In addition, we see that students can solve qualitative questions correctly, yet many are unable to apply this qualitative understanding to quantitative problems.

Results: How does the Tutorial curriculum affect student coherence and problem-solving ability?

Between 1993 and 1999 The University of Maryland used conceptual worksheets called *Tutorials*[8] in the discussion sections of some of its introductory calculus-based physics classes. Tutorials come from a research and curriculum development program at the University of Washington led by Professor Lillian C. McDermott. The tutorial section replaces the traditional one-hour problem-solving recitation with worksheets the students go through in groups of three or four. The tutorials used at UMd include both tutorials that have been developed by the Physics Education Group at the University of Washington (PEG) and tutorials that have been developed by the Physics Education Research Group at the University of Maryland (PERG). Research conducted with students at both institutions and a number of pilot sites has shown that the tutorial curriculum can aid students in gaining a qualitative understanding of the material in the course. But there has been little research on whether student problem-solving skills benefit from the tutorial curriculum.

Our results show that in certain contexts a conceptual curriculum such as *Tutorials* can improve problem-solving performance for some students. In one study, we examine how student coherence develops as they progress through the introductory mechanics course. Analyzing the dynamics of a class shows that, although some of the students are making the connection between qualitative and quantitative knowledge, many are not. This illustrates some of the limitations of the Tutorial curriculum. In another study we compare student performance on quantitative problems in two instructional modes. One population went through the tutorial curriculum and the other went through traditional problem-solving recitations. In this study we observed that students in the tutorial section performed much better than students in a problem-solving recitation.

Curriculum Designed to address Problem-Solving Ability

There are a number of innovative curricula designed to foster problem-solving ability. These will be discussed in the final section of this dissertation. In addition we will discuss some modest efforts conducted by the PERG at the University of Maryland to help students make the connection between qualitative knowledge and quantitative problem solving. Curricula materials designed by the PERG are included in the Appendix.

Summary and Speculations for the Future

In the conclusion we briefly present some of the major results from this work. We also summarize the methods we used in this dissertation to evaluate coherence in the students' understanding of physics. These methods can be used by instructors and physics education researchers to understand the type of connections students are making in the course. The data we present is dependent on the context of the problems we have studied. Future work might therefore focus on the general characteristics of different types of schemas; characteristics that cut across many contexts.

[1] See A. A. diSessa, “Knowledge in Pieces,” In *Constructivism in the Computer Age,* G. Forman and P. Pufall (Eds.) (Lawrence Erlbaum, NJ, 1988), and F. Reif, "Millikan Lecture 1994: Understanding and teaching important scientific thought processes," Am. J. Phys. **63**, 17-32 (1995).

[2] See L. C. McDermott, and the Physics Education Group, A perspective on physics education research as a guide to the improvement of instruction, unpublished collection, (1998); I. A. Halloun and D. Hestenes, "Common sense concepts about motion," Am. J. Phys. **53** (11) 1056-1064 (1985);

[3] See chapter 2 and the references contained therein.

[4] D. Hammer, “Two approaches to learning physics,” Phys. Teach. **27** (9) 664-670 (1989).

[5] See Ref. 4.

[6] See L. C. McDermott, “Millikan Lecture 1990: What we teach and what is learned – closing the gap,” Am. J. Phys. **59** (4) 301-315 (1991), and R. Hake, “Interactive engagement versus traditional methods: a six-thousand-student survey of mechanics test data for introductory physics courses,: Am. J. Phys., 65 (5) 418-428 (1997).

[7] F. Reif and J. I. Heller, "Knowledge structures and problem solving in physics," Educational Psychologist, **17** (2), 102-127 (1982).

[8] Tutorials come from a research and development project from the University of Washington Physics Education Group. See L. C. McDermott, P. S. Shaffer, and the PEG, *Tutorials in introductory Physics,* (Prentice Hall, NY, 1997).