Chapter 9: Summary and Speculations for the Future

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Through a series of studies on student problem-solving we provide evidence that students solve problems using locally coherent sets of knowledge we call schemas. Activating these schemas bring a set of declarative knowledge and procedural rules that students use to accomplish the goal of a problem. Unfortunately the schemas our students activate contain small sets of knowledge, and are isolated from other schemas. If the schema they activate is not sufficient for solving the problem many of our students have difficulty accessing the relevant knowledge.

Specific Examples

In our first study we compare student responses on open-ended exam problems and responses on corresponding multiple choice questions. Results show that even though the corresponding questions test identical physics concepts, students often answered differently on the exam problem and the multiple-choice question. For instance on a question asking students to compare the magnitudes of the two forces acting on object moving at constant speed, 90% of the students answer correctly on the open-ended problem, yet only 54% answer correctly on the corresponding multiple choice question. (This is shown in Figure 9 - 1.) Each question triggers a different set of physics knowledge, which in this case, are inconsistent with each other.

Summary Example

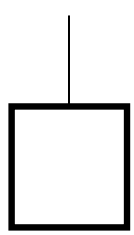
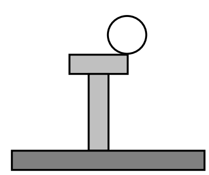
Elevator moving down at constant speed. (Real-world context)	Steel ball moving up at constant speed. (Physics context)
Multiple-choice question 	Open ended problem 
54% correctly state that the force of gravity is equal to the force from the rope.	**90%** correctly state that the force of gravity is equal to the force from the platform.

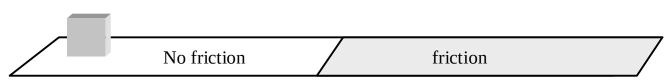
Figure 9 - 1

Example from chapter 4.

Our next study involved responses to a dynamics and work-energy problem. In this problem students had to use knowledge from multiple topics and both qualitative and quantitative understanding. Interviews with advanced students and undergraduate students in engineering physics showed that students had difficulty activating knowledge from work-energy. Most students only used dynamics knowledge to solve the problem. When they were stuck, they were rarely able to activate the relevant schema to solve the problem. Qualitative questions designed to aid the students in solving the problem actually caused many of the students to perform worse because they were less likely to bring up the ideas of work and energy. On the version of the problem with the qualitative questions 15% of the students answered correctly, while 30% of the students correctly answered the version without the qualitative questions. (This is shown in Figure 9 - 2.)

Summary Example

A hand applies a constant force to a block along a surface with friction and a surface without friction. Calculate the coefficient of kinetic friction. (paraphrased)



Version with no qualitative parts	Version with qualitative parts
30% answer correctly • **19%** used work-energy • **11%** used other methods	**15%** answer correctly • **4%** used work-energy • **11%** used other methods

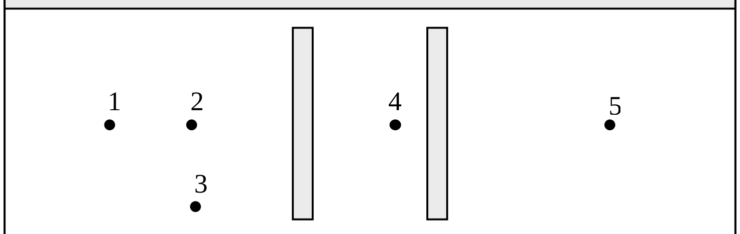
Figure 9 - 2

Example from Chapter 5.

Student responses to open-ended exam problems indicated that students often respond to qualitative questions differently from the way they respond to quantitative questions. The students rarely integrated their qualitative and quantitative knowledge. We have provided results from the three semesters of the engineering physics sequence showing that even in a single problem, some students would give contradictory answers to qualitative questions and quantitative questions. Sometimes students are successful on the quantitative questions and other times they are successful on the qualitative questions. For instance on a problem asking students to calculate the potential between two parallel plates 27% of the students treated the electric field as constant in the equation $\int_1^5 E \cdot dl = -V$ even though over three-quarters of those students drew electric field vectors that were not constant in the three regions (This is shown in Figure 9 - 3.)

Summary Example

Two large conducting plates, each with a charge +Q, are places as shown.
Draw electric field vectors.
Calculate the potential from point 1 to point 5.



27% of the students treated the E field to be constant in $\int_1^5 E \cdot dl = -V$. Most of these students (21% out of the 27%) correctly stated that the field at point 4 was zero.

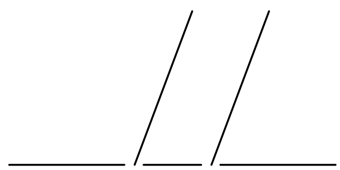
Figure 9 - 3

Example from Chapter 6.

The tutorial curriculum designed by the University of Washington Physics Education Group (PEG) has been shown to be effective in promoting qualitative understanding of various topics in physics. But there is little work documenting how students perform on traditional quantitative problems after going through the Tutorials. Our results show that after going through the tutorial curriculum performance on traditional problems improves in certain cases, but not others. In the first case we see only modest improvements in a quantitative problem about NII and tension. These results point out some of the limitations in solely relying on the tutorial curriculum; students are still not connecting their qualitative understanding to quantitative problem-solving. In another example involving a quantitative exam problem on physical optics, students who went through the tutorial curriculum performed much better than students enrolled in a class with problem-solving recitations. We observed that 60% of the students answered correctly after tutorial instruction and 16% answered correctly after a traditional problem-solving recitation. (This is shown in Figure 9 - 4.)

Summary Example

Light with λ = 500 nm is incident on 2 narrow slits. An interference pattern is observed on a distant screen. The first dark fringe is located 1.5 cm from the central maximum. Find L. (paraphrased)



	Tutorial	Recitation
Correct response	**60%**	**16%**
Used formula for maximum	**9%**	**40%**
Other	**31%**	**44%**

Figure 9 - 4

Example from chapter 7.

Summary

We have observed that our students tend to activate particular schemas in particular contexts. Often these schemas are centered around isolated topics such as in the example with dynamics and work-energy. Students in the introductory calculus-based physics course only sometimes activate schemas containing integrated topic knowledge. In addition students often view questions and problems as either qualitative or quantitative. They therefore activate qualitative schemas for qualitative questions and quantitative schemas for quantitative questions. In a single problem we have observed students directly contradicting their responses on the qualitative parts with their responses on the quantitative parts.

Evaluation of students' understanding in the introductory class often focuses on evaluating knowledge on a particular topic (for example, with end of chapter problems). Exam and homework questions are usually either quantitative or qualitative and rarely ask students to integrate their qualitative and their quantitative knowledge. Evaluation therefore focuses on the quality of particular schemas but not necessarily on the quality of physics knowledge and the coherence of physics knowledge.

Our data shows that although students may possess local knowledge that is correct and coherent they often do not possess the global coherence that characterizes expert problem solvers. In this dissertation we have provided a number of methods that can be used to evaluate coherence in student understanding of physics.

How can instructors and researchers evaluate coherence?

Evaluation of performance in physics classes is often one-sided. Instructors in the physics course usually use traditional problems, which test how well students can manipulate formulas rather than how well students can apply their qualitative knowledge. In a revised course consisting of a conceptual component, such as the tutorial curriculum, students may be given questions and problems that test their qualitative understanding. But, it is rare that students are given problems requiring both qualitative skills and quantitative skills.

An example of this is the engineering physics course at the University of Maryland with tutorials. On each exam in the tutorial class the students are given a qualitative question (the tutorial question) and usually three quantitative questions (similar to the questions students find in the textbook.) The qualitative question rarely requires the use of quantitative skills and the quantitative problems rarely require integrating qualitative skills. These questions therefore give the instructor a measure of how students answer the qualitative question and how well students answer the quantitative question but they usually do not tell us about how well qualitative knowledge is integrated with quantitative knowledge. By having questions segregated like this, instructors may actually be encouraging their students to treat the two types of questions in different ways.

In this dissertation we have outlined a number of ways that an instructor or a researcher can evaluate coherence. The following list provides a brief summary of the different methods we have used.

- The use of *problem-solving interviews* provides us with a detailed account of how our students solve problems. After transcribing these interviews we can create *interview maps* showing the types of knowledge students use to solve complex problems. Color coding the maps by the topic can help us understand whether students are able to go back and forth between different physics topics.[1]
- Asking open-ended *bridging problems* that require both qualitative and quantitative responses testing the same material can help us see how these two types of knowledge are integrated. Our problems often contain three to four qualitative parts about the situation and then a quantitative part. By examining how the students respond to the different questions we can look for consistency in their responses. In an instructional setting these problems can help the student recognize inconsistencies in their work. Many bridging problems are too difficult and require too much time for an exam context. They are more appropriate as in-class activities or homework assignments.[2]
- Asking different versions of problems (with and without qualitative parts) and comparing solutions on the two versions provide us with information on how students integrate their qualitative and quantitative knowledge. We have observed that the qualitative questions often degrade performance for our introductory students. This indicates that students can get cued by the qualitative questions into certain schemas where they get trapped. Because their schemas are not linked they do not employ methods that they may

apply if there were no qualitative questions or cues. Asking two versions of problems therefore allows us to see if students are linking different schema.[3]

- Using open-ended and multiple choice questions testing identical physics topics provide information about student coherence within a specific topic. We have observed that different types of questions can cue our students into different schemas, causing them to answer differently even though the questions test the same physics ideas and concepts.[4]
- Asking an identical question on two different exams and constructing a *pre-post progression* table helps us understand the dynamics of coherence in physics knowledge. We asked students questions after the students had traditional instruction but before they went through a modified curriculum. The question was then repeated after the students had the modified curriculum. By doing this we can examine how a particular class progresses and how individual students progress in developing coherence.[5]

In this dissertation we have demonstrated that the context of problem-solving can tell us about the links our students make between different physics concepts and principles and between their qualitative and quantitative knowledge. Constructing problems that that tie together different physics topics and require both qualitative and quantitative skills can help us evaluate coherence and also help our students develop global coherence.

Speculations for Future Work

Schema theory provides us with a useful framework to understand why student qualitative knowledge and quantitative knowledge is only weakly connected. In this dissertation we have presented evidence for the weak connection by examining many physics contexts. Qualitative and quantitative schemas were viewed in terms of the specific questions and problems we asked. The next step in this research would be to identify characteristics of qualitative schemas and quantitative schemas that cut across many contexts. By doing this we may be in a better position to address some of the issues concerning student coherence in physics.

The previous research in problem-solving has characterized general methods and procedures that experts and novices use to solve problems. In this work we have focused on the schemas students use to solve qualitative questions and quantitative questions in specific physics topics. The next step is tying these two areas of research together. Some relevant questions are:

- Can we identify general schemas students use for qualitative questions and quantitative questions? Or are the schemas students used dependent on the topic?
- Do the general schemas experts use for qualitative (and quantitative) questions differ from the general schemas novice's use for qualitative (and quantitative) questions?
- What methods can we use to identify general schemas?

[1] See chapter 5 to see how problem-solving interviews and interview maps are used in a research context.

[2] See chapter 3 for a description of bridging problems; see chapter 5,6 to see how these methods are used in a research context.

[3] See chapters 5 and 6 to see how this method is used in a research context.

[4] See chapter 4 to see how this method is used in a research context; see also R. S. Steinberg and M. S. Sabella, "Performance on multiple-choice diagnostics and complimentary exam problems," Phys. Teach. **35** (3), 150-155 (1997).

[5] See chapter 7 to see how this method is used in a research context.