

## **CHAPTER 6 DISCUSSION**

Wish I knew what you were looking for.

Might have known what you would find.

- The Church

The purpose of this study was to examine the development of the problem solving skills of students during an introductory college physics course where the students were taught an explicit problem-solving strategy. The results were not as obvious as one might expect. This chapter will discuss these results as well as the limitations and implications of the results.

### **Overview of Study**

Even though the effectiveness of problem-solving strategies is well documented in the cognitive science and physics education research literature (Larkin, 1983; Chi, Feltovich, & Glaser, 1981; Reif & Heller, 1982), few of these studies involved a cohesive curriculum change. Rather, most were laboratory studies or limited classroom interventions. Given the lack of classroom-based studies of teaching problem-solving skills to students (Wright & Williams, 1986; Van Heuvelen, 1991; Huffman, 1994; Heller, Keith, & Anderson, 1992) and the under emphasis on the development of these skills (McDermott, 1984; Laws, 1991; Thornton & Sokoloff, 1990), this study examined a population of students in a three academic-quarter, calculus-based physics course for scientists and engineers who were taught an explicit problem-solving strategy. Since there is a lack of research examining how student's problem-solving skills and conceptual understanding develop during any physics course, it would be difficult to interpret the

answer to this question without knowing what actually happens in a course without problem-solving instruction. For this reason another classroom was examined using the same questions and surveys. Therefore, the two research questions of this study are:

- (1) To what extent do students' problem-solving skills develop in a physics course taught by an instructor who emphasizes the Minnesota Problem-solving Strategy?
- (2) To what extent do student's problem-solving skills develop in a physics course taught by an instructor who does not emphasize a problem-solving strategy?

Answering these questions took a very thoughtful research design, which began with the context of the study. It would have been incorrect to compare a very traditional lecture/recitation physics course with any course teaching an explicit problem-solving strategy because inherent with such an explicit approach would be student practice. Effectively teaching a problem-solving strategy requires that the students practice their problem-solving with guidance. This guided practice is typically lacking in a traditional lecture/recitation physics course. Therefore, to understand the effectiveness of teaching an explicit problem-solving strategy, the best possible comparison group would come from another physics course that had a similar environment of guided practice, but did not explicitly teach problem-solving. Such a course was available for this study.

The two courses used in this study both used an instructional intervention called Cooperative Group Problem Solving (Heller, Keith, & Anderson, 1992). In each course the students worked on context-rich problems in cooperative groups in discussion

sessions and exams. Additionally, the students in both classes worked on problem-solving laboratory problems. These course components gave the students plenty of guided practice which added an overall problem-solving emphasis to both courses. Of the two courses used in this study, the course without any additional problem solving instruction was labeled the TRD course. In the other course, the Minnesota problem-solving strategy was explicitly taught. This course was labeled the EPS course.

Explicitly teaching a problem-solving strategy permeated several aspects of the EPS course. In lecture, the Minnesota Problem-solving Strategy was modeled for every problem worked in class. In the discussion sessions, the TAs coached the students on their use of the strategy. The students could practice with the Minnesota Problem-solving Strategy on their own with the help of a specially prepared workbook called *The Competant Problem Solver* (Heller & Heller, 1995). Finally, the students were graded in the EPS cohort for their ability to present a logical argument. This may seem like a major change, but it was shown in Chapter Three that the EPS and TRD classes were, on balance, more similar than different.

An important difference between the two classes was the instructors. For this study, it was impossible to have the same instructor teach both courses. To address this issue (called the Instructor Effect), this study used a case-study design where the cases were two matched cohorts of twenty-four students each. With this methodology, two matched teams of students had their problem-solving solutions examined for the development of the desired problem solving skills.

Since the research design was a case study, the principle unit of analysis was each cohort. Examining the data at this level produced a partial description of the cohorts. It

was also vital to examine the students within the cohorts to get an adequate description of the cohorts and to triangulate the results as much as possible. The individual development graphs for each skill from each student in the cohorts were inspected and then grouped with other students who showed similar behavior. These clusters completed the description of the development of problem-solving skills in each cohort.

The last important issue in the design of this study was defining problem-solving skills. There are many skills that could have been examined, but out of practicality only four were measured. The first was General Approach, which was a measure of the correctness and completeness of the principles the student chose to use when solving the problems. The next skill was Specific Application of Physics which assessed how well did the students do what they thought they needed to do. The third skill was Logical Progression. This skill measured the planfulness of the student's solution. Finally, Appropriate Mathematics measured how well the students applied mathematics to the content of physics. Chapter Four reported on several analyses demonstrating the validity of coding these skills. With the research design described, it is possible to report on the results of this study.

## **Results**

There are three sub-sections to the presentation of the results. The first section reports on an unexpected complication and its cause. The next two subsections answer the research questions.

### Mismatched Cohorts

The students for the cohorts were selected assuming that they would be representative of their classmates. This was important for generalizing the results from the cohorts to

the class as a whole. It was possible given the data collected for this study to check this assumption. The students in both cohorts were representative of their classmates on most of the demographic information; characteristics such as sex, math background and age. However, it was determined that the TRD cohort was not a representative sample of the students in the course in one discernable manner: The TRD cohort got significantly better grades than their classmates who were not in the study. This was not surprising given the high drop-out rate among the lower-scoring students in the TRD class. In contrast, the EPS cohort was a fair sampling of the remainder of their classmates.

This was a very troubling result since the TRD cohort was used to select the EPS cohort because the EPS course provided larger sample from which to draw students. The answer to this puzzle was the effect that math background had on the student's grades. In the TRD cohort, math background had a positive effect on grades, while in the EPS cohort, the effect was negative. Had the correlation between math background and grades for the EPS cohort also been negative, the EPS cohort may have over-represented their classmates as well. The consequence of this cohort mismatch will be seen in next few sections of this thesis.

### TRD Cohort Results

There were two research questions that guided this study. The best way to answer them both is to start with the TRD cohort.

- (2) To what extent do student's problem-solving skills develop in a physics course taught by an instructor who does not emphasize a problem-solving strategy?

The extent to which student's problem solving skills develop in a course taught using cooperative group problem-solving was reassuring. In spite of the changing (and progressively harder) topics encountered during the school year, the students in the TRD showed stable development on most of the skills. Only in Specific Application of Physics did the TRD cohort fail to develop. On the other three skills the TRD cohort actually showed growth during the first term. This rapid development may imply that the TRD cohort students were more than just better-than-average when compared to their classmates grades. It is hypothesized that these students may have consciously changed their problem-solving strategies in order to pass the course.

This hypothesis is supported by three observations. First, only the Logical Progression and Appropriate Mathematics scores were correlated. This suggests that only these two skills needed to be related to pass the course. The second observation was that the student's math background predicted their physics grade. Therefore the students level of mathematical sophistication predicted their success. Finally, the grade awarded to the TRD students seemed determined by the completeness of the solution. Therefore, it is possible that the TRD cohort students, who had sufficient sophistication to change their problem solving skills, concentrated this problem-solving skill redevelopment on where it mattered the most: the final answer. This hypothesis needs closer scrutiny in a subsequent study.

Finally, the TRD cohort performed very well on the multiple-choice concept tests. There is a national measure of how well students perform on the Force Concept Inventory (FCI). It is called the Hake Factor (Hake, 1998) and it measures the how much the students gained on the test. For the TRD cohort the Hake factor was a very respectable

$\langle g \rangle = 0.46$ . Most traditional courses have Hake factors around  $\langle g \rangle = 0.2$ . The mid-range score of the TRD cohort suggests that cooperative group problem-solving not only helps students' problem-solving skills, but improves their conceptual understanding of physics. Also the Maryland Physics Expectation Survey (MPEX), a measure of the students' views about physics, provided some interesting results. Even though the average scores did decrease during the course for the TRD cohort as the MPEX developers report for most courses (Redish, Steinberg, & Saul, 1998), the decrease was barely significant. All told, it appears that the TRD cohorts problem-solving skills, conceptual understanding, and attitudes seem to develop very well using the cooperative-group problem solving methodology.

#### EPS Cohort Results

With the basic description of the extent of the development of student's problem-solving skill completed for the TRD cohort, the benefit of adding explicit problem-solving instruction to the EPS cohort can be examined.

- (1) To what extent do students' problem-solving skills develop in a physics course taught by an instructor who emphasizes the Minnesota Problem-solving Strategy?

The extent to which the EPS students developed their problem-solving skills was also reassuring. The problem-solving skill graphs for the EPS cohort was remarkably similar to the TRD cohort, with a few noteworthy exceptions. The first exception was that the EPS development graphs generally started higher than the TRD development graphs. This implies that teaching an explicit problem-solving strategy helps the students get off to a strong start in the course and to maintain that skill level. There was also the

exception that the students in the EPS cohort decreased their bad problem-solving habits as the year progressed. This was illustrated best by the Appropriate Mathematics skill. Furthermore, the EPS students wrote longer solutions by almost half-a-page. The final noteworthy exception between the TRD and EPS cohorts problem-solving skill was that the EPS cohorts' problem-solving skill scores were all correlated with Logical Progression. This implies that the EPS students were producing more cohesive solutions. All of these results based on the development graphs are made even more remarkable when the above-average grade performance of the TRD cohort is factored in. The EPS cohort performed the same as or better than a cohort of the top performing students from the TRD class.

There were also differences between the cohorts beyond the development of problem-solving skills. The EPS cohort FCI average was outstanding. The Hake Factor (Hake, 1998) was  $\langle g \rangle = 0.67$ . This is a very high Hake Factor and rivals Workshops Physics (Laws, 1991). In addition to the FCI, the EPS cohort outperformed the TRD cohort on every multiple-choice test. It is hypothesized that the EPS students had a more consistent grasp on the concepts of physics, which lead to this remarkable result. This hypothesis is supported by the observation that the General Approach and Specific Application of Physics scores were correlated for the EPS cohort. This correlation suggests that the students knew the physics principles and applied them consistently. This is evidence of a cohesive understanding of physics which manifested itself by higher concept-test scores. Finally, the EPS cohort had higher MPEX scores than the TRD cohort by the end of the year suggesting that not only did the EPS cohort have a solid conceptual understanding, but they also had more expert-like views of physics.



## **Limitations of the Study**

There are several limitations to this study which must be considered. The first is the Instructor Effect mentioned earlier in this chapter. It was simply impossible to be absolutely certain that the differences seen between the EPS and TRD cohorts are directly attributable to the Minnesota Problem Solving Strategy and not the instructors. Physics education literature strongly suggested that in introductory college physics, the instructor has little direct impact on learning (Halloun, & Hestenes, 1985) and that the curriculum was the predominate factor (Hake, 1998). This research does not imply that the instructor was useless, but rather the role tended to be more motivational and organizational. In spite of this evidence, concerns about the Instructor Effect were strong enough to motivate using case studies in this study, which naturally have their own limitations. For examples, conclusions reached cannot be automatically generalized across contexts.

One method of increasing the strength of comparisons across cases was to populate the cases with matched students. The goal was to create two balanced teams of students and follow them through the courses. However, in this study there was unexpected interference from the students' math backgrounds, which lead to another limitation of this study. This interference left the TRD cohort as a population of students whose grades were significantly better than the populations they were supposed to represent. This over-representation meant that it was unlikely that the results from the TRD cohort could be used to describe the performance of their classmates. This over-representation did not affect comparisons between cohorts so long as the comparisons were made factoring in this difference. Future studies would be wise to include student's

course grade into the matching parameters, since this study had shown that the problem-solving coding scheme is valid with respect to grades.

Another limitation of this study was that it examined only four problem-solving skills. It is possible that there are other differences between the two cohorts which were not a part of this study. This limitation was relevant because the written solutions were visibly different between the two cohorts. Not only were the EPS solutions longer, but they were much more detailed and rarely without a diagram. The EPS students often checked their units and compared results to their experiences. All of these skills were left unexamined because the TRD students were not instructed to do these actions and measuring these skills would bias the sample toward the EPS class. Further research is needed to examine student performance on additional problem-solving skills.

The last limitation is that neither cohort was very traditional. In both classes students worked on context-rich problems in cooperative groups in both discussion sessions and in the laboratories. These interventions added an overall problem-solving emphasis to both courses. The study, by design, limits the generalizability of the results to more traditionally taught physics classes. Further research might want to examine a traditional class and get measurements of student performance using the tools of this study.

### **Implications for Research Literature**

Within the limitation of this study, conclusion can still be drawn. In this section, the conclusions will be related to the research literature in an effort to expand what is known about physics problem solving. The next section covers the instructional implications.

This study was the first to examine the development of physics problem-solving skills. Most studies have been laboratory snap-shots or limited classroom interventions. Instead, this study followed two cohorts of students throughout an academic year of introductory physics. From the two cohorts used in this study it was evident that both cohorts develop the measured skills during the academic year. However, most of development occurs in the first third of the academic year. For the remainder of the course, the students do not waver from their skill bands. While staying in a skill band across new content is definitely development, there was little evidence, beyond a few individuals, of students developing into the next higher skill band during the course. This first ever mapping of student development is an important contribution to our understanding of physics problem solving.

Beyond the development graphs, There are several more implications for our understanding of physics problem-solving. First, students do develop in their problem-solving skills during the year, but this development occurs early in the course, earlier if an explicit problem solving strategy is used. Therefore teaching the Minnesota Problem-solving strategy was effective in boosting students early in the year and may have played a role in sustaining the stable, within skill band growth.

Another implication involved Huffman's (1994) assertion that six weeks of instruction might be insufficient time to detect problem-solving performance. It is clear that the first six weeks of the EPS course had a noticeable impact on those students' problem-solving performance when compared to the TRD cohort. The contradiction between Huffman's results and those of this study might be due to the difference in the

amount of practice, instruction, and support the students receive. It might also lie in the difference between college and high school students. These issues need to be examined.

Third, the sustained problem-solving skill growth of the EPS cohort occurs while the cohort continually outperforms the TRD cohort on the multiple-choice, concept measures used in this study. Therefore, not only can an explicit problem-solving strategy be taught in a physics course, but the strategy helps the students understand the physics content better. This effect was hypothesized to be due to the EPS students having their physics knowledge and the application of that knowledge better connected. This hypothesis could be easily verified in future work involving a card-sorting task (Chi, et. al, 1981).

A related experiment might also be useful for testing another hypothesis made during this study. There was an indication from the General Approach problem-solving development graphs that even though the students displayed stable development, there was less-than-expected performance on the third term final exam. It was hypothesized that the students did not have their electricity and magnetism concepts efficiently structured. They were not as confident of which concepts to use on the third term final exam. Since this trend was not seen on the previous two final exams, it was assumed to be due to the third term instruction. More research needs to be done to see if this effect is common, if different instruction can help the students, and what role an explicit problem-solving strategy would have in such instruction.

### **Implications for Instruction**

This study makes several implications for instruction in an attempt to answer the big question concerning the utility of teaching a problem-solving strategy beyond

cooperative group problem-solving. The first implications for instruction include the ability for instructors and researchers to predict success on context-rich problems based on the number of difficulty traits each problem has. Not only can instructors tailor the difficulty of their exams but physics education research can be one step closer to Fred Reif's ideal of a problem bank (Reif, 1996). But more work still needs to be done with the difficulty traits. The traits need to be confirmed on another population of students and broadened to include more traditional problems. It could also be fruitful to systematically examine each trait through student interviews with problem isomorphs. Understanding student's specific difficulties with problems could go a long way to designing better courses.

There should be little doubt based on the data from this study that teaching an explicit problem-solving strategy to students increases their problem-solving performance on mechanics problems and has a pronounced impact on their Force Concept Inventory scores. Earlier studies have shown this to be true in other mechanics courses (Heller, Keith, & Anderson, 1991). Instructors of mechanics courses would be wise to teach their students a problem-solving strategy.

However, once the course progresses into electricity and magnetism the utility of the Minnesota Problem-solving Strategy becomes unclear. This lack of clarity introduces the "big question." Basically, is it worth the cost and overhead to add explicit problem-solving instruction on top of cooperative group problem-solving for an entire year of introductory physics? Teaching the strategy did help the students on the multiple-choice questions and in unifying the various problem-solving skills during the year. Teaching the strategy also helped the students' MPEX scores by the end of the course. And it

brought the skill level of average students to the level of better-than-average students. Yet there was no additional growth past the first term.

It was possible that the abstract nature of electricity and magnetism topics was not amenable to the current version of the Minnesota Problem-solving Strategy. Perhaps there existed a critical element of solving electricity and magnetism topics missing from the strategy, such as explicitly drawing on connections to familiar situations. There are a lot of unknown questions surrounding the structure of the electricity and magnetism part of the course and its impact on the students. It might also be possible after two-academic terms students naturally develop into better problem-solvers. Those who have the wherewithal to survive in a more traditional problem-solving presentation can acquire these skills. Those who can't change, don't survive. It was also true that no attempt was made in this study to see if instruction with the Minnesota Problem-solving Strategy helped disadvantaged students in the course or aided retention. In light of all the differences between the cohorts, there seems to be enough evidence to recommend adding instruction of a problem-solving strategy to cooperative group problem-solving. Yet more research and engineering needs to be done, especially in the later parts of the course, to add certainty to this decision.