CHAPTER 5: Implications

This chapter will provide a brief summary of the study, relate the findings to prior research, and suggest possible directions for future studies.

Summary of the study

The goal of this convergent study was to use a larger sample of physics instructors from various higher education institutions to refine and expand an initial explanatory model of physics instructor's conceptions about the problem-solving process in introductory calculus-based physics. The initial explanatory model was developed based on interview data with six university physics instructors, and the refinements and expansions were made based on analyses additional interviews with 24 other higher education physics instructors. All 30 instructors were interviewed under the same protocol. The interview was designed around three types of concrete instructional artifacts that were all based on a single introductory physics problem. It consisted of specific questions relating to a particular instructional artifact or teaching situation, as well as more general questions about the teaching and learning of problem solving in introductory calculus-based physics.

The interviews were transcribed, and each transcript was broken into statements that captured the information relevant to this convergent study. Based on the statements, a concept map about the problem-solving process was constructed for each instructor. Each concept map reflected how the respective instructor conceived the problem-solving process. Once this task was completed for each instructor, the individual concept maps were combined to form a composite concept map that reflected the similarities of all 24 instructors. This new composite concept map of the problem-solving process was then compared with the initial composite concept map (with six research university physics instructors) from the previous stage of the research program. The comparison led to the refinements that this convergent study purported to accomplish. This refined composite concept map consisted of two major components; conceptions of the problem-solving process, and conceptions of the metacognition that underlie each conception the problem-solving process.

The physics instructors in this convergent study described three qualitatively different conceptions of the problem-solving process, of which two of the conceptions included descriptions of the process (see Figure 4-3). Twenty-two of the thirty instructors (73%) had a Linear conception, and described problem solving as a linear decision-making process. In this process, the decisions made are always correct, and backtracking is not necessary. Seven of the thirty instructors (23%) had a Cyclical conception, and described problem solving as a cyclical decision-making process. In this conception, mistakes and errors are regarded as part of problem solving, and the decisions may not always be correct. Thus, backtracking is a necessary part of problem solving. Another result of this convergent study is the parsing of the metacognition within the problem-solving process. The instructors with the different conceptions of the problem-solving process also held qualitatively different conceptions of the role that metacognition plays in problem solving.

These refinements to the explanatory model can be used to help researchers and curriculum developers understand better how physics instructors think about problem solving in introductory calculus-based physics courses. It is hoped that this convergent study will further the understanding that will aid in bridging the gap that currently exists between physics instructors' conceptions of the problem-solving process and the curricular material that have been shown to improve students' problem-solving skills in introductory calculus-based physics.

Limitations

The physics instructors in this study expressed two qualitatively different conceptions of the problem-solving process, and each instructor expressed only one conception. Furthermore, the internal and external consistency checks of the bulk distributions also yielded qualitative differences between the instructors in the different conceptions. However, it is still conceivable that some of the instructors who expressed one conception (e.g., Linear) may have expressed the other conception (e.g., Cyclical) if only they were prompted differently during the interview.

A limitation of this study is that the refined explanatory model of physics instructors' conceptions about the problem-solving process was not presented to the instructors for feedback. This "member check" (Creswell, 1994, p. 158) would have provided information on the accuracy of the refined explanatory model in describing these physics instructors' conceptions in this domain. Perhaps if the instructors had had a chance to critique the conclusions of this study, the resulting refined explanatory model would be a more accurate and viable description of physics instructors' conceptions about the problem-solving process in introductory calculus-based physics.

A second limitation of this study is that the refined explanatory model only pertains to the context of introductory calculus-based physics. The situations within the interview in this study only dealt with that particular context, and consequently the instructors responded accordingly. As such, the conceptions that the physics instructors expressed in this study cannot be generalized beyond the context of introductory calculus-based physics. In other words, the refined explanatory model should not be interpreted as a viable description of physics instructors' conceptions about the problem-solving process in general.

A third limitation of this study is that the instructors' conceptions are inferred from what they talked about when describing the problem-solving process during the interview. The refined explanatory model describes these instructors' conceptions about what the problem-solving process should be for their students in the context of the introductory calculus-based physics course. The conceptions in the refined explanatory model do not represent what these instructors do when they themselves solve problems. The conceptions in the refined explanatory model also do not represent what and how these instructors teach problem solving in their introductory calculus-based physics courses.

Theoretical Implications

The previous stage of this research program showed that it was possible to generate an initial explanatory model of physics instructors' conceptions about the teaching and learning of the problem solving in introductory calculus-based physics.

True to the form of an exploratory study, the previous stage utilized a small sample to gain insight into the nature of the interested conceptions. The results, however, were preliminary and cannot be generalized easily. Although the initial explanatory model from the previous stage met all of the relevant criteria for viability (Clement, 2000), the results were preliminary, and some parts were too vague and incoherent to be considered as a complete model that is representative of physics instructors. This convergent study has shown that it is possible to take a part of the initial explanatory model and refine it with an expanded sample. One of the major implications of this convergent study is that the initial explanatory model can serve as a productive framework from which to study instructor conceptions about problem solving in more detail.

This study moves the research program towards a more convergent form. In convergent studies, attention is paid to whether observations are generalizable across similar samples: the extent to which patterns observed in one study are similar to patterns observed in another study in which the conditions are similar. This study utilized the characteristics of convergent studies to criticize and refine elements of the initial explanatory model developed in the previous stage. Several aspects served to increase the reliability of observation findings that described the conceptions (the analyses over smaller segments of transcripts, articulation of more explicit descriptions of model elements, refinements of model elements, and triangulations of observational support). The observational reliability in this convergent study with respect to the findings in the previous stage yielded a means for generalizing over samples in the same population, further strengthening the refined explanatory model as a viable model of physics instructor's conceptions about problem solving in introductory calculus-based physics.

Methodological Implications

Although the research methods used in this convergent study were not new, they were combined in ways that had not been done previously. In particular, the analysis method started with the identification of relevant sections of the interview transcript from the relevant parts of the initial explanatory model. This allowed for a more targeted analysis procedure that is the nature of more convergent studies (Clement, 2000). The method of breaking the interview transcript into statements of relevant meaning, forming individual concept maps, and then forming a composite concept map was again utilized. This is similar to the analysis method that led to the development of the initial explanatory model. The new composite concept map was then used to refine and critique the corresponding part of the initial explanatory model. It again proved to be a fruitful analysis method that led to a refined explanatory model that described complicated data.

The fact that this analysis method made the connections explicit proved to be useful when critiquing and refining the model elements. The model elements and interconnection were easily compared and contrasted between the initial composite concept map of the problem-solving process and the new composite concept map. This also made merging the two composite concept maps into the refined composite concept map easily accomplished. Again, the method provided transparent ways to ensure the viability of the refined explanatory model through the inclusion of references, both in the individual concept maps and the composite concept map.

The targeted analysis method utilized in this convergent study has shown itself to be quite effective at targeting the conceptions that physics instructors have about problem solving. Furthermore, due to the concentration on the problem-solving process, this method has also proved to be quite effective at uncovering other implicit conceptions that physics instructors have that underlie problem solving. Metacognition, uncovered in this way, proved to be easily identifiable, and can be readily embedded within the descriptions of the problem-solving process.

Relation to Prior Research

Although this convergent study was done within the specific context of introductory calculus-based physics, the results can nonetheless be related to the research on problem solving as described in Chapter 2. Overall, physics instructors' conceptions about problem solving that resulted from this convergent study are consistent with the major findings from the literature. Physics instructors' conceptions about problem solving identified in the context of this convergent study are similar to the descriptions of problem solving found by previous studies that examined different contexts.

As discussed in Chapter 2, research in problem solving spans many subject fields, and ranges from descriptions of what problem solving entails to identifying differences between how experts and novices solve problems. This section will discuss how the results of this convergent study relate to the previous research findings.

The instructors in this convergent study conceived of problem solving in two qualitatively different ways: a linear decision-making process and a cyclical decision-making process. Each conception reflected similarities to different representations of problem-solving frameworks. Although different words were used, both the Linear and the Cyclical conceptions consisted of all of the key steps when compared to the problem-solving framework as proposed by Polya (1973), and any subsequently proposed problem-solving frameworks. The overwhelming majority of the instructors in this convergent study held the Linear conception, which is consistent with the fact that an overwhelming majority of the representations of problem-solving frameworks are linear. The Cyclical conception is consistent with problem-solving frameworks that explicitly attempt to show the iterative and uncertain nature of problem solving.

As research has shown, problem solving is a complex, dynamic activity that involves uncertainties and errors. It requires problem solvers to make many decisions on what to do, when to do it, how to best do it, and whether to do it at all. These decisions are managed by the executive control known as metacognition. Since problem solving is a process where the path towards the goal is uncertain, errors are in essence the very nature of the process. In other words, “if no mistakes are made, then almost certainly no problem solving is taking place” (Martinez, 1998, p. 609). Therefore, the drawbacks of the linear representation of the problem-solving framework are that it gives the impression that problem solving is a linear process, and it assumes that the correct consideration is always made. The Linear conception of problem solving presents the process as inherently straightforward, that decisions are necessarily correct in order to proceed through the process. Such a presentation may result in the perpetuation of the tradition that perfect performance is the ideal, and errors are failures that do not merit high marks. By definition, the Linear conception does not constitute “problem” solving. The Cyclical conception of the problem-solving process illustrates, as part of the conception, an acceptance of the nature of problem solving. The framework recognizes that any attempt at solving a problem can be tentative, and illustrates the idea that mistakes and errors are expected, and can be undone. This conception may be a starting point towards revising the attitude about errors in problem solving, and facilitate the acceptance of errors, uncertainties, and indirect paths as natural and normal parts of problem solving.

Previous research also identified several differences in the way expert problem solvers differ from novices. It was found that experts, when encountering a problem, first qualitatively analyze the situation, and then set up a plan for solving the problem. Recognizing that there is uncertainty in the plan, the expert spends time monitoring the progress of the implementation of the plan, making adjustments as necessary. After the completion of the plan, the expert also evaluates the final solution for possible errors. Experts possess the implicit knowledge that such management is essential to successful problem solving. This is metacognition. The instructors in this convergent study also described some metacognitive processes in conjunction with both conceptions of the problem-solving process.

The instructors in this convergent study, however, did not describe either problem-solving process in very much detail. They also did not describe the metacognitive processes equally, or in much detail. These may be consequences of their expertise. Just as experts in other fields can perform tasks with little conscious thought, the instructors in this convergent study can look at an introductory physics problem and immediately know what approach would be most appropriate. As a result of their expertise, these instructors appeared to have automated much of the process of problem solving, as well as the metacognitive processes that underlie problem solving, and were unable to unpack those implicit knowledge.

Practical Implications

Research has shown that a problem-solving framework can be an effective tool in the instruction of problem solving. Other research has suggested that a problem-solving framework that embodies metacognitive processes can be an even more effective tool in the instruction of problem solving. Instructors often assume that there are some college students who will be able to acquire metacognitive skills on their own, while others lack the ability to do so (Pintrich, 2002). Researchers, however, are continually surprised at the lack of metacognitive skills in many college students (Hofer et. al., 1998; Pintrich et. al., 1987; Schoenfeld, 1987). So, to help students develop their own metacognitive skills during problem solving, instruction using a problem-solving framework needs to make explicit the metacognitive processes that are involved, and facilitate opportunities for students to make their own metacognitive processes explicit.

There are a few possibilities of how this explicit focus can be manifested in instruction. The key is that instructors must plan to include some goals for explicitly teaching metacognition within their regular instruction of problem solving. Because metacognitive processes are largely implicit, one of the most important aspects is the explicit labeling of metacognition for students. For example, during a lesson, the instructor should note the occasions when metacognition comes up, such as in a discussion of the different strategies students use to plan an approach to a problem. This explicit labeling and discussion helps students connect the strategy to other knowledge they may already have. In addition, making the discussion of metacognitive processes a part of the everyday discourse of the classroom helps foster a language for students to talk about their own cognition. The shared language and discourse about cognition among peers, as well as between students and the instructor, helps students become more aware of their own metacognition. Overall, this type of discourse and discussion may help make metacognition more explicit and less opaque to students.

Another way to help students develop metacognitive skills in problem solving is for the instructor to act as a model and moderator. This is similar to the cognitive apprenticeship model of instruction (Collins, Brown, & Newman, 1989). Many instructors are familiar with the modeling of solutions to exercises. Modeling of metacognitive processes in problem solving, however, is a more challenging endeavor. Instead of simply presenting a solution, the instructor must describe their cognitive and metacognitive processes while solving a problem. Instructors must characterize their actions as well as their mental management of their actions and thoughts. Such modeling includes explicit examples of assessing one's understanding of the problem, generating possible approaches and the process of selecting among them, and monitoring the progress. Such modeling helps focus students' attention on the metacognitive processes in problem solving; this method of instruction, however, should be implemented with caution. Lester, Garofalo, and Kroll (1989) suggests that, to focus students' attention on the metacognitive processes in problem solving, instructors must make every effort to remain in the role of a problem solver, and not start to explain, guide, and question.

As a moderator, the instructor encourages the students to clarify and justify their ideas, orally and in writing, while solving problems. The role of the moderator during problem solving engages the instructor as a monitor, raising questions about the usefulness of suggested ideas and steps. This is to be done regardless of whether the suggestions are actually useful in solving the problem. The instructor in this method does not guide the students to correct solutions. The instructor in this method also does not judge the students' suggestions, but rather raises questions that require the students to assess their own suggestions and progress. Once a solution has been reached, the instructor moderates a discussion of the solution attempts.

The methods of instruction mentioned above require the instructor to not only have extensive knowledge of problem-solving frameworks, but also extensive knowledge of metacognitive processes. As experts in the field, it is not unreasonable to expect that the instructors meet these requirements. This convergent study has shown that, when provided with the opportunity and sufficient prompting, instructors can describe a problem-solving process as well as some of the underlying metacognition. It is unclear, however, whether the instructors can do so without being prompted. It is also unclear whether the instructors can adequately unpack all of the internalized knowledge so as to make the instruction on problem solving and metacognition explicit and coherent.

The results of the current study indicate two suggestions. First, physics instructors have conceptions about the problem-solving process. The two conceptions are qualitatively different in the inherent nature of the process; one is linear, and the other is cyclical in nature. The descriptions of these conceptions are very similar to the various problem-solving frameworks that had been proposed in the research literature. The instructor conceptions, however, are different in wording and the number of steps that are involved. Nevertheless, the existence of such conceptions indicates the possibility that explicit presentation of a problem-solving framework may be an acceptable instructional approach to physics instructors. The caveat may be for curriculum developers to provide problem-solving frameworks and instructional structures that are flexible and, in essence, open source. This will allow the instructors to have the freedom to refine the framework and structure as they see fit. The problem-solving frameworks and instructional structures need also to be robust. This will ensure that the instructor refinements are not detrimental, and the underlying benefits, as indicated by previous research (see Chapter 2, p. 51), remain beneficial to student learning.

Second, the physics instructors in this convergent study expressed limited conceptions about the metacognitive processes that are necessary for successful problem solving. Instructors in both the Linear and Cyclical conceptions of the problem-solving process expressed mostly the “knowing what to do” type of metacognition; not much was expressed in terms of the “when”, “why”, and “whether to do it” types of metacognition. As discussed before, this may be the result of the instructors’ expertise in solving introductory physics problems, and their lack of opportunity to unpack knowledge that has long been internalized. On the other hand, the physics instructors may simply not be aware of such thought processes, or have deemed them unnecessary as part of their instruction. In either case, the message that explicit instruction of the metacognitive processes within the explicit instruction of problem-solving frameworks are beneficial to student learning (see Chapter 2, p. 46) need to be addressed and conveyed. Instructors need to be provided with opportunities to unpack the internalized knowledge about their own thinking processes when solving problems, with the opportunity to see first hand the benefits of such explicit instruction in thinking processes, and with the language with which to frame such thinking processes during instruction.

Future Studies

This convergent study has provided refinements to the problem-solving process part of the initial explanatory model on instructors' conceptions about the teaching and learning of problem solving in introductory calculus-based physics. The refined explanatory model of instructors' conceptions about the problem-solving process in introductory calculus-based physics provided observational generalizability over a sample of physics instructors that underwent identical interview protocols within identical contexts, and have similar characteristics as the sample of instructors from which the initial explanatory model was developed. A good explanatory model, however, should also provide theoretical generalizability. Theoretically generalizable explanatory models can be applied using different methodologies, under different context, and across larger populations to successfully yield similar results. To determine the theoretical generalizability of the explanatory model on instructors' conceptions about the problem-solving process in introductory calculus-based physics, other studies need to be conducted.

One way to establish the theoretical generalizability of the problem solving explanatory model could be through conducting a survey study. A survey study, for example, could consist of a close-ended questionnaire as the measurement instrument. The results of the current study can be used to inform the development of the questionnaire items. The wording of the questionnaire items could be phrased in authentic language consistent with the way that physics instructors in the current study worded them. A survey study would have the advantage of dramatically increasing sample size, thus providing a large enough database for relevant statistical analyses. With the advances in hardware and software capabilities, and the widespread access to the Internet, the questionnaire could also be web-based. The utility of such technology would dramatically reduce the instrument delivery and data collection times. The web-based questionnaire could also be programmed to automatically register each entry and download results in appropriate formats, making manual data entry obsolete. The utility of a survey study as the next step towards theoretically generalizability of the explanatory model would thus seem obvious.

The current study, as mentioned earlier, is focused on the refinement and expansion of the problem-solving process part of the initial explanatory model on instructors' conceptions about the teaching and learning of problem solving in introductory calculus-based physics. There are many other parts in the initial explanatory model that could be refined and expanded. The benefit of the interview data is that it is extremely rich with information. The current study used a targeted analysis method to distill only a fraction of the information that is relevant. The interviews can be further analyzed using similar targeted analysis methods to distill information about the other aspects of the initial explanatory model on instructors' conceptions about the teaching and learning of problem solving in introductory calculus-based physics. The results of these additional analyses could then respectively inform the development of future survey studies as described above.

The ultimate goal of the research program is the development of a viable explanatory model on instructors' conceptions about the teaching and learning of problem solving in introductory calculus-based physics. The future studies suggested here will provide a means for that development. The findings that emerge from these studies could conceivably make available a refined explanatory model with observational and theoretical generalizability. These studies will thus provide the physics education research community with a framework with which to conduct studies of the kind in other areas. The curriculum development community can also utilize the refined explanatory model to inform more suitable material that would be adopted, and subsequently be adapted by instructors for whom the materials are created.