A STRUCTURAL EQUATION MODEL OF EXPERTISE IN COLLEGE PHYSICS

by

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(Under the Direction of Martha Carr)

ABSTRACT

A structural equation model of expertise in college physics was tested on a sample of 374 college students in two different level physics courses. The variables that characterize expertise in physics including strategy use, pictorial representation, categorization skills, and motivation were examined for their influence on achievement in physics. Gender was included in the model to determine its impact on physics achievement. Results suggested a similar model across both level courses: Student motivation had a significant influence on students' strategy use and categorization. Categorization, in turn, influenced student achievement directly, and indirectly, through strategy use. Strategy use also had a significant influence on achievement. Pictorial representation basically played no role in the model. Gender played an important role in the model, particularly for the more advanced level course for physics and engineering majors. Implications of these findings for physics instruction are discussed.

INDEX WORDS: structural equation modeling, path analysis, expertise, gender differences, college physics, problem solving, context-based physics

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B.A., Emory University, 2002

M.A., University of Georgia, 2005

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial

Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2007

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DEDICATION

To Ziba, Kathy, Shiva and Amir.

ACKNOWLEDGEMENTS

I would like to thank Dr. Marty Carr first and foremost for all of her help and support in helping me to attain my Masters and Doctoral Degrees. I thank Dr. Shawn Glynn for helping me become a better writer, instructor, and researcher. I would like to thank Dr. Deborah Bandalos for teaching me to do structural equation modeling, and much more statistics. I thank Dr. Koballa for introducing me to context-based physics. I would also like to thank all of the physics instructors that allowed me to study their students.

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CHAPTER 1

GENDER DIFFERENCES IN SCIENCE: AN EXPERTISE PERSPECTIVE

Gender Differences in Science

The underrepresentation of women in the sciences is a significant and well documented societal concern (Miller, Blessing, & Schwartz, 2006; Stake, 2006). This underrepresentation has been predicted to continue until the problem is understood and addressed (Gallagher, 1993). Although the reasons for the problem are debated, there is no debate about the fact that women are underrepresented in the scientific community. For instance, in recent years, women received 34% of the Masters degrees in computer science, 21% of the Masters degrees in physics, 41% of the Masters degrees in chemistry, and 21% of the Masters degrees in engineering (National Science Foundation [NSF], 2004). Results for doctoral degrees were similar: women received 19% of the doctoral degrees in computer science, 13% of the doctoral degrees in physics, 32% of the doctoral degrees in chemistry, and 17% of the doctoral degrees in engineering. Thus women are greatly underrepresented in the sciences, particularly in more advanced degrees and degrees involving physics and engineering.

Gender differences in science achievement on standardized tests and in the classroom from elementary school until college have been thought to keep females from pursuing advanced courses and careers in science. Researchers have identified a number of possible explanations for why females perform more poorly than males in science including gender differences in the ability to deal with different test formats, differences in enrollment patterns, teacher and parent support, motivation, prior knowledge, and hands-on experience. Although this research has provided insight into the variables that may influence gender differences in science, there is a lack of research examining the problem solving strategies and conceptual understanding of males and females in science. This is surprising because the bulk of the research examining the emergence of expertise in science, including expertise in physics, chemistry, and biology, medicine, and computer science, focuses on the development of cognitive skills needed for proficient performance in a particular field of science (e.g. Boster & Johnson, 1989; Chi, Feltovich, & Glaser, 1981; Heyworth, 1999; McIver, 2000; Schmidt & Boshuizen, 1993).

A new line of research needs to examine gender differences in science achievement in different areas of science from the perspective of the work on expertise. Because gender differences are largest in physics, the focus of this review is on physics. Discussed first is the current literature on gender differences in science, particularly in physics, and then the research on the development of expertise in physics is reviewed. Using what is learned from these two areas of research, recommendations are made for future research on gender differences in physics, as well as other areas of science.

Gender Differences in Science Achievement

Significant differences in science achievement, as assessed using standardized tests, have been reported as early as the third grade, and the gap in achievement has been found to increase as students progress through school. These gender differences exist on both the life science and physical science sections of achievement tests (e.g. Government of Alberta, 2004; National Assessment of Educational Progress [NAEP], 2005; Husen, Fagerlin, & Liljefor, 1974). However, the largest differences in achievement, as well as participation, exist in the physical sciences, particularly in physics (Beller & Gafni, 1996; NSF, 2004). Males have been found to have higher physics scores on achievement tests, have a more positive attitude towards physics, take more physics courses, and be more likely to major in physics (e.g. Benbow & Minor, 1986). Although not always the case, in contrast to the physical sciences, no gender differences, or a female advantage in achievement is often found on the life science section of achievement tests (Bell, 2001). Furthermore, the life sciences is one area where the number of females enrolled equals (Greenfield, 1995), or exceeds the number of males (Keeves & Kotte, 1992).

When course grades are examined, the gender gap in science achievement increases as students progress through school. In elementary and middle school, males receive lower grades than females in all subjects, including science (Kleinfeld, 1998; Posnick-Goodwin, 2005). In high school (Willingham & Johnson, 1997), males and females receive similar grades in their science courses, including physics and biology courses. The research examining science Grade Point Average (GPA) in college is inconsistent, with some research suggesting that female undergraduate students perform as well as males in science courses (Adelman, 1991), and other research suggesting that male students outperform females in science courses, particularly in physics and engineering courses (e.g. Felder, Felder, Mauney, Hamrin, & Dietz, 1995). These results held for both science majors and non-science majors.

It is unclear why females are able to perform as well as males in the classroom, but not on science achievement tests. Further, when examining classroom grades, it is unclear why females perform as well as, or better than, males until college, when a gender gap in achievement begins. Possible explanations include that females are more concerned with pleasing the teacher (DeBacker & Nelson, 2000), are more extrinsically motivated (Rouse & Austin, 2002), and have fewer disciplinary problems in the classroom (Posnick-Goodwin, 2005). These explanations are feasible if teachers interpret females' compliance and extrinsic motivation as evidence of achievement. Classroom grades may measure good behavior in addition to actual skill and knowledge. It is unlikely that achievement tests do the same. It is also unlikely that good behavior plays a role in classroom grades in college. No research, however, has examined these hypothesized causes.

Researchers have identified a number of possible explanations in order to explain females' lower achievement and participation in science. Females have been found to perform more poorly on tests using multiple-choice items, and achievement tests typically use this item format (DeMars, 1998). Poor achievement in science has also been linked to patterns of course enrollment with females taking fewer science courses (Enman & Lupart, 2000). Females are also thought to have less teacher (She, 2001) and parental support (Tenenbaum & Leaper, 2003), to have poor motivation (Collis & Williams, 1987), poor prior knowledge (Desouza & Czemiak, 2002), and a lack of hands-on experience (Shin & McGee, 2002). These variables and their influence on gender differences in science are described in detail below.

Test Format

Although gender differences have been found on all science sections of achievement tests, research indicates that gender differences in performance on achievement tests differ as a function of test format. When assessing the same content, males have been found to perform better on multiple-choice items and females have been found to perform better on short-answer items (Breland, Danos, Kahn, Kubota, & Sudlow, 1991; Burton & Lewis, 1988). DeMars (1998) found after administering the general science section of the Michigan High School Proficiency Test (HSPT) that 11th grade males scored higher on multiple-choice items, and that females scored higher on short-answer items. Females have better verbal skills than males (Stumpf & Stanley, 1996), and this may give them an advantage on short-answer items that require

formulating a written response. This would explain why females would do better on short-answer items but does not explain why they would do worse on multiple-choice items.

These findings suggest that different methods of measuring science achievement influence gender differences in science. Gender differences may be less pronounced on an achievement test that includes items that are open-ended. Test item construction may provide some explanation for gender differences on science achievement tests, which are primarily multiple-choice in format, but does not explain why females often perform as well, or better than males on the life science section of achievement tests. In this case, we should see life science items using a constructed-response format; however, this is not the case. Further, differences in test format do not explain why females perform as well as males in the classroom, where both types of test format are used.

Enrollment Patterns

Females take fewer science courses in high school and college, particularly physics courses, and this would create an obvious disadvantage for them as far as science GPA in high school and college, and on achievement tests. When females do enroll in science courses, it is often in biology and other life science courses (Keeves & Kotte, 1992, National Commission on Excellence in Education [NCES], 2000).

The failure of females to enroll in science classes would make it less likely that they would pursue a science career. Although gender differences in performance on science achievement tests can be partially accounted for by differences in course work, the gap is not eliminated when this variable is held constant (Burkam, Lee, & Smerdon, 1997). This suggests that encouraging females to take more science courses will have some payoff in the form of increased participation in science, higher performance on achievement tests, and most likely

higher achievement in the classroom, it will not completely eliminate gender differences in science achievement.

Teacher and Parent Support

Teachers and parents contribute to gender differences in science achievement by providing males with more attention and support in the classroom and in the home. In science classrooms, males receive more attention from teachers than do females (She, 2001). In middle and high school classrooms, males are called on more frequently to answer questions (Jones & Wheatley, 1990), typically dominate almost every type of classroom interaction, and receive more academically related questions than do females (Lee, Marks, & Byrd, 1994). Science teachers have also been found to have lower expectations for females than males (Worrall & Tsarna, 1987). As an example, Shepardson and Pizzini (1992) examined elementary school teachers' perceptions of the scientific ability of their students. They found that teachers perceive males to be stronger than females on cognitive intellectual skills, including the ability to analyze, synthesize, hypothesize, evaluate, interpret, and question. Females were perceived to be stronger than males on cognitive process skills, including the ability to measure, observe, communicate, graph, manipulate equipment and materials, and record findings. The perception that females are not as competent in the intellectual skills needed for advanced science may influence studentteacher interactions, and keep females from enrolling in science courses.

Gender differences in teacher beliefs and responsiveness exist even though females are more concerned than males with pleasing the teacher (DeBacker & Nelson, 2000), and initiate as many teacher interactions as do males (Greenfield, 1997). Teachers' additional support and attention towards males may be to keep them on task (Posnick-Goodwin, 2005), but it is unclear why teachers have lower evaluations of females. The quality of student-teacher interactions needs to be better examined to determine whether low teacher expectations for females is communicated to students and how it is that females perform as well as males in elementary, middle, and high school classrooms despite these low expectations.

Parents believe that science is less interesting and more difficult for their daughters than for their sons (Tenenbaum & Leaper, 2003). This belief appears to influence the way parents interact with children when discussing science. Mothers of children between five and nine years of age were found to use a higher proportion of science process talk with their sons than with their daughters (Tenenbaum, Snow, Roach, & Kurland, 2005). Furthermore, when discussing exhibits in science museums with their preschool and elementary school children, parents provided their sons with scientific explanations 29% of the time, and provided their daughters with scientific explanations only 9% of the time (Crowley, Callanan, Tenenbaum, & Allen, 2001). Tenenbaum and Leaper (2003) found that fathers were more likely to use scientific vocabulary with their pre-adolescent and adolescent sons than daughters across a variety of different science tasks, and that their use of scientific vocabulary was most gender-differentiated for physics tasks. These findings are critical because parental support is found to have significant effect on achievement which, in turn, is found to influence self-efficacy and outcome expectations (Ferry, Fouad, & Smith, 2000).

Female students are more influenced by both their teachers' and parents' perceptions, and pay more attention than male students to advice given to them by teachers and parents (Hess, Hollowly, Dickson, & Price, 1984). Thus, females appear to rely more on support from parents and teachers than do males, and a lack of support and feedback may keep them from achieving and participating in science. Nevertheless, it has been found that after controlling for social

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support, gender differences still exist (Foote, 1996), indicating that social support in the home and classroom does not entirely account for gender differences in performance and participation.

Motivation

Most of the research on gender differences in science has focused on motivation with females showing substantially less motivation to pursue science (e.g. DeBacker & Nelson, 2000; Mattern & Schau, 2002). While all students lose interest in science by the time they reach middle school (Jones, Mullis, Raizen, Weiss, & Weston, 1992), the drop is more drastic for females. In both middle and high school, females have less interest in science than do males (Lupart, Cannon, & Telfer, 2004) and feel less confident about their scientific abilities (She, 2001).

Females' low confidence in their scientific abilities is thought to orient them away from science courses and careers. By the fourth grade, males are more likely to state that they are good at science, whereas females are more likely to state that they do not understand science or that they are not good at it (Lupart et al., 2004). O'Brien, Martinez-Pons, and Kopala (1999) found perceived ability to be predicted by academic performance. Perceived ability, in turn, predicts participation (Simpson & Oliver, 1990).

The tendency to view science as a masculine field may lower females' motivation to pursue science classes and careers. Students from elementary to high school have been found to perceive science as a masculine subject, and perceive scientists as predominantly male. Chambers (1983) administered the Draw a Scientist Test (DAST) and found that only 28 of the 4,807 students in kindergarten through fifth grade that were asked to draw a picture of a scientist drew a female scientist. All of these 28 drawings were drawn by females. Fort and Varney (1989), who also administered the DAST, found that among the 1,600 drawings from students in grades 2-12, only 135 of the pictures included female scientists. Furthermore, only six of these pictures were drawn by males. Huber and Burton (1995) also administered the DAST, and of the 223 students aged 9-12, 72 of the students drew female scientists. Of these 72 pictures, only 13 were drawn by males. When administering the Draw an Engineer Test (DAET) to students in grades 3-12, Knight and Cunningham (2004) found that of the 64 students, 61% of the drawings were of males and 39% of the drawings were of females. Further, like the DAST, most of the drawings of female engineers were found to be drawn by the females. The results of these studies indicate that although over time more students, including more male students, perceive scientists to be female, the stereotype of scientists as being primarily male is prominent among students.

Females may not be motivated to pursue careers in the physical sciences because these careers are not perceived as people-oriented type professions (Morgan, Isaac, & Sansone, 2001). Female college students are significantly more likely than male students to choose careers that allow them to help and interact with people, whereas male students are significantly more likely than female students to choose careers that offer high pay and status (Jones, Howe, Rua, 2000; Morgan, et al., 2001). Females may find careers in physics, engineering, and computer science less interesting than do males if they perceive these careers as offering fewer opportunities for helping and working with others. Medical careers offer opportunities for high pay and status, similar to careers in the physical sciences, but also offer opportunities for helping and interacting with others. It is likely for this reason that when women choose to enter science related careers that they tend to pursue medically related professions (Lupart et al., 2004).

Performance in the classroom does not seem to be linked to motivation. Until college, females perform as well as males in science classes. This should support motivation and selfconfidence in science, but this does not seem to be the case. Factors other than classroom performance may come into play. It may be that the perception that science is a male-dominated career plays a large role in females' motivation to participate in science. Also, the need to help and work with others may drive females away from many careers in the physical sciences.

Prior Knowledge and Hands-on Experience

Beginning as early as five years of age, males tend to have more prior knowledge about science than do females (Desouza & Czemiak, 2002). Gender differences in hands-on experiences throughout school influence differences in prior knowledge in science (Desouza & Czemiak, 2002). For instance, in science classrooms, males are more likely than females to be active participants when conducting experiments (Jones & Wheatley, 1990). Shin and McGee (2002) found that when working in groups with science materials, males tend to be the ones who work with the lab equipment and direct activities, whereas females tend to play the role of recorder.

Gender differences in hands-on experience tend to be subject specific. Females are more likely to have hands-on experiences in the life sciences while males have more experiences in the physical sciences. For example, males are more likely than females to work with batteries, microscopes, and electric toys, whereas females are more likely than males to observe birds and plant seeds (Jones et al., 2000). These differences in hands-on experience reflect gender differences on science achievement tests with males excelling in the physical sciences and females tendency to achieve in the life sciences.

Differences in motivation, enrollment patterns, and social support likely result in males having more hands-on experiences and greater prior knowledge. Hands-on experiences and the knowledge that emerges from these experiences appear to be reflected in gender differences in achievement test scores. However, it is unclear why differences in hands-on experience and knowledge are not reflected in the classroom grades of males and females in science until college, when males begin to outperform females in the physical sciences.

Summary

Although gender differences have been found in these suspected causes of females' lower science achievement and lack of participation in science, the literature neglects the interactions that likely occur among these potential causes. Given that many of the potential causes may be interrelated in predicting performance, it is necessary to determine to what extent each hypothesized cause accounts for gender differences in achievement in science.

Another major problem with this body of research is the almost complete lack of research examining the problem solving strategies and conceptual understanding of males and females. This is in sharp contrast to the research on expertise, which focuses on the development of cognitive skills needed for expert performance in a particular field of science. Research needs to be done examining gender differences in science achievement in different areas of science from the perspective of the work on expertise. For the purpose of this paper, however, the focus is on the domain of physics, where the largest gender differences exist, and factors necessary for expertise in physics are examined.

Expertise in Physics

The way physics problems are solved, including the actual problem solving strategies, the way problems are represented, the way problems are categorized, and metacognitive strategies used all distinguish novices from experts (e.g. Anzai, 1991; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Davis, 1989; Larkin, Heller, & Greeno, 1980). This paper focuses on how novices and experts differ in these various skills.

Problem Solving Strategies

When solving physics problems, novices tend to use the working backward strategy. Novices start by forming an equation that contains the goal of the problem. If the equation contains additional unknown variables that are not provided in the statement of the problem, the novice creates additional equations, aiming to solve for those unknown variables. This process is repeated until all variables are known or can be solved. The process is data driven with a goal of performing calculations to solve equations to find unknowns. Experts, on the other hand, tend to use the working forward strategy. When solving physics problems, experts work forward from a set of equations generated from the information provided in the problem, concluding the solution sequence with the goal of the problem. This process is based on the understanding of physics principles and laws that lead to meaningful calculations. An example illustrated by Priest and Lindsay (1992) helps illustrate the problem solving involved when using the working forward and working backward strategies (see Figure 1).

Although the working forward and working backward strategies may result in the same answer, the working forward strategy is considered to be purposeful problem solving, while the working backward strategy involves manipulating formulas with almost no planning and little conceptual understanding of what is being done (Larkin, 1985; Schoenfeld, 1985). However, without having an understanding of the equations being used and the direction the problem solver is going, a novice is likely to find himself at a dead-end and unable to solve the problem.

A useful analogy provided by Foster (2000) helps to describe the difference between working the forward and working backward strategies. When an expert plumber comes into a person's home to stop a drip, he assesses the situation, decides a plan of action to solve for the cause of the leak, goes to his truck, and returns with exactly the right tools. This is working forward. A novice plumber will need to make continuous trips to his truck, getting new tools with each trip, as he works backwards from the drip to the cause of the drip.

Although the working forward strategy is a characteristic of experts, the research indicates that novices do use this strategy. Larkin, McDermott, Simon, and Simon (1980a) asked eight novices, who were first year college physics students, and eleven experts, who were either physics professors or graduate students in the physics department, to solve mechanics problems and think-aloud as they solved the problems. They found that the experts solved almost all of the problems using the working forward strategy while the novices solved almost all of the problems using the working backward strategy. Priest and Lindsay (1992) compared 74 novices (non physics majors) to 30 physics experts (doctoral physics students) and found that the experts used the working forward strategy to a greater extent than the novices. Zajchowski and Martin (1993) examined 10 introductory college physics students solving mechanics problems and thinking aloud as they solved the problems. They found that the more novice problem solvers (as assessed by a pretest) were using the working forward strategy to the same extent as the more expert problem solvers. The authors suggested that these results occurred because prior to the study, the students had received extensive instruction on how to conceptually analyze problems before solving them. As a result, their strategy use reflected that of experts.

Problem Representation

Another major difference between expert and novice problem solvers in physics is in the use of schematic problem representation. Before solving a problem, experts will represent the relationships in the problem by sketching a picture of the problem. Novices, on the other hand, focus solely on representing the problem as a set of equations (e.g. Dhillon, 1988; Larkin, McDermott, Simon, & Simon, 1980b). Pictorially representing a problem is important because it

allows the problem solver to determine which approach to the problem is appropriate, to identify the forces and energies at work, and to reduce the amount of information that must be attended to at one time (Anzai, 1991; Larkin et al., 1980b; Larkin & Simon, 1987). A pictorial representation also allows the problem solver to visualize the role and interaction of the various factors in a problem. Pictorially representing problems before beginning to work on calculations is particularly important as problems become more complex and additional factors (e.g. angles, forces) begin to play a role in the problems.

Van Heuvelen (1991) suggests that novices often fail to draw a sketch of the problems they are solving because they do not understand the concepts and principles involved in the problems. Thus, as novices progress towards expertise and gain more conceptual knowledge, the use of pictorial representations is likely to emerge. With the emergence of this greater understanding and use of pictorial representations, it is likely that the use of the working forward strategy will increase as a deeper understanding of the concepts and principles and their relationship to one another develops.

Problem Categorization

One factor that has a significant impact on expert performance is domain specific knowledge and the organization of that knowledge. Experts in all subject domains have greater domain knowledge, and this knowledge is more conceptual and better organized from that of novices (Bruning, Schraw, Norby, & Ronning, 2004; Chi et al., 1981; Reif & Heller, 1982). Strategy use in physics is linked to this rich and well organized knowledge with experts' use of the working forward strategy when solving physics problems being due to their well-organized declarative and procedural knowledge (Schneider, 1993). In physics, evidence of the difference between experts and novices in their conceptual understanding and how they store, relate, and use this knowledge can be found in how they categorize problems (Chi et al., 1981), with experts focusing on the principles and laws underlying the problems, and novices focusing on surface features of the problems.

Studies of problem categorization indicate that expert problem solvers tend to view two problems as similar when the same law or principle can be applied to solve the problems. Novice problem solvers, in contrast, tend to view two problems as similar when the problems share the same surface features such as terminology or objects (Chi et al., 1981; Dufresne, Gerace, Hardiman, Mestre, 1992; Larkin et al., 1980a). For example, Chi, Feltovich, and Glaser (1981) asked eight experts (doctoral physics students) and eight novices (undergraduate physics students who had just completed a semester of mechanics) to categorize 24 mechanics problems based on their similarities, and to think-aloud as they categorized the problems. They found that the novices tended to categorize the problems based on surface features, including the objects referred to in the problems (e.g. ladder, inclined plane) and the physics terms mentioned (e.g. friction, gravity). The experts tended to categorize the problems based on the major principles underlying the problems.

This focus on the surface features of problems appears to reflect and influence how novices solve physics problems. If novice problem solvers are focusing on the surface features of the problems, it is likely that they only look at the key variables and unknowns, forming equations without considering the principles underlying the problems. As a result, they would be more likely to use the working backward strategy.

Metacognition

Effective metacognition is considered essential for efficient problem solving and for the transition from novice to expert (Beyer, 1987; Tobias & Everson, 2000). Because good problem

solving depends on both the appropriate selection of a strategy as well as its correct execution, expert problem solvers can explain the strategies they are using, why they are using them, and will select another strategy if the one they are using is not working. In contrast, novice problem solvers are often unable to explain and monitor their choice and use of strategies very well, and will continue to use a strategy even after it has failed to work (National Research Council [NRC], 2001).

Metacognition has been found to be so critical in problem solving that high levels of metacognition can compensate for low problem solving ability (Howard, McGee, Shia, & Hong, 2000). For example, Swanson (1990) found when examining high school students' verbal responses to a questionnaire, that low-aptitude, highly metacognitive students outperformed high-aptitude, low metacognitive students in determining the number of steps needed to solve pendulum and fluid problems.

Metacognition is especially important with problems that require an understanding of the principles or laws. Shin, Jonassen, and McGee (2003) found that high school astronomy students who had good metacognitive skills were more likely to do well on problems that required a good conceptual understanding. In contrast, metacognition was not a strong predictor of performance on problems that could be solved through rote computation. These results suggest that metacognition is most important when students must use their conceptual knowledge to set up and solve problems.

Understanding has been found to improve when metacognitive skills are explicitly taught. Neto and Valente (2005) found that high school students who were instructed to reflect on their problem solving processes while solving mechanics problems were able to form a deeper conceptual understanding of the material in comparison to students not receiving metacognitive instruction. Koch (2001) taught introductory college physics students techniques to use to selfassess their comprehension while reading their physics text. She found that these students, as compared to students who did not receive the instruction, received higher scores on a physics assessment. Although it is likely that good metacognitive skills are tied to the use of the working forward strategy, there is no research to date examining the relationship between the two.

Importance of a Good Conceptual Understanding

The most common type of physics problem assigned in both high school and college level physics courses requires students to perform computations that result in a single solved quantity. Instruction in both high school and college physics courses is also centered around presenting and solving these computation-type problems (Briscoe & Prayaga, 2004; Kang & Wallace, 2005). Students rarely are exposed to "thinking" problems that go beyond performing computations. The use of problems that can be solved through rote application of computation often causes students to conclude that conceptual understanding is unnecessary in physics (Neto & Valente, 2005).

Many efforts have been made to improve student understanding and achievement by encouraging students to consider the conceptual aspects of physics problems rather than just focusing on equations and calculations. For example, Mestre, Dufresne, Gerace, Hardiman, and Touger (1993) implemented a software program that allowed introductory college physics students to perform a conceptual analysis of mechanics problems prior to solving them. They found that the group of students using the program had higher performance on a physics exam measuring the relevant content in comparison to students in the control group who just solved the problems without conceptually analyzing them. Focusing students on the conceptual aspects of problems also improves their problem categorization in that problems are more likely to be categorized on the basis of common underlying principles or laws as opposed to surface features. Dufresne, Gerace, Hardiman, and Mestre (1992) examined university physics students who received either traditional textbook instruction on mechanics problems or who used a software program to perform conceptual analysis of mechanics problems prior to solving them. The students who used the software program classified the problems based on underlying principles significantly more than students who received the traditional textbook instruction.

Encouraging students to focus on the conceptual aspects of problems also appears to improve their problem solving strategies. Zajchowski and Martin (1993) examined 10 introductory college physics students solving mechanics problems and found that the more novice problem solvers were using the working forwards strategy to the same extent as the more expert problem solvers. The authors suggested that these results occurred because prior the study, the students had received extensive instruction on how to conceptually analyze problems before solving them. The results of these studies suggest that students' problem solving, understanding, and achievement can be improved by directing them to focus on the concepts that underlie the material and problems as opposed to the use of computations to solve problems.

Gender Differences in Strategy Use

While the research on gender differences in science achievement has focused primarily on gender differences in social support, motivation, prior knowledge, and hands-on experiences, the literature that examines differences between novices and experts in science focuses almost exclusively on cognitive factors. Little research on gender differences in science has focused on cognitive differences, particularly differences in conceptual understanding and strategy use as possible explanations, and what has been done does not examine the emergence of expertise as a framework for understanding these differences.

Gender differences in science achievement have been hypothesized to be due to females' use of rote strategies (Ridley & Novak, 1983). The few studies that have examined gender differences in students' strategy use focus on students' learning strategies rather than problem solving strategies, and examine whether students are focusing on the conceptual aspects of the material when learning science or on the rote memorization of facts. Atkin (1977) examined college students' strategy use in organic chemistry and found no gender differences for rote memorization, but reported that males were more likely than females to use conceptual strategies. Meece and Jones (1996) used self-reports to examine gender differences in fifth and sixth grade students' strategy use during lessons over six science topics including the human body, forces of energy, and space travel. They found little evidence for gender differences in students' use of conceptual and rote strategies. Nolen (1988) used a self-report to determine gender differences in eighth grade students' strategy use in science in general, and found that females used more conceptual and fewer rote strategies than males. Anderman and Young (1994) also used a self-report to determine gender differences in sixth and seventh graders' strategy use in science in general, and found no gender differences in students' use of conceptual and rote strategies. The results for middle school students indicate that females may be using more expert strategies than males or that there are no gender differences that exist. The one study examining strategy use in an older population indicates gender differences in favor of males' use of more expert strategies.

There are a number of critical problems with these studies. All but one of the studies used self-reports to examine differences in students' strategy use, and in these studies, students' actual

strategy use was not documented as is typically done in research on expertise. There may be problems with the validity of the reports if the students were unable or unwilling to respond accurately. For instance, females have been found to be more concerned than males with pleasing the teacher (DeBacker & Nelson, 2000), and may respond in such a way as to look good to the teacher or researcher. For this reason, it is necessary to look beyond self-reports, and observe students' completed work and engagement in relevant activities in order to get a more accurate picture of students' strategies. Of the studies that used self-reports to determine strategy use, two of the studies examined students' strategy use, but not strategies linked to performance within specific domains of science, likely making it difficult for the students to respond accurately. Further, it is unclear whether the strategies reported would be useful as expertise emerges within a specific domain, because more advanced strategies are linked to advanced domain knowledge. None of the studies examined students' strategy use in a specific subject domain using the research on expertise as a guide for understanding the strategies being used. Almost all of the studies were conducted among a younger age group for which expert performance is less likely to be evident. The one study that assessed actual strategy use in college students found gender differences favoring males.

Gender and Expertise

The current research on gender differences in science has focused on differences in ability to deal with different test formats, differences in enrollment patterns, teacher support, parental support, motivation, prior knowledge, and hands-on experience. Although these variables likely play a role in the gender differences in science achievement, no research has examined how these variables interact to influence gender differences. Further, there is a lack of research examining the problem solving strategies and conceptual understanding of males and females, both which are critical for the development of expertise in all areas of science.

A new line of research needs to examine gender differences in science achievement in different areas of science from the perspective of the work on expertise. Focusing on gender differences from the perspective of expertise would provide insight into the role of variables such as social support, motivation, prior knowledge, and hands-on experiences in influencing expertise. For instance, it is likely that high motivation leads to behaviors that result in expert performance in science, and this motivation is linked to hands-on experiences and social support. Below, discussed first is the current literature on expertise in physics in light of what is known about gender differences in science, and then the research on gender differences in science in light of the expertise literature is discussed.

Expertise Literature from the Gender Differences Perspective

Problem Solving Strategies

Females may be using less productive strategies when participating in science, possibly contributing to their poor achievement and participation. The one study that assessed actual strategy use in college students found gender differences favoring males (Atkin, 1977). Further, females tend to describe learning science as facts to memorize (Kahle & Lakes, 1983), suggesting that they may use rote memorization to learn physics. For physics, rote memorization is negatively related to classroom achievement (Cavallo, Rozman, Blickenstaff, & Walker, 2004), and would likely lead to the use of the working backward strategy and poor problem categorizations. Research indicates that instructional programs in physics that focus on teaching conceptual understanding instead of memorization of facts and formulas improve understanding and achievement, particularly among females (Huffman, 1997). Such interventions may be

especially beneficial for females if they are using rote strategies. Differences in strategic approaches to problem solving may also explain the discrepancy between course grades and standardized tests. Much of science instruction and assessment in elementary, middle, and high school classrooms involves the memorization of scientific terms and facts (Dietel, Heman, & Knuth, 1991). This may explain why females are able to perform as well as males in science classes at these grade levels. The use of memorization, however, is less likely to be useful on achievement tests or in college level science courses. If males are using more conceptual strategies, this would still allow them to succeed in the classroom, but also on achievement tests and in college level science courses.

What little research that has been done on gender differences in strategy use has been problematic because self-reports were used to determine students' strategy use, and the strategies students used were not linked to the emergence of expertise in science. In physics, no research has compared males to females in regard to their working forward and working backward strategies, and how these strategies influence physics achievement.

Problem Representation

Experts typically schematically represent a physics problem before setting up and solving the problem. Pictorially representing a problem is expected to be helpful because it allows the problem solver to outline the key variables and their relationships to each other (Anzai, 1991). Although there is no research suggesting that males are more likely than females to pictorially represent the problems they are solving, there is ample research indicating that males outperform females on tests of spatial ability, including three-dimension, mental rotation, spatial perception, spatial visualization, and dynamic spatial ability tasks (e.g. Law, Pelligirino, & Hunt, 1993; Linn & Petersen, 1985). Gender differences in science achievement, including physics achievement, have been linked to gender differences in spatial ability (Benbow & Stanley, 1984). For instance, Law, Pelligrino, & Hunt (1993) examined college physics students' spatial abilities and found that the males' spatial abilities were significantly better than that of females, resulting in higher achievement on a physics task.

Physics is taught in an abstract and mathematical way that involves the interpretation of visual and spatial relations (Larkin et al., 1980b). The male advantage in physics may be partly due to the spatial and visualization demands common to physics problems. When solving physics problems, pictorial representations may be used more by males than females because of their more expert spatial abilities, and these representations may be more complex when drawn by males. This has yet to be examined. Further, no research has examined the quality of pictures represented in physics, and no research to date has examined whether and how representing a physics problem plays a role in student strategy use, understanding, and achievement.

Problem Categorization

Although there is no research studying gender differences in students' problem categorizations, if females are using memorization to learn in physics, their knowledge base may be poorly organized in a way that would result in categorizations based on superficial rather than deep features of problems. This focus on superficial features would likely lead to the use of the working backward strategy.

Metacognition

Although metacognition has been found to be critical for successful problem solving, no research has examined gender differences in the metacognitive skills of males and females in science. The ability to monitor problem solving is related to the emergence of expertise. If females are using less expert strategies than males, then they may be monitoring their problem solving less than males.

Gender Differences from the Expertise Perspective

Discussed briefly is the research on gender differences in science in light of the expertise literature. In some cases, such as teacher and parent support, the research on gender differences helps provide some insight into why females are less likely to acquire expertise than males. Other gender differences are not well explained by the expertise research.

Test Format

Gender differences in performance on achievement tests differ as a function of test format. Males have been found to perform better on multiple-choice items and females have been found to perform better on short-answer items assessing the same content (Breland et al., 1991; Burton & Lewis, 1988). These differences appear to have little to do with gender differences in science. For instance, females often perform as well as, if not better than males on achievement tests covering the life sciences despite these questions being multiple choice (Benbow & Minor, 1986). *Enrollment Patterns*

Females take fewer science courses in high school and college, particularly physics courses, and this would create an obvious disadvantage for them in terms of understanding and achievement. Greater enrollment in science courses would result in males having more hands-on experiences and greater knowledge. This additional knowledge would likely lead to not only more advanced and well organized conceptual understanding, but to more expert pictorial representations and problem solving strategies.

Teacher and Parent Support

Practice needed to acquire expertise in any domain is often overseen by parents and instructors who provide instruction, feedback, and emotional support. Bloom (1985) identified three key phases in the development of expertise. In each of these phases, social support is critical. In the first few years of practice, there is a highly supportive home environment in which motivation and deliberate practice are stressed. During the middle years, the first signs of expertise are expected to emerge, and the student becomes increasingly dependent on skilled mentors. In the later years, as an individual becomes more advanced, social support is obtained through a single master teacher alongside steady practice and feedback. Thus social support from parents and teachers is critical for the move from novice to expert. In the classroom and at home, males receive more attention, instruction, and feedback about science than do females. This is particularly true when it comes to physics (Tenenbaum & Leaper, 2003). This lack of support can result in females having less practice and experience needed for the knowledge leading to expertise.

Motivation

Motivation to engage in activities that lead to expertise is critical (Ericsson, Krampe, & Tesch-Romer, 1993), particularly when practice becomes tiring, frustrating, or boring. Ericsson (1996) describes the role of motivation in the process of deliberate practice. During deliberate practice, students set a goal, act on that goal, assess the outcome, and revise their behavior. This process requires a great deal of effort, which is unlikely to occur without significant motivation. Social support is helpful for providing encouragement to keep students motivated when faced with difficulties.

Prior Knowledge and Hands-on Experience

The development of expertise is strongly related to the time and efficiency of deliberate practice (Ericsson, 1996). The more practice one gets, the better one gets, regardless of innate talent and ability. In science, males have more hands-on experiences than do females (Shin & McGee, 2002), particularly in physics, and in turn, have more prior knowledge (Desouza & Czemiak, 2002), likely leading to more expert knowledge and skills.

Implications for Future Research

The current research on gender differences in science has focused on differences in the ability to deal with different test formats, differences in enrollment patterns, teacher support, parental support, motivation, prior knowledge, and hands-on experience. In the gender differences literature, there is a lack of research examining the problem solving strategies and conceptual understanding of males and females in science. Future research needs to examine whether such differences exist, and should do so from the perspective of the work on the development of expertise. If females are showing more novice knowledge and skills when participating in science, this information could help researchers, teachers, and parents provide females with specific support and instruction in order to help transition them from novice to expert, increasing their achievement and participation in science.
A block of mass 7 kg starts sliding down a plane of length 5 m, inclined at an angle of 30 degrees to the horizontal. If the coefficient of friction between the block and the plane is 0.2, find the velocity *vt* of the block when it reaches the bottom of the plane.

Equations generated by working backwards: $vt \times vt = 0 \times 0 + 2 \times a \times 5$ (solves for vt, introduces a) $7 \times g \times sin(30) - F = 7 \times a$ (solves for a, introduces F) $F = mu \times R$ (solves for F, introduces R) $R = 7 \times g \times cos(30)$ (solves for R)

Equations generated by working forwards: $R=7 \times g \times cos(30)$ (solves for R) $F=mu \times R$ (solves for F) $7 \times g \times sin(30) - F=7 \times a$ (solves for a) $vt \times vt = 0 \times 0 + 2 \times a \times 5$ (solves for vt)

Figure 1: Example of the working forward and working backward strategies.

CHAPTER 2

A STRUCTURAL EQUATION MODEL OF EXPERTISE IN COLLEGE PHYSICS

The Emergence of Expertise in Physics

Novices and experts differ in their use of problem solving strategies, the way they represent problems, and the way they categorize problems, and these differences play a significant role in physics achievement (e.g. Anzai, 1991; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Davis, 1989; Larkin, Heller, & Greeno, 1980). Unfortunately, traditional physics instruction does a poor job at moving students from novice to expert levels of performance. Two main goals of physics instruction are to help students achieve a deep conceptual understanding of the subject and to help them develop powerful problem-solving skills (Mestre, Dufresne, Gerace, Hardiman, & Touger, 1993). However, traditional physics instruction frequently results in a failure to achieve either goal and students develop neither the strategies typical of expert performance nor the underlying conceptual knowledge used to expertly categorize and solve problems (Anzai, 1991; McDermott, 1991). Research has shown that traditional physics instruction leaves most students confused about the basic concepts of mechanics (Viennot, 1979), optics, thermodynamics, electricity, and magnetism (McDermott, 1991), and tends to lead to the use of poor problem solving strategies (Larkin, McDermott, Simon, & Simon, 1980a).

Although research specifies the variables that characterize expertise in physics, no research has examined the relationship among these variables and no research indicates which variables are most important for expert performance. Instructors do not know what should be focused on and what is of less importance. For instance, although it might be expected that the conceptual knowledge used to expertly categorize and solve problems is the most important variable for expertise in physics, in practice, much more focus is centered on the importance of pictorial representations for effective problem solving. Finally, little research provides guidance on the best way to move students towards more expert levels of performance, although researchers are suggesting we do just that (e.g. Ploetzner, Fehse, Kneser, & Spada, 1999).

Females, in particular, appear to have a hard time obtaining expert levels of performance in physics. The largest gender differences in achievement and participation exist in physics (Beller & Gafni, 1996). While the research on gender differences in science achievement has focused primarily on differences in social support and motivation as possible explanations, no research to date has examined gender differences from the perspective of expertise. This is important because the literature on expertise in science focuses almost exclusively on cognitive factors whereas the literature explaining gender differences in science tends to focus primarily on motivational and social factors. Although there is some research examining the strategy use of males and females, none of these studies examine the strategies used from the perspective of the work on expertise.

The purpose of this study is to examine the relationship between the variables that influence expertise in physics, to determine which are the most important for expert performance, and to examine the role gender plays in influencing expert performance. This will help provide more directed support for instructors and researchers in helping to transition students from novice to expert. Any advancement in understanding the differences between novice and expert behavior is a necessary prerequisite for transforming one into the other (Priest & Linsday, 1992). When examining the research on expertise in physics, the key variables that differentiate novices from experts include problem solving strategies, pictorial representation, and problem categorization. These variables are described in detail below. Although not described in the expertise literature in physics, the role of motivation in influencing expertise is expected to be critical in any domain, and also described in detail below. This is followed by a description of the research on gender differences in physics.

Problem Solving Strategies

When solving physics problems, novices tend to use the working backward strategy. Novices start by forming an equation that contains the goal of the problem. If the equation contains additional unknown variables that are not provided in the statement of the problem, the novice creates additional equations aiming to solve for those unknown variables. This process is repeated until all variables are known or can be solved. The process is data driven with a goal of performing calculations to solve equations to find unknowns. Experts, on the other hand, tend to use the working forward strategy. When solving physics problems, experts work forward from a set of equations generated from the information provided in the problem, concluding the solution sequence with the goal of the problem. This process is based on the understanding of physics principles and laws that lead to meaningful calculations.

Although the working forward and working backward strategies may result in the same answer, the working forward strategy is considered to be purposeful problem solving, while the working backward strategy involves manipulating equations with almost no planning and little conceptual understanding of what is being done (Larkin, 1985; Schoenfeld, 1985). However, without an understanding of the equations being used and the direction the problem solver is going, a novice is likely to find him or herself unable to solve the problem.

Although the working forward strategy is a characteristic of experts, the research indicates that novices do use this strategy. Larkin, McDermott, Simon, and Simon (1980a) asked

eight novices, who were first year college physics students, and eleven experts, who were either physics professors or graduate students in the physics department, to solve mechanics problems and think-aloud as they solved the problems. They found that the experts solved almost all of the problems using the working forward strategy while the novices solved almost all of the problems using the working backward strategy. Priest and Lindsay (1992) compared 74 novices (non physics majors) to 30 physics experts (doctoral physics students) and found that the experts used the working forward strategy to a greater extent than the novices. Zajchowski and Martin (1993) examined 10 introductory college physics students solving mechanics problems and thinking aloud as they solved the problems. They found that the more novice problem solvers (as assessed by a pretest) were using the working forward strategy to the same extent as the more expert problem solvers. The authors suggested that these results occurred because prior to the study, the students had received extensive instruction on how to conceptually analyze problems before solving them. As a result, their strategy use reflected that of experts.

Pictorial Representation

Another major difference between more expert and novice problem solvers in physics is in the use of schematic problem representation. Before solving a problem, experts tend to represent the relationships in the problem by sketching a picture of the problem. Novices, on the other hand, tend to focus solely on representing the problem as a set of equations (e.g. Dhillon, 1988; Larkin, McDermott, Simon, & Simon, 1980b). Pictorially representing a problem is important because it allows the problem solver to determine which approach to the problem is appropriate, to identify the forces and energies at work, and to reduce the amount of information that must be attended to at one time (Anzai, 1991; Larkin et al., 1980b; Larkin & Simon, 1987). A pictorial representation also allows the problem solver to visualize the role and interaction of the various factors in a problem. Pictorially representing problems before beginning to work on calculations is particularly important as problems become more complex and additional factors (e.g. angles, forces) begin to play a role in the problems.

Van Heuvelen (1991) suggests that novices often fail to draw a sketch of the problems they are solving because they do not understand the concepts and principles involved in the problems. Thus, as novices progress towards expertise and gain more conceptual knowledge, the use of pictorial representations is likely to emerge. With the emergence of this greater conceptual knowledge and the use of pictorial representations, it is likely that the use of the working forward strategy will increase as a deeper understanding of the concepts and principles and their relationship to one another develops.

Problem Categorization

One factor that has a significant impact on expert performance is domain specific knowledge and the organization of that knowledge. Experts in all subject domains have greater domain knowledge, and this knowledge is more conceptual and better organized from that of novices (Bruning, Schraw, Norby, & Ronning, 2004; Chi, Feltovich & Glaser, 1981). In physics, evidence of the difference between experts and novices in their conceptual knowledge can be found in how they categorize problems (Chi et al., 1981), with experts focusing on the principles and laws underlying the problems, and novices focusing on surface features of the problems.

Studies of problem categorization indicate that expert problem solvers tend to view two problems as similar when the same law or principle can be applied to solve the problems. Novice problem solvers, in contrast, tend to view two problems as similar when the problems share the same surface features such as terminology or objects (Chi, et al., 1981; Larkin et al., 1980a). For example, Chi, Feltovich, and Glaser (1981) asked eight experts (doctoral physics students) and eight novices (undergraduate physics students who had just completed a semester of mechanics) to categorize 24 mechanics problems based on their similarities, and to think-aloud as they categorized the problems. They found that the novices tended to categorize the problems based on surface features, including the objects referred to in the problems (e.g. ladder, inclined plane) and the physics terms mentioned (e.g. friction, gravity). The experts, on the other hand, tended to categorize the problems based on the major principles underlying the problems. Differences in categorization are linked to differences in strategy use with principle-based categorization supporting the working forward strategy (Schneider, 1993).

Motivation

Although not described in the expertise literature in physics, the role of motivation in influencing expertise is critical in any domain (e.g. Ericsson, 1996). Students who are highly motivated and persistent engage in behaviors that lead to more expert knowledge and skills, and ultimately, high performance (DeBacker & Nelson, 1999; Ericsson, 1996). The role of motivation on expertise is particularly important when practice becomes tiring, frustrating, or boring (Ericsson, Krampe, & Tesch-Romer, 1993). Ericsson (1996) describes the role of motivation in the process of deliberate practice. During deliberate practice, students set a goal, act on that goal, assess the outcome, and revise their behavior. This process requires a great deal of effort, which is unlikely to occur without significant motivation.

Research indicates that the important components that should be taken into account when examining students' motivation to learn science include intrinsic motivation, extrinsic motivation, relevancy of a task to personal goals, self-determination, self-efficacy, and assessment anxiety (e.g. Glynn & Koballa, in press). What follows is a brief discussion of these components.

Motivation to perform a task for its own sake is mainly intrinsic, whereas motivation to perform a task as a means to an end is mainly extrinsic (Ryan & Deci, 2000). For instance, students who are intrinsically motivated work on a task because they find it interesting; students who are extrinsically motivated work on a task to attain a desirable outcome such as a good grade. However, both types of motivation are important in contributing to students' success in their science courses (Pintrich & Schunk, 2002).

Another important component of motivation is the relevancy of a task to a student's goals. How important a student finds a task or how much he or she values a task influences time spent on the task (Feather, 1988). Self-determination refers to students having a bit of choice and control in their learning (Ryan & Deci, 2000). When college science students have the opportunity to choose what their assignments will be, they are more likely to benefit from the assignments (Glynn & Koballa, 2005).

Self-efficacy refers to a student's belief that they can achieve in a specific area (Bandura 1997). Self-efficacy affects choice of activities, including career choice (Hackett & Betz, 1981). Self-efficacy also influences achievement. Zusho and Pintrich (2003) found that even after controlling for prior achievement, students' self-efficacy was the best predictor of grades in an introductory-level college chemistry course. Finally, assessment anxiety is an important component of motivation. A high level of assessment anxiety has been found to interfere with a student's performance on a task, and students perform best when their level of anxiety is at a low to moderate level (e.g. Cassady & Johnson, 2002).

Gender and Expertise in Physics

The largest gender differences in achievement, as well as participation, exist in the physical sciences (Husen, Fagerlin, & Liljefor, 1974; National Science Foundation [NSF], 2004),

particularly in physics (Beller & Gafni, 1996). Males have been found to have higher physics achievement, have a more positive attitude towards physics, take more physics courses, and be more likely to major in physics (Benbow & Minor, 1986). While the research on gender differences in science achievement has focused primarily on differences in social support and motivation as possible explanations, the literature that examines differences between novices and experts in science focuses almost exclusively on cognitive factors. There is a lack of research examining the problem solving strategies and conceptual understanding of males and females, both which are critical for the development of expertise in all areas of science. Thus we do not know whether females' poorer performance is linked to less expert strategy use and conceptual understanding.

Gender differences in science achievement have been hypothesized to be due to females' use of rote strategies (Ridley & Novak, 1983). The few studies that have examined gender differences in students' strategy use focus on students' learning rather than problem solving strategies, and examine whether students are focusing on the conceptual aspects of the material when learning science or on the rote memorization of facts. Atkin (1977) examined college students' strategy use in organic chemistry and found no gender differences for rote memorization, but reported that males were more likely than females to use conceptual strategies. Meece and Jones (1996) used self-reports to examine gender differences in fifth and sixth grade students' strategy use during lessons over six science topics including the human body, forces of energy, and space travel. They found little evidence for gender differences in students' use of conceptual and rote strategies. Nolen (1988) used a self-report to determine gender differences in eighth grade students' strategy use in science in general, and found that females used more conceptual and fewer rote strategies than males. Anderman and Young (1994) also used a self-report to determine gender differences in sixth and seventh graders' strategy use in science in general, and found no gender differences in students' use of conceptual and rote strategies. The results for middle school students indicate that females may be using more expert strategies than males or that there are no gender differences that exist. The one study examining strategy use in an older population indicates gender differences in favor of males' use of more expert strategies.

There are a number of critical problems with these studies. All but one of the studies used self-reports to examine differences in students' strategy use, and in these studies, students' actual strategy use was not documented as is typically done in research on expertise. There may be problems with the validity of the reports if the students were unable or unwilling to respond accurately. For instance, females have been found to be more concerned than males with pleasing the teacher (DeBacker & Nelson, 2000), and may respond in such a way as to look good to the teacher or researcher. For this reason, it is necessary to look beyond self-reports, and observe students' completed work or engagement in relevant activities in order to get a more accurate picture of students' strategies. Of the studies that used self-reports to determine strategy use, two of the studies examined students' strategy use, but not strategies linked to performance within specific domains of science, likely making it difficult for the students to respond accurately. Further, it is unclear whether the strategies reported would be useful as expertise emerges within a specific domain, because more advanced strategies are linked to advanced domain knowledge. Almost all of the studies were conducted among a younger age group for which expert performance is less likely to be evident. The one study that assessed actual strategy use in college students found gender differences favoring males.

In physics, no research has compared males to females in regard to their working forward and working backward strategies, and how these strategies influence physics achievement. Females may be using less productive strategies in physics, possibly contributing to their poor achievement and participation. For instance, females tend to describe science as facts to memorize (Kahle & Lakes, 1983), suggesting that they may use rote memorization strategies to learn physics. For physics, rote memorization is negatively related to classroom achievement (Cavallo, Rozman, Blickenstaff, & Walker, 2004), and would likely lead to the use of the working backward strategy and poor problem categorizations.

Students who are highly motivated and persistent engage in behaviors that lead to more expert knowledge and skills, and ultimately, high achievement (DeBacker & Nelson, 1999; Ericsson, 1996). If females have lower motivation in physics, they may be less likely to engage in the problem solving practice and studying needed for a good conceptual understanding of the material and expert problem solving strategies, and may instead focus on memorizing and computing formulas and facts. This faster and more superficial way of learning would result in less expert performance.

Present Study

The purpose of this study is to examine the relationship between the variables that characterize expertise in physics, as well the role of gender in influencing expert performance. This will allow the opportunity to determine which variables are most important for the transition to expertise so that it is better understood which variables to focus on during instruction in order to move students toward more expert levels of performance. This is important because some variables may be characteristic of expertise but may not predict performance directly and may affect performance only through other variables. The current study examines the relationship between these variables among two different groups of introductory-level physics students. The first group is comprised of students in an introductory course required for science majors, while the second group is comprised of students enrolled in a more advanced introductory course required for physics and engineering majors. Students from these two courses were compared in order to examine if the relationship among gender, strategy use, categorization, pictorial representation, motivation, and achievement at two levels of expertise.

Based on the existing research on expert and novice differences in physics and the research on gender differences in science, the model shown in Figure 2 was developed. Specifically the relationships posited include: Students' gender will influence their motivation, strategy use, and categorizations, with males having higher motivation, using better strategies, and having better categorizations. Students with higher motivation will be more inclined to engage in behaviors that will result in them learning the material at a deeper level, leading to better categorizations. Similarly, students with higher motivation will engage in more problem solving practice, leading to the more expert working forward strategy. A focus on the deeper aspects of the material and problems, as indicated by categorizations, will influence student achievement both directly, and indirectly, through the use of the more expert working forward strategy. A deeper understanding of the material will also result in more complex pictorial representations. With more complex pictorial representations, the use of the working forward strategy will increase as a deeper understanding of the concepts and principles and their relationship to one another increases. Strategy use will also directly influence achievement with the working forward strategy leading to higher achievement.

In the present study, structural equation modeling was used to test the preceding assumptions about gender, strategy use, categorization, pictorial representation, motivation, and physics achievement; to understand the patterns of correlations among these variables; and to explain as much of their variance as possible. Although a correlation does not imply causation, path analysis makes it possible to cautiously draw causal inferences from patterns of correlations. To satisfy the conditions for the inference of causality, the hypothesized relationships involved time precedence and a logical direction of causality, consistent with the research reviewed. Also, the relationships were hypothesized to remain intact when external variables were held constant. Finally, the model was recursive in that the causal effects were unidirectional and the sources of unexplained variance assumed to be uncorrelated.

For both level courses, the hypothesized model is compared to alternate models. Because the bulk of the research attempting to explain gender differences in science achievement focuses on motivation, an alternative model in which gender differences in strategy use and conceptual understanding are the result of motivation was tested. Thus the model without the paths from gender to strategy use and gender to categorization is also tested. The second alternate model assumes that a focus on conceptual knowledge leads to increased achievement only indirectly through improved strategy use. This is because physics instruction and assignments are centered on students correctly setting up and solving problems. Thus the path from categorization to achievement is removed in order to test a model where a good conceptual understanding only influences achievement through strategy use.

Method

Participants

Subjects included a total of 374 students (185 males and 189 females) from two different level physics courses offered at the physics departments of five different universities in Georgia. These two level physics courses were selected in order to examine the influence of gender, strategy use, categorization, pictorial representation, and motivation on achievement at two levels of expertise.

The first course was a trigonometry-based introductory-level physics course required for science majors, such as biology and chemistry majors. Students only needed a background of high school level algebra and precalculus for the course. Eight trigonometry-based classes from four universities (two large public universities and two small public universities) participated in the study. Specifically, 245 students (100 males and 145 females) from a total of 481 students (230 males and 251 females) participated in the study. The number of males and females that participated was proportional to the total number of males and females in the course. Overall, a majority of the students participated in the study (53%), and students who participated earned a small amount of extra credit.

The second physics course was a calculus-based introductory-level physics course for physics and engineering majors. The course covered the same material as the trigonometry-based course, but used calculus rather than trigonometry for much of the problem solving. Differential calculus was a prerequisite for the course. The course was a more difficult version of the trigonometry-based physics course, and students in this course were expected to be more expert at physics. Four classes at this level from three universities (one large public university, one large private university, and a small public university) participated in the study. Specifically, 129

students (85 males and 44 females) from a total of 181 students (120 males and 61 females) participated in the study. The number of males and females that participated was proportional to the total number of males and females in the course. A majority of the students participated in the study (71%), and students who participated earned a small amount of extra credit.

Procedure and Materials

Students in the two different level courses were administered a packet that included a motivation questionnaire, five physics problems designed to assess strategy use, pictorial representation, and achievement, as well as four categorization tasks used to determine if students were focusing on conceptual or surface features of physics problems. This packet was administered late in the fall semester after the unit on mechanics was covered (See Appendix A for the packet). Information about students' gender was also collected.

Motivation

Student motivation in physics was assessed using the Physics Motivation Questionnaire (PMQ) (Glynn & Koballa, in press). The PMQ (pages 2 and 3 of the packet) includes 30 items that assess six important components of student motivation in physics including intrinsically motivated physics learning (items 1, 16, 22, 27, and 30), extrinsically motivated physics learning (items 3, 7, 10, 15, and 17), relevance of learning physics to personal goals (items 2, 11, 19, 23, and 25), self-determination for learning physics (items 5, 8, 9, 20, and 26), self-efficacy in learning physics (items 12, 21, 24, 28, and 29), and anxiety about physics assessment (items 4, 6, 13, 14, and 18). Students responded to each of the 30 randomly-ordered items on a 5-point Likert scale ranging from 1 (never) to 5 (always) from the perspective of "when learning physics.." The anxiety about physics assessment items were reverse scored when added to the total, so that a higher score on this component meant less anxiety.

Previous findings (Glynn & Koballa, in press) indicate that the PMQ is reliable as measured by coefficient alpha ($\alpha = .93$), and valid in terms of positive correlations with college students' science grades, decision to major in science, interest in science careers, and number of science courses taken. For this study, internal consistency was found to be ($\alpha = .91$) for both the trigonometry and calculus-based level course.

Strategy Use, Pictorial Representation, and Achievement

Five mechanics problems were administered to students (see fourth page of packet). The five problems required a single solved mathematical solution. Students were asked to solve the problems, showing all of their work. Each of the problems is based on one of five major topics in mechanics including Kinematics, Forces and Newton's Laws of Motion, Work and Energy, Impulse and Momentum, and Simple Harmonic Motion and Elasticity (Cutnell & Johnson, 2001). The first problem deals with Forces and Newton's Laws of Motion; the second problem deals with Kinematics; the third problem involves Impulse and Momentum; the fourth problem involves Work and Energy; the fifth problem deals with Simple Harmonic Motion and Elasticity.

The first of the five problems is designed by Priest and Lindsay (1992), and used in their own study in assessing the working forward and working backward strategies. The other four problems are from a physics final examination used by a professor teaching both the trigonometry-based and calculus-based courses at a university that did not participate in the study. The solved problems were scored for the working forward and working backward strategies. Specifically, students received zero points for using the working backward strategy and one point for using the working forward strategy. Points were summed across the problems and ranged from zero to five. In order to carefully score for the working forward or working backward strategy,

guidelines developed by Priest and Lindsay (1992) were used. If the working backward strategy was used, the first equation generated contained the sought quantity, and additional equations aimed to solve for unknown quantities introduced by previous equations. If the working forward strategy was used, the first equation contained only a single unknown. Each subsequent equation provided the value of a single unknown quantity, resulting in solvable and sensible equations that lead to the sought quantity.

Each problem was also analyzed for pictorial representation. The pictures drawn by the students were compared to a target sketch of each problem. The target sketch was created by a physics professor and included the necessary factors (e.g. angles, forces) needed to have a complete and inclusive pictorial representation. For the first problem, a complete sketch included the representation of two forces (normal force and force of gravity broken into its horizontal and vertical components), and one angle, resulting in a total of three main factors. In the second problem, a complete sketch included two important factors, the change in the vertical distance and the horizontal velocity. In the third problem, a complete sketch included two important factors, the velocity of the object both before and after collision. In the fourth problem, a complete sketch included a total of four factors, including two forces (the normal force and the angle of the slant. In the fifth problem a complete sketch included the angle, spring, and spring constant, for a total of three factors. For each sketch, students received one point for each main factor pictorially represented with a range of scores being between zero and 14.

In order to obtain a measure of students' achievement during physics problem solving, students' performance on the five physics problems was scored one point for correct and zero points for incorrect. Students could earn up to a total of five points.

Problem Categorization

Four problem categorization tasks based on major topics in mechanics including Kinematics, Forces and Newton's Laws of Motion, Work and Energy, and Impulse and Momentum (Cutnell & Johnson, 2001) were administered to students (see last four pages of Appendix A). Each task included four physics problems, two problems from two major subtopics within a major topic. Students were not required to solve the problems, but were asked to categorize the four problems into pairs, and then describe in detail why they felt those particular problems went together. For the first task, concerning the topic of Kinematics, the problems involved either Kinematics in one dimension or Kinematics in two dimensions. For the second task, Forces and Newton's Laws of Motion, the problems involved ether the equilibrium or nonequilibrium application of Newton's Laws of Motion. For the third task, Work and Energy, the problems involved either work done by a constant force or work done by a varying force. Finally for the fourth task, Impulse and Momentum, the problems involved either collisions in one dimension or collisions in two dimensions. The problems for the tasks came from two undergraduate level physics textbooks (Cutnell & Johnson, 2001; Serway & Faughn, 2003) that were not being used at participating universities. Students' categorizations and explanations were used to determine if students were focusing on surface features of problems or underlying conceptual laws and principles when encountering problems. In order to deal with chance levels of correct responses to the pairings, correct explanations were needed to receive full credit for the correct pairings of problems. Specifically, for each task, students could receive up to three

points: one point for correctly categorizing the tasks, and one point for each correct explanation. Students could receive up to a total of 12 points, where a higher score suggested a focus on and understanding of laws and principles when encountering physics problems.

Of the total 374 physics packets, 100 of the trigonometry-based packets and 100 of the calculus-based packets were analyzed by two coders. Specifically, students' problem solving strategies, problem categorization explanations, and pictorial representations were analyzed by the two coders who compared their analysis to resolve differences in interpretation. There was a 93% interrater agreement for problem solving strategies, 95% interrater agreement for problem categorization explanations, and 93% for pictorial representations. To further check the reliability of scoring, five students (two from the calculus-based course, and three from the trigonometry-based course) were randomly selected and interviewed. The students were asked about the strategies they used and their methods of problem categorization. There was a 98% agreement between the rater and student.

Results

Described first are the results obtained from the trigonometry-based physics course. This is followed by the results obtained from the calculus-based physics course. Finally a comparison of students' motivation, pictorial representation, categorization, strategy use, and achievement between the two courses is presented.

Trigonometry-based Physics

Descriptive Statistics, Mean Comparisons, and Correlations

The *Statistical Program for the Social Sciences*, version 14.0 (SPSS, Inc., 2005), was used to compute descriptive statistics, mean comparisons, and correlations among the variables in the model. Five independent-samples *t*-tests were conducted to determine if there were any

gender differences among the model variables, including motivation, pictorial representation, categorization, strategy use, and achievement. There was a significant difference in the motivation ratings of the males (M = 98.69, SD = 14.77) and females, (M = 91.01, SD = 16.21), t(243) = 3.78, p < .05, with the males having more motivation in physics than the females.

There was no significant difference in the pictorial representation of the males (M = 7.01, SD = 3.42) and the females (M = 6.58, SD = 3.20), t(243) = 1.00, p > .05, or the problem categorization of the males (M = 3.99, SD = 2.99) and the females (M = 3.36, SD = 2.82), t(243) = 1.68, p > .05. There was also no significant difference in the strategy use of the males (M = 2.20, SD = 1.36) and the females (M = 2.12, SD = 1.34), t(243) = .43, p > .05, with both the males and females using the working forward strategy an average of approximately two out of five possible times. Finally, there was no significant difference in the physics achievement of the males (M = 1.73, SD = 1.38) and the females (M = 1.75, SD = 1.42), t(243) = -.12, p > .05, with both the males and the females answering almost an average of two out of five items correctly.

The correlations among the model variables can be seen in Table 1. Although there was not a significant correlation between gender and strategy use (r = .03) and gender and categorization (r = .12), there was a significant correlation between gender and motivation (r =.24), with males being more motivated in physics than females. There was a significant correlation between motivation and strategy use (r = .19); however the correlation between motivation and categorization was not significant (r = .12). There was not a significant correlation between pictorial representation and strategy use (r = .07); however, the correlation between categorization and pictorial representation (r = .14) was significant, indicating that a focus on the deeper aspects of problems leads to more advanced pictorial representations. Further, there were significant and substantial correlations between categorization and strategy use (r = .39) and categorization and achievement (r = .43), indicating that a focus on the deeper aspects of problems leads to more expert strategy use and higher achievement in physics. Finally, strategy use was significantly and highly correlated with achievement (r = .81). Thus the use of the more expert working forward strategy appears to lead to higher achievement.

Model Testing

Structural equation modeling was used to test the model. There were no missing data values. Before empirically testing the model, the data were examined for normality and homoscedasticity. Based on the data plots (histograms of the variables), examination of skewness and kurtosis statistics (see Table 1), and Mardia's coefficient = .93, the data met the assumptions of both univariate and multivariate normality. Based on a DeCarlo macro test, no skewness, kurtosis, or outliers were found, also suggesting normality of the data. *LISREL* Version 8.80 (Jöreskog & Sörbom, 2006a), with a covariance matrix generated by *PRELIS* Version 2.80 (Jöreskog & Sörbom, 2006b), was used to test the model by means of the maximum likelihood method of estimation. This method was used because the data were normally distributed.

The overall fit of the model was very good, as indicated by a number of fit indices, all which are described in detail in the paragraphs below. To evaluate the fit of the model, several fit indices were used, as recommended by Kline (2005) because any given single index evaluates only particular aspects of model fit. First, the chi-square statistic was used. The chi-square is a fit index that addresses the degree to which the variances and covariances implied by the model match the observed variances and covariances. A *non-significant* chi-square indicates that the model is a good representation of the underlying covariance matrix. The chi-square, $\chi^2(5) = 6.18$, p = .29, indicated a good fit because the *p*-value was greater than .05 (i.e., failed to reject the null hypothesis that the observed and estimated covariance matrices are the same). Further, the χ^2/df

ratio was 1.24, suggesting a good fit based on Kline's (1998) rule that values less than three indicate good fit.

The standardized root-mean-square residual (SRMR) is an index based on the residuals between the observed and estimated covariance matrices (Hu & Bentler, 1999). The advantage of the SRMR is that it is sensitive to model misspecification (Hu & Bentler, 1998). A value below .08 indicates a good fit (Hu and Bentler, 1999). The SRMR for this model was .03.

The Steiger-Lind root-mean-square error of approximation (RMSEA) assesses a lack of fit of the population data to the estimated model. It is an index that includes adjustments for model complexity so that evaluation of fit is not overly influenced by the number of parameters in the model (Steiger, 1995). The RMSEA for this model was .03, which was below the cutoff value of .06 suggested by Hu and Bentler (1999).

The incremental fit index (IFI) is a fit index that is sensitive to model misspecification, but not to sample size (Bentler, 1990; Hu & Bentler, 1999; Widaman & Thompson, 2003), making it a valuable indication of fit. The IFI compares the model to a baseline model in which all variables are assumed to be uncorrelated. This is the standard "null" model (independence model) that assumes zero population covariances among the observed variables. The IFI values range from zero to one, with larger values indicating a better fit. A value greater than .95 is considered to be a good fit (Hu & Bentler, 1999). The value for this model was 1.00.

Finally, the adjusted goodness of fit index (AGFI) is a measure of the proportion of the observed covariance that is accounted for by the model. The AGFI is adjusted for degrees of freedom so that evaluation of fit is not overly influenced by the number of parameters in the model. A value greater than .90 is considered to be a good fit (Schumacker & Lomax, 1996). The value for this model was .97.

Path analysis was used to estimate the direct and indirect effects in the model, control for the correlations among the hypothesized causal variables, and "decompose" the observed correlations into their component causal parts. The standardized path values and their associated *t*-values for the model are reported in Table 2; the model with standardized path values can be seen in Figure 3. A cutoff value of t = 1.96 for a two-tailed test was used to determine if direct and indirect paths were statistically significant. In terms of size and influence of the standardized path coefficients, the paths are described using Keith's (1993) suggested criterion in that standardized paths ranging from .05 to .10 are small, but meaningful influences, paths ranging from .10 to .25 are moderate in size and influence, and paths above .25 may be considered large in size and influence. The criterion R^2 (proportion of variance explained) by motivation was .06, by pictorial representation was .02, by categorization was .02, by strategy use was .18, and by achievement was .68.

Decomposition of Effects

Direct paths. The decomposition of effects can be seen in Table 2. Of the 10 direct effects, six were significant. Gender had a significant and moderate influence (.24) on motivation, with males having greater motivation than females in physics. Motivation had a significant and moderate influence (.16) on strategy use. Thus greater motivation leads to the use the more expert working forward strategy. Categorization had a significant and moderate (.14) influence on pictorial representation, indicating that a focus on the more conceptual aspects of the material and problems leads to more complex and expert pictures. However, pictorial representation did not influence strategy use. Categorization had a significant and large influence (.38) on strategy use. Thus a focus on the deeper conceptual aspects of the material and problems leads to the use the more expert working forward strategy; the working forward strategy had a

significant and large (.76) influence on achievement. Finally, categorization had a significant and moderate (.13) influence on achievement, suggesting that a focus on the conceptual aspects of the material and problems leads to higher achievement.

Indirect paths. Indirect paths and associated *t*-values can be seen in Table 2. Gender had a significant influence on strategy use through its influence on motivation and categorization. Further, motivation had a significant influence on achievement through its influence on strategy use and categorization. However, it was the moderate sized path

Motivation→Strategy→Achievement that appeared to contribute to this influence, as the path from Motivation→Categorization→Achievement was negligible in size, and thus played a smaller role in this indirect influence. This suggests that higher motivation leads to the use of the more expert working forward strategy, which leads to higher achievement. This may be because so much focus in physics is placed on correctly setting up and solving problems. Thus students who are motivated likely spend much of their time engaging in problem solving practice that leads to better strategy use. However, the following indirect path indicates that a conceptual understanding of the material is also critical in influencing strategy use and achievement: Categorization had a significant influence on achievement through its influence on strategy use as the path from Categorization→Strategy→Achievement was significant and large in size, suggesting that a focus on the conceptual aspects of the material and problems leads to the use of the more expert working forward strategy, which leads to higher achievement.

Thus in addition to the direct paths indicating the importance of motivation and categorization on strategy use and achievement, the indirect paths Motivation→Strategy→Achievement and Categorization→Strategy→Achievement were found to be critical. These two paths indicate that efforts to improve motivation and conceptual understanding would be useful in improving strategy use and achievement.

Alternative Models

Because the bulk of the research attempting to explain gender differences in science achievement focuses on motivation, an alternative model in which gender differences in strategy use and conceptual understanding are the result of motivation was tested. Thus the paths from Gender->Strategy and Gender->Categorization were removed. Results indicated a good model fit as indicated by $\chi^2(7) = 8.52$, p = .29, χ^2 /df ratio was 1.22, the SRMR was .04, the RMSEA was .03, the IFI was .99, and the AGFI was .97. The direct and indirect path values stayed the same as far as size and significance. A chi-square difference test between the two models was conducted to see if there was a significant difference between the two models. The chi-square difference test was $\chi^2(2) = 2.34$. The critical value of a chi-square distribution with two degrees of freedom at p = .05 is 5.99. Because 2.34 is less than 5.99, it is concluded that there is not a significant difference between the two models. Removing the two paths did not make a difference in the fit of the model because the direct path values were small and not significant.

The second alternate model assumes that a focus on conceptual knowledge leads to increased achievement only indirectly through improved strategy use. This is because physics instruction and assignments are centered on students' use of correct strategies to set up and solve problems. Thus the direct path from Categorization \rightarrow Achievement was removed from the model. Results indicated an adequate model fit as indicated by $\chi^2(6) = 16.78$, p = .01, χ^2/df ratio was 2.80, the SRMR was .04, the RMSEA was .08, the IFI was .96, and the AGFI was .92. The direct and indirect path values stayed the same as far as size and significance. A chi-square difference test between the two models was conducted to see if there was a significant difference

between the two models. The chi-square difference test was $\chi^2(1) = 10.60$. The critical value of a chi-square distribution with one degree of freedom at p = .05 is 3.84. Because 10.60 is greater than 3.84, it is concluded that there is a significant difference between the two models, and that the model with the path Categorization \rightarrow Achievement is a better fit model. Thus is appears that a good conceptual understanding influences achievement beyond what is accounted for by strategy use. However, the paths from Categorization \rightarrow Strategy (.38) and Categorization \rightarrow Achievement (.29) are both larger than the direct path from Categorization \rightarrow Achievement (.13), emphasizing the importance of the role of a good conceptual understanding on strategy use, and in turn, achievement.

Calculus-based Physics

Descriptive Statistics, Mean Comparisons, and Correlations

The *Statistical Program for the Social Sciences*, version 14.0 (SPSS, Inc., 2005), was used to compute descriptive statistics, mean comparisons, and correlations among the variables in the model. Five independent-samples t-tests were conducted to determine if there were any gender differences among the model variables, including motivation, pictorial representation, categorization, strategy use, and achievement. There was a significant difference in the motivation ratings of the males (M = 104.85, SD = 15.27) and the females (M = 92.86, SD = 17.43), t(127) = 4.03, p < .05, with the males having more motivation in physics than the females.

There was no significant difference in the pictorial representation of the males (M = 8.40, SD = 2.87) and the females (M = 8.84, SD = 2.52), t(127) = -.86, p > .05, or the problem categorization of the males (M = 3.69, SD = 2.70) and the females (M = 4.02, SD = 2.90), t(127) = -.64, p > .05. There was, however, a significant difference in the strategy use of the males (M = 4.02, SD = 2.90), t(127) = -.64, p > .05. There was, however, a significant difference in the strategy use of the males (M = 4.02, SD = 2.90), t(127) = -.64, p > .05.

3.22, SD = 1.34) and the females (M = 2.55, SD = 1.23), t(127) = 2.80, p < .05, with the males using the working forward strategy almost 20% more than the females. Finally, there was a significant difference between the physics achievement of the males (M = 2.68, SD = 1.45) and the females (M = 1.95, SD = 1.22), t(127) = 2.85, p < .05, with the males answering almost one more item correctly.

The correlations among the model variables can be seen in Table 3. Although there was a significant correlation between gender and strategy use (r = .24) and gender and motivation (r = .34), the small correlation between gender and categorization (r = .06) was not significant. There was a significant and large correlation between motivation and strategy use (r = .55), and a smaller, but still significant correlation between motivation and categorization (r = .18). This indicates that higher motivation results in behaviors that lead to better conceptual understanding and strategy use. There was not a significant correlation between categorization between pictorial representation and strategy use (r = .08) or between categorization and pictorial representation (r = .01). There were significant and substantial correlations between categorization and strategy use (r = .31) and categorization and achievement (r = .37), indicating that a focus on the conceptual aspects of the material and problems leads to more expert strategy use and higher achievement (r = .78). Thus the use of the more expert working forward strategy leads to higher achievement.

Model Testing

Structural equation modeling was used to test the model. There were no missing data values. Before empirically testing the model, the data were examined for normality and homoscedasticity. Based on the data plots (histograms of the variables), examination of skewness and kurtosis statistics (see Table 3), and Mardia's coefficient = .96, the data met the assumptions

of both univariate and multivariate normality. Based on a DeCarlo macro test, no skewness, kurtosis, or outliers were found, also suggesting normality of the data. *LISREL* Version 8.80 (Jöreskog & Sörbom, 2006a), with a covariance matrix generated by *PRELIS* Version 2.80 (Jöreskog & Sörbom, 2006b), was used to test the model by means of the maximum likelihood method of estimation. This method was used because the data were normally distributed.

The model resulted in a very good fit model as indicated by $\chi^2(5) = 4.82$, p = .44, χ^2/df ratio was .96, the SRMR was .03, the RMSEA was .00, the IFI was 1.00, and the AGFI was .95. Figure 4 includes the model with standardized path values. The standardized path values and their associated *t*-values for the model are reported in Table 4. A cutoff value of t = 1.96 for a two-tailed test was used to determine if direct and indirect paths were statistically significant. The paths are described using Keith's suggested criterion as previously explained. The criterion R^2 (proportion of variance explained) by motivation was .11, by pictorial representation was .00, by categorization was .05, by strategy use was .36, and by achievement was .63.

Decomposition of Effects

Direct paths. The decomposition of effects can be seen in Table 4. Of the 10 direct paths, seven were significant. Gender had a significant and large influence on motivation (.34), suggesting that males are more motivated to learn physics than females. Further, gender had a significant and moderate influence (.10) on strategy use. Thus males are more likely to use the more expert working forward strategy. Student motivation had a significant and large influence (.47) on strategy use. Thus higher motivation leads to greater use of the more expert working forward strategy. The influence of motivation on categorization was significant and moderate (.22), indicating that higher motivation leads students to focus on the deeper aspects of the material and problems. Categorization had a significant and moderate influence (.24) on strategy

use, and achievement (.13). Thus a focus on the deeper aspects of the material and problems leads to the use of the more expert working forward strategy and leads to higher achievement; the working forward strategy also had a significant and large (.74) influence on physics achievement. Pictorial representation did not play a role in the model.

Indirect paths. Indirect paths and associated *t*-values can be seen in Table 4. Gender had a significant influence on strategy use through its influence on motivation and categorization. However, because the path from Gender \rightarrow Categorization \rightarrow Strategy was negligible in size, it appears that the moderate sized path from Gender \rightarrow Motivation \rightarrow Strategy played a larger role in this influence, indicating that males have higher motivation, and this higher motivation supports more expert strategy use. Gender also had significant influence on categorization through its influence on motivation. Gender had a significant influence on achievement through its influence on strategy use and categorization, but it was the path Gender \rightarrow Strategy \rightarrow Achievement that contributed to this effect, as the path from Gender \rightarrow Categorization \rightarrow Achievement was negligible in size.

The path from motivation to strategy use as mediated by categorization approached significance (t = 1.93), indicating that high motivation leads to a focus on the more conceptual aspects of problems, which in turn, leads to the use of the more expert working forward strategy. Motivation had a significant influence on achievement through its influence on strategy use and categorization. However, it was the large sized path Motivation \rightarrow Strategy \rightarrow Achievement that appeared to contribute to this influence, as the path from

Motivation \rightarrow Categorization \rightarrow Achievement was negligible in size. This suggests that higher motivation leads to the use of the more expert working forward strategy, which leads to higher achievement. This may be because so much focus in physics is placed on correctly setting up and

solving problems. Thus students who are motivated likely spend most of their time engaging in problem solving practice that leads to better strategy use. However, the following indirect path indicates that a conceptual understanding of the material is also critical in influencing strategy use and achievement. The path from categorization to achievement as mediated by strategy use was significant, suggesting that a focus on the conceptual aspects of the material and problems leads to the use of the more expert working forward strategy, which leads to higher achievement.

Thus in addition to the direct paths, the indirect paths suggest that working to improve motivation and conceptual understanding will be useful in improving strategy use and achievement. Gender played a larger role for the calculus-based students, as seen in both the direct and indirect effects.

Alternative Models

The alternative model in which gender differences in strategy use and achievement are the result of motivation was tested. Thus the paths from Gender->Strategy and Gender->Categorization were removed. Results indicated a good model fit as indicated by $\chi^2(7)$ = 8.59, p = .28, χ^2 /df ratio was 1.23, the SRMR was .04, the RMSEA was .04, the IFI was .99, and the AGFI was .94. The direct and indirect path values stayed the same as far as size and significance. A chi-square difference test between the two models was conducted to see if there was a significant difference between the two models. The chi-square difference test was $\chi^2(2) =$ 3.77. The critical value of a chi-square distribution with two degrees of freedom at p = .05 is 5.99. Because 3.77 is less than 5.99, it is concluded that there is not a significant difference between the two models. Removing the two paths did not make a difference in the fit of the model. This suggests that motivation is the key variable in influencing any gender differences in expert performance. Another possible model is that, in physics, a focus on the conceptual aspects of the material and problems leads to increased achievement only indirectly through improved strategy use. Thus the direct path from Categorization \rightarrow Achievement was removed from the model. Results indicated a good model fit as indicated by $\chi^2(6) = 10.17$, p = .12, χ^2/df ratio was 1.70, the SRMR was .03, the RMSEA was .07, the IFI was .98, and the AGFI was .91. The direct and indirect path values stayed the same as far as size and significance. A chi-square difference test between the two models was conducted to see if there was a significant difference between the two models. The chi-square difference test was $\chi^2(1) = 5.35$. The critical value of a chi-square distribution with one degree of freedom at p = .05 is 3.84. Because 5.35 is greater than 3.84, it is concluded that there is a significant difference between the two models. The model with the path from Categorization \rightarrow Achievement (.18) are both larger than the direct path from Categorization \rightarrow Achievement (.13), emphasizing the importance of the role of a good conceptual understanding on strategy use, and in turn, achievement.

Comparison of Trigonometry-Based Physics and Calculus-Based Physics

In order to determine if there were differences in the variables that influence expertise in physics between the two courses, five independent-samples t-tests were conducted. Results indicated that there was a significant difference in the motivation of the trigonometry-based physics students (M = 94.14, SD = 16.06) and calculus-based students (M = 100.76, SD = 16.96), t(372) = 3.72, p < .05, with the calculus-based students having significantly more motivation than the trigonometry-based students.

There was not a significant difference in the problem categorization of the trigonometrybased students (M = 3.62, SD = 2.90) and the calculus-based students (M = 3.81, SD = 2.76), t(372) = .61, p > .05. There was, however, a significant difference in the quality of the pictorial representations of the trigonometry-based students (M = 6.76, SD = 3.30) and the calculus-based students (M = 8.55, SD = 2.76), t(372) = 5.29, p < .05, with the calculus-based students drawing more complex pictorial representations. There was also a significant difference in the strategy use of the trigonometry-based students (M = 2.16, SD = 1.35) and the calculus-based students (M = 2.99, SD = 1.34), t(372) = 5.73, p < .05, with the calculus-based students using the working forward strategy almost 20% more than trigonometry-based students. Finally, there was a significant difference in the physics achievement of the trigonometry-based students (M = 1.74, SD = 1.40) and the calculus-based students (M = 2.43, SD = 1.41), t(372) = 4.52, p < .05, with the calculus-based students (M = 2.43, SD = 1.41), t(372) = 4.52, p < .05, with the calculus-based students (M = 2.43, SD = 1.41), t(372) = 4.52, p < .05, with the calculus-based students (M = 1.74, SD = 1.40) and the calculus-based students (M = 2.43, SD = 1.41), t(372) = 4.52, p < .05, with the calculus-based students answering almost one more item correctly.

Discussion

The purpose of this study was to develop and test a theoretical model of expertise in physics across two levels of expertise. Results indicated that the model did a good job explaining the relationship among the variables for both levels of students. For both groups, motivation had a significant influence on students' strategy use (and categorization for the calculus-based model). This motivation was greater among males than females. Categorization had a significant influence on strategy use and achievement. Strategy use had a significant influence on achievement, and the males in the calculus-based course were more likely than the females to use the working forward strategy. Pictorial representation played basically no role in the model across the two levels of expertise. For both courses, results indicated important indirect paths. Motivation had a significant impact on achievement as mediated by strategy use and categorization had a significant influence on achievement as mediated by strategy use.

Implications of these findings for physics instruction indicate that much more focus needs to be placed on the conceptual aspects of physics material and problems, as well as the motivation that leads to conceptual understanding and expert strategy use. Further, efforts to teach the working forward strategy would be useful in improving achievement, but the ability to do so is likely linked to a good conceptual understanding. Results also indicate that less focus should be placed on pictorial representations of problems.

The current findings are in line with previous research pointing to the value of instruction for conceptual understanding in improving problem solving and achievement (Mestre et al., 1993; Zajchowski and Martin, 1993). In practice, however, most physics problems assigned for homework, administered on assessments, and presented in class in both high school and college level physics courses focus on students performing computations to solve for a single unknown quantity, and almost no focus is placed on the underlying concepts (Briscoe & Prayaga, 2004; Kang & Wallace, 2005). This focus on problems that can be solved through the rote application of computations often causes students to conclude that conceptual understanding is unnecessary in physics (Neto & Valente, 2005). Instruction needs to change and much more attention needs to be placed on the conceptual aspects of the material and problems in physics.

Efforts to make students aware of the working forward and working backward strategies, the differences between the two strategies, and also to teach the working forward strategy may be useful in improving achievement. In this study, students who used the working forward strategy tended to answer the problems correctly, while students who used to working backward strategy usually found themselves in a dead-end with an incorrect answer. However, the working-forward strategy appears to be linked to conceptual knowledge. One student in the calculus-based course, when interviewed, stated that she used the working backward strategy "when I'm not sure how to solve the problem or when I don't know what I'm doing. I know the chapter used this type of equation, so I figure I will try to use this one because it has the variable I need to solve for to see if it works and gets me the answer." Thus students cannot be directly taught to use the working forward strategy unless they have some understanding of how to solve the problem and the direction they are going in their strategy use. Thus focus should be on conceptual knowledge, and the link between this knowledge and strategy use.

The results of this study indicate that efforts made to increase student motivation are critical in improving strategy use, conceptual understanding, and ultimately achievement. The indirect path Motivation -> Strategy -> Achievement was particularly important across both levels of expertise. The results of this study indicate that gender differences are linked to student motivation. For the calculus-based course, although gender differences were found in strategy use and achievement, there were not differences in ability to categorize problems. Motivation appeared to be the key variable in influencing differences in strategy use and, in turn, achievement. This was also evident in the alternative model in which the paths from gender to strategy use and gender to categorization were removed and the model with only the path from gender to motivation was tested. Removing the two paths made no difference in the fit of the model, indicating that motivation was the critical variable in leading to differences in expert performance. Thus in addition to working on improving students' conceptual knowledge, and allowing them to see the importance of this knowledge on strategy use and achievement, efforts should also be made to increase student motivation, particularly for females. Glynn, Taasoobshirazi and Brickman (in press) found that making science more relevant to students increases their motivation, and recommends the use of case studies that make science more relevant to students' interests, majors, and future career goals. This would be particularly

beneficial for females as females, more than males, feel that feel that physics is irrelevant to them and to their future goals (Murphy & Whitelegg, 2006).

Pictorial representation did not play a significant role in either of the models. This is surprising and informative because in both high school and college physics classrooms, there is a great deal of emphasis placed on pictorial representations. Textbooks include figures to go along with sample problems and continuously encourage students to draw free-body diagrams to represent the problems they are solving (e.g. Serway & Faughn, 2002; Serway & Faughn, 2003). Furthermore, high school and college instructors encourage their physics students to pictorially represent the problems they are solving and even do so in their own class examples (Heil, personal communication, October 30, 2006; Snow, personal communication, October 21, 2005). Such a practice may be misguided. Pictorial representation played no role in the calculus-based course model, and although categorization did have a moderate influence on pictorial representation in the trigonometry-based model, pictorial representation did not influence strategy use. Time would be better spent encouraging students to develop conceptual understanding to improve their strategy use and achievement.

Limitations and Future Research

Although not described in the expertise literature in physics, effective metacognition is considered important for efficient problem solving and for the transition from novice to expert (Tobias & Everson, 2000). Because of the large sample size, metacognition was not studied, but future research should examine students' think-alouds as they solve physics problems and categorization tasks in order to understand the role of metacognition on students' problem solving strategies and categorizations. Future research should also include two additional courses including a higher level mechanics course for physics majors and a physics course for nonscience majors. This would allow the opportunity to examine differences in the relationship among the variables that categorize expertise, as well as the role gender plays on expert performance across different levels of expertise.

From both sections of the course, some of the students who participated in the study were from minority groups, including Asian/Pacific Islander, African American, or Hispanic or Latino. However, because the percentages in each group and overall were so small, minority status was not treated as a variable to avoid misleading statistical inferences. A larger sample size may provide the opportunity to study minority students, helping to explain the differences in achievement and participation that exist among minority students in physics (NSF, 2004).

Results of this study have important implications for instruction in these level physics courses. Given the decline in participation by all students in physics (Murphy & Whitelegg, 2006), we need to be doing a better job teaching physics. The results of the current study provide an understanding of the relationship between the variables characterizing expertise in physics, and help indicate which are most critical for expert performance. Physics instructors need to spend much more time focusing students on the conceptual aspects of the material they are learning, and to help foster the motivation that leads to conceptual understanding and expert strategy use. Instructors should also show students the difference between the working forward and working backward strategies, the connection between the two strategies and conceptual understanding, and encourage students to work forward when solving problems. The significant time and energy placed on pictorial representations of problems would be better spent working to improve students' conceptual understanding, motivation, and strategy use.
Correlation Matrix, Means, Standard Deviations, Skewness, and Kurtosis for the Trigonometry-

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Variable	1	2	3	4	5	6
1. Gender						
2. Motivation	.24**					
3. Categorization	.12	.12				
4. Pictorial	.06	.13*	.14*			
5. Strategy	.03	.19**	.39**	.07		
6. Achievement	.00	.18**	.43**	.04	.81**	
М		94.14	3.62	6.76	2.16	1.74
SD		16.06	2.90	3.29	1.35	1.40
Skewness		23	.71	39	.14	.48
Kurtosis		.64	47	56	86	71

* p < .05. ** p< .01

Decomposition of Effects in the Model for Trigonometry-Based Physics Students

		Effect				
Predictor		Direc	ct	Indir	ect	
	Criterion	PC	t	PC	t	
Gender	Motivation	.24	3.78			
	Strategy	.05	.43	.08	2.52	
	Pictorial			.01	1.34	
	Categorization	.08	1.68	.02	1.41	
	Achievement			.04	.66	
Motivation	Strategy	.16	3.00	.04	1.47	
	Pictorial			.01	1.25	
	Categorization	.10	1.51			
	Achievement			.16	3.00	
Categorization	Strategy	.38	6.44	.00	.06	
	Pictorial	.14	2.22			
	Achievement	.13	7.25	.29	6.11	
Strategy	Achievement	.76	19.30			
Pictorial	Strategy	.00	.06			
	Achievement			.00	.06	

Note. PC refers to standardized path coefficient. A cutoff value of t = 1.96 for a two-tailed test was used to determine if paths were statistically significant. In terms of the relative size and influence of the standardized path coefficients: paths ranging from .05 to .15 were considered small, but meaningful influences. Paths ranging from .10 to .25 are moderate in size and influence, and paths above .25 may be considered large in size and influence (Keith, 1993).

Correlation Matrix, Means, Standard Deviations, Skewness, and Kurtosis for the Calculus-Based

Phy	vsics	Cou	rse
~			

Variable	1	2	3	4	5	6
1. Gender						
2. Motivation	.34**					
3. Categorization	06	.18*				
4. Pictorial	08	.06	.01			
5. Strategy	.24**	.55**	.31**	.08		
6. Achievement	.25**	.46**	.37**	.00	.78**	
М		100.76	3.81	8.26	2.99	2.43
SD		16.96	2.76	2.73	1.34	1.41
Skewness		26	.77	52	30	03
Kurtosis		.04	.14	.37	65	79

p < .05. ** p< .01

Decomposition of Effects in the Model for Calculus-Based Physics Students

			Effect				
		Direc	rt	Indir	Indirect		
Predictor	Criterion	PC	t	PC	t		
Gender	Motivation	.34	4.02				
	Strategy	.10	2.88	.15	2.63		
	Pictorial			.00	16		
	Categorization	13	63	.07	2.06		
	Achievement			.18	2.50		
Motivation	Strategy	.47	6.72	.05	1.93		
	Pictorial			.00	.16		
	Categorization	.22	2.40				
	Achievement			.42	6.10		
Categorization	Strategy	.24	3.26	.00	.16		
	Pictorial	.01	.16				
	Achievement	.13	4.03	.18	3.16		
Strategy	Achievement	.74	12.99				
Pictorial	Strategy	.06	.87				
	Achievement			.04	.87		

Note. PC refers to standardized path coefficient. A cutoff value of t = 1.96 for a two-tailed test was used to determine if paths were statistically significant. In terms of the relative size and influence of the standardized path coefficients: paths ranging from .05 to .15 were considered small, but meaningful influences. Paths ranging from .10 to .25 are moderate in size and influence, and paths above .25 may be considered large in size and influence (Keith, 1993).



Figure 2: Theoretical model of expertise in college physics.



Figure 3: Model for trigonometry-based physics students, with standardized path values. Significant values are marked *.



Figure 4: Model for calculus-based physics students, with standardized path values. Significant paths are marked *.

CHAPTER 3

A REVIEW AND CRITIQUE OF CONTEXT-BASED PHYSICS

Context-Based Physics

Two main goals of physics instruction are to help students achieve a deep conceptual understanding of the subject and to help them develop powerful problem-solving skills (Mestre, Dufresne, Gerace, Hardiman, & Touger, 1993). Traditional physics instruction frequently results in a failure to achieve either goal (Anzai, 1991; McDermott, 1991). Research has shown that traditional physics instruction leaves most students confused about the basic concepts of mechanics (Viennot, 1979), optics, thermodynamics, electricity, and magnetism (McDermott, 1991), and appears to lead to the use of poor problem solving strategies (Larkin, McDermott, Simon, & Simon, 1980a). In response, a great deal of research has focused on the use of new instructional practices in physics, many which appear to have a positive influence on student problem solving and achievement (e.g. Redish, 2003; Zajchowski & Martin, 1993). This paper describes one of these innovative instructional approaches, called context-based physics, which involves placing physics material within a real-life context in an effort to improve student motivation, problem solving, and achievement.

This paper first describes the concerns with traditional physics instruction that resulted in the shift away from traditional teaching methods. This is followed by an in-depth description of context-based physics and the materials designed to support this instructional method. Then the existing research on context-based physics is reviewed and critiqued, and recommendations for future research using this instructional method are provided.

The Transition from Traditional Physics Classrooms

In a typical or traditional high school or college physics class, the instructor presents the material, calculates example problems on the board, and occasionally performs lab demonstrations (Briscoe & Prayaga, 2004; Kang & Wallace, 2005). Students listen to the lecture, take notes, but rarely ask questions or make comments. In best-case circumstances, students perform physics experiments in which they follow strict directions to confirm already known results (Kang & Wallace, 2005). This teacher-centered type of instruction usually involves very little active learning, and often causes students to become bored and disengaged (Lord, 1997; McCarthy & Anderson, 2000).

In traditional physics classrooms, the most typical problems given to students in class and on homework assignments and tests are problems that require students to calculate a precise quantitative solution (Briscoe & Prayaga, 2004; Neto & Valente, 2005). When solving these problems, students tend to focus on finding the right equations, manipulating them, and calculating an answer (Larkin, 1983; Redish, Saul, & Steinberg, 1998). This focus on equations and calculations often results in students failing to understand the deeper conceptual relationships present in the problems (Anzai, 1991), which encourages poor problem solving strategies (e.g. Larkin, McDermott, Simon, & Simon, 1980b).

To make matters worse, physics instructors present and assign these problems expecting that students understand the underlying conceptual relationships involved in the calculations (Taconis, Ferguson-Hessler, & Broekkamp, 2001). During a typical lesson, an instructor will present practice problems by going through extensive and step-by-step problem solving on the board, expecting the students to see the conceptual relationships in each equation. However, the combination of the format of the problems and instruction that focuses on procedures results in students believing that physics is centered around memorization and computation (Whitelegg & Edwards, 2001), again contributing to their poor problem solving strategies and understanding of material (Leonard, Dufresne, & Mestre, 1996).

One major study that helped bring to light some of the problems with traditional physics instruction, and encouraged the use of more effective teaching methods, was conducted by Richard Hake. Hake (1998) administered the Force Concept Inventory (FCI) test to 6,542 high school and college physics students. The FCI is a multiple-choice test that examines students' ability to apply the concepts of Newtonian physics to everyday situations. The test uses non-technical language to describe the situations, and uses distracters that specifically address common misconceptions about mechanics. Results of the study indicated that before physics instruction, students held naive beliefs that were incompatible with Newtonian physics in most respects. It was also found that traditional physics instruction resulted in only small changes in these beliefs. However, Hake found that instruction that involved more interactive activities, including more hands-on and discussion-based activities, resulted in much greater changes in student beliefs.

As a result of such studies, there has been much focus on improving physics instruction in order to improve student understanding and achievement. One popular attempt includes curriculum for introductory high school and college physics classes that encourages students to conceptually analyze problems prior to solving them (e.g. Dufresne, Gerace, Hardiman, & Mestre, 1992; Leonard et al., 1996; Zajchowski & Martin, 1993). The purpose of this approach is to move students away from just forming and manipulating equations, and toward understanding the principles and laws underlying the problems they are solving. Results of these studies indicate that the students who perform conceptual analysis of problems before solving them have greater understanding, higher achievement, and use better problem solving strategies in comparison to students who do not conceptually analyze the problems they are solving.

Another major effort to improve physics instruction includes engaging students in group discussion over the material they are learning. Engaging students in discourse has been found to improve their comprehension of the material (Redish, 2003). Further, engagement in discourse has been found to support self-regulation (Meyer & Turner, 2002) such that as students hear diverse ideas, they are able to reflect on their own ideas and the ideas of others, which can help them tackle misconceptions and develop better understandings. Through discussion, students are also able to become familiar with the way that scientific language is used (Lemke, 1990), allowing their discourse to become more like that of practicing scientists. In physics classrooms, engaging students in scientific discourse results in higher learning gains than traditional physics instruction on relevant material (e.g. Redish, 2003).

Group discussion is often used alongside inquiry-based learning, which has been described as a "pedagogical method combining intellectual questioning with student-centered discussion and discovery of pivotal concepts through laboratory activities" (National Research Council, 1996, p.1). This too has been found to be successful in improving student understanding and achievement when compared to traditional physics instruction (Thacker, Kim, & Trefz, 1994).

Although these efforts to improve physics instruction have been successful, many researchers feel that the context in such approaches remain implicit (Finkelstein, 2001). For instance, although students may become more reflective, active, and involved in what they are learning, they may still not have an understanding of how they can apply their newly learned

skills and knowledge outside the classroom. In response, many researchers suggest moving a step further by contextualizing the physics students are learning.

Context-Based Physics Instruction

A contextual approach to physics emerged in response to students' perception that physics is impersonal, objective, and irrelevant to everyday life (Lye, Fry, & Hart, 2001; Traweek, 1998), and that the material and problems in physics are something to either memorize or compute (Whitelegg & Edwards, 2001). Context-based instruction "emphasizes using concepts and process skills in real-world contexts that are relevant to students from diverse backgrounds" (Glynn & Koballa, 2005, p. 75). Students learn a subject by tying it to a real-world context in a way that allows them to make connections between the subject and its applications to their lives as citizens, family members, and students (Yam, 2005).

It is expected that integrating context into a subject allows students to see the relevance of what they are learning. When studying a subject, it is common for students to think or ask "Why do I have to know this?" or "Will I ever use this again?" With a contextual approach to instruction, the answers to these questions become apparent, as students begin to understand how and why they will use their new skills and knowledge. This is found to help students become more motivated in their learning (Kaschalk, 2002; Rayner, 2005). Finally, because integrating context into the lesson often involves the presentation of real and controversial issues (Shiu-sing, 2005), students have the opportunity to become more socially and environmentally aware.

A Context-Based Physics Classroom

In order to better describe context-based instruction and its role in physics, a high school classroom in Georgia using this instructional approach is described. The classroom was made up of 17 students, including nine males and eight females. Described are observations from the

classroom on a day in which the students were completing a lab to build their understanding of projectile motion. The students worked on the lab in self-selected groups, and were expected to use a launcher that was previously set up for them by the instructor to determine where a plastic ball inside the launcher would land. This lab was a practice lab preparing the students for the main lab, which was called Water Balloon Day, in which students would go to their school football stadium, and in groups, use a launcher to try to hit their instructor with water balloons. Students were spending time before the main lab practicing how to measure the required distances and angles so that on the actual lab day, they would be able to shoot out water balloons from the launcher with the accuracy needed to hit their instructor. Rather than just conducting a hands-on and collaborative learning activity where students had to measure where a ball flying out of a launcher would land, this teacher contextualized the material so that the lab was meaningful to the students because it was preparing them for the opportunity to hit their own teacher with water balloons.

This use of context in physics instruction is also seen in the amusement park field trip in which many physics departments across the United States participate (e.g. Michael, 2005). On this field trip, students enjoy the rides, but at the same time complete an assignment in which they examine aspects of the rides in relation to the mechanics content they are learning. Through such a field trip, students are provided with the opportunity to see the theories and principles they are learning become real.

Selecting a Context

It is often difficult for teachers to find resources that can provide contextualized physics material and problems, or help them design their own. In more recent years, a few textbooks have been designed to help support context-based physics instruction. Crawford et al.'s (2001)

Physics in Context is one example of a textbook that integrates context into the physics material and allows students to explore the physics content in light of real-life situations. The Supported Learning in Physics Project (SLIPP) (Whitelegg & Edwards, 2001) has designed a set of eight books that helps teachers contextualize physics. For instance, in one of the textbooks, *Physics for Sport,* equilibrium of forces is taught through the consideration of the way rock climbers use hand and foot holds at various angles on a climbing wall. Unlike traditional textbooks which teach the concepts and then use real-life examples to help students better understand the material, the physics concepts in these texts are embedded within the contexts.

Researchers have also provided useful guidelines for how to design context-based materials and problems in physics. Researchers point out that the actual context used is critical. For instance, it has been suggested that the context should be realistic, interesting, and familiar to students (Yam, 2005). Although the context should be relevant, if the context is too emotionally pertinent, students may become too focused on the context, and fail to think about the underlying physics content (Shui-sing, 2005). Highly interesting, but tangential information presented in text suppresses learning by priming inappropriate prior knowledge (Harp & Mayer, 1998). Further, inappropriate use of contexts, or contexts that are overly complicated can confuse students. For instance, some material may be better understood using a real-life context, while other information may be better understood using the traditional context (Gomez, Pozo, & Sanz, 1995).

When specifically designing context-based problems, it has been suggested that the problems use the pronoun "you" to make them more relevant to students, provide a context in which students will be motivated to find the answer, include more information than is required to solve the problem, require students to make assumptions about the relations in the problem, and

be set up in a way where the unknown variable is not explicitly specified (Heller & Hollabaugh, 1992). The purpose of these suggestions is to keep students interested and to have them approach the problems focusing on the conceptual aspects. Benckert (1997) helps illustrate the difference between a context-based and traditional physics problem (see Figure 5). One can see that compared to traditional problems, context-based problems are personalized and solved within a real-life context, require more reading, thinking, and analysis, and tend to take longer to solve than traditional textbook problems.

Review of the Research on Context-Based Physics

There are two types of research on context-based physics. The first type compares context-based assessment versus traditional assessment in classrooms using only traditional teaching methods. The instruction in these studies is not context-based. The context-based assessments in these studies use traditional textbook problems redesigned to integrate various real-life contexts. The second type of research examines students' performance in classrooms that have implemented both context-based instruction and assessment. Described first is the research comparing context-based physics assessment to traditional assessment in traditional physics classrooms. This is followed by a description of the research on context-based physics instruction and assessment.

Context-Based Physics Assessment

There are three studies that have examined students' motivation, problem solving, and achievement using context-based assessment versus traditional assessment in classrooms using only traditional teaching methods. Rennie and Parker (1996) investigated the effect of integrating context into physics by examining the achievement of eight high school physics students from five different schools. The students were assessed using two sets of matched force and motion problems, where the first set included physics problems embedded in a real-life context and the second set included problems that were typical abstract textbook problems. The small sample size precluded use of statistical analyses, but it was found that students scored higher on the context-based problems in comparison to the traditional textbook problems. Interviews with the students indicated that the students found the context-based problems to be more interesting than the traditional problems.

Park and Lee (2004) used a substantially larger sample size of 93 high school students receiving traditional physics instruction. They asked the students to think aloud as they solved four sets of context-based and traditional physics problems. They found that the students performed equally on the contextualized and traditional problems for two of the sets, performed significantly better on the contextualized problems for one set, and performed significantly better on the traditional problems for another set. Students' responses on a questionnaire indicated that the students preferred the context-based problems to the traditional problems.

Heller and Hollabaugh (1992) observed 400 students from two traditional college level physics classrooms working in small groups on either context-based problems or traditional problems, and analyzed the students' work and discourse. They found that the work and discourse of the students solving the traditional problems was centered around what formulas should be used to solve the problems, while the work and discourse of the students solving the context-based problems was centered around what principles and laws should be used to solve the problems. This is in line with previous research (e.g. Larkin et al., 1980a) indicating that traditional textbook problems appear to encourage students to focus on forming and manipulating equations rather than considering the conceptual knowledge needed to solve the problems, leading to poor problem solving. This indicates that even when students are taught

using traditional methods, contextual problems support more effective problem solving. Unfortunately, achievement was not assessed in this study to determine whether context-based assessment resulted in higher achievement in comparison to traditional assessment.

Taken together, the data on context-based assessment provides little support for the claim that it improves achievement. However, the dearth of research also means that there is little evidence that context-based assessment does not work to improve achievement. Only one of the two studies examining achievement (Park & Lee, 2004) had a sufficiently large sample size to perform statistical analyses, and the results were inconsistent. The work by Heller and Hollabaugh (1992) hints at the possibility of higher achievement in the form of better problem solving. More research needs to be done in this area before recommendations should be made to educators about the usefulness of context-based assessment.

Context-Based Physics Instruction

There are few studies examining students' motivation, problem solving, and achievement in classrooms implementing context-based physics instruction and assessment. No research has examined whether context-based instruction produces higher achievement in comparison to traditional instruction. The research that has been done indicates that students are more motivated when context-based instruction is used and that they are more likely to use more effective problem solving.

Kaschalk (2002), a high school physics teacher who wanted to implement context-based physics in his classroom, first spent 10 weeks of his summer interning at a power/voltage test facility to learn how he could tie the context of the facility into the material and standards that would need to be covered in his class. When school started, he took his students to the plant site so that they could meet the lab technicians and the lab manager, and learn about how voltage was measured and used in a job setting. Students were then asked to help the lab by designing a voltage divider sensor circuit that would be capable of sampling voltages as high as 10kV. The teacher, when observing his class working on the voltage divider circuit, noted that student participation and motivation was the highest he had seen in any of his physics classes. However, it was not determined whether this experience resulted in better student understanding of the relevant standards in comparison to traditional instruction.

Rayner (2005), a physics instructor for college students majoring in physiotherapy, redesigned her lectures and assessments to integrate the context of physiotherapy into the physics content, and replaced individual assignments with group work to encourage discussion of the material. Her goal was to help students develop an understanding of physics, while at the same time, consider the relationship between physics and their profession. The activities and assessments students completed required them to use physics to analyze physiotherapy situations. In doing so, the students were expected to demonstrate an understanding of physics, as well as how the physics concepts could be used to explain a treatment. Based on student responses on questionnaires administered throughout the duration of the course, Rayner found that integrating the physiotherapy context into the physics material was useful in improving the motivation of her students. Of greater significance, responses on the questionnaires indicated that the students began to move away from using memorization to learn the material and solve the problems, and toward forming a deep understanding of the physics material and problems. The professor stated that the students tended to achieve at an 80% average or above on the assessments administered, but no pretest measure was administered to provide information on increase in learning, and the design of the study did not involve a comparison to a traditional

instruction group, making it impossible to determine whether the instruction resulted in better learning than traditional physics instruction.

Benckert (1997) implemented both context-based physics and collaborative group work in five introductory-level university physics classrooms by replacing 50% of the traditional lecture sessions with collaborative group work and context-based instruction and assessments. The contexts in this study included many different everyday situations that were integrated into the physics material. Benckert administered questionnaires to the implementation students, as well as to students in traditional physics classrooms. She found that the students participating in the implementation had a more positive attitude, and were more motivated than students receiving traditional physics instruction. Furthermore, in comparison to students receiving traditional instruction, fewer of the students in the implementation classrooms stated on the questionnaires that solving physics problems meant finding and manipulating equations. Test performance was not provided for the implementation or comparison classrooms.

Cooper, Yeo, and Zadnik (2003) studied 78 high school physics students in three schools studying nuclear technology using context-based instruction and assessment. They found that the students had large gains from pre to post-test assessing the relevant material. However, the test was not administered to students in a traditional physics course, so it is unclear whether context-based instruction produces better learning than traditional instruction.

The lack of research examining whether context-based instruction results in higher achievement when compared to traditional physics instruction is a major problem. A primary goal of integrating context into physics is to improve understanding and achievement, but there is little evidence that it does so. There is evidence that context-based instruction promotes more conceptually-based learning and problem solving, suggesting better performance in the form of

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better problem solving. However, more research needs to be conducted before recommendations are made to educators about the effectiveness of context-based instruction.

There is evidence that both context-based instruction and assessment is more motivating, but this is not the same as higher achievement. While it seems logical that motivated students are more likely to learn than unmotivated students, we cannot assume that is the case. There is a substantial body of work in motivation that indicates that students may find some activities as highly motivating, but learn little from them (e.g. Harp & Mayer, 1998). In fact, highly motivating activities may draw students' attention away from key knowledge and skills that they need to learn (Shui-sing, 2005).

Critique of the Research and Implications for Future Research

The existing research suggests that using context-based assessment, even alongside traditional physics instruction, appears to be useful in improving students' motivation and problem solving. In regard to the impact of context based assessment, the sparse literature examining students' achievement on context-based assessment in comparison to traditional assessment provides inconsistent and inconclusive results. However, after receiving only traditional instruction, it may be difficult for students at first to solve the more complex context-based problems. The fact that students were using better strategies is promising. This suggests that using context-based assessment may encourage students to study the material and problems that they will be tested on in a more conceptual manner, eventually leading to higher achievement.

As for the studies that have actually implemented context-based instruction in physics, all have failed to examine the effect of this instructional method on students' understanding and achievement in comparison to traditional physics instruction. Given this, context-based instruction should not be recommended to physics teachers until there is evidence that it has a significant impact on achievement and that it is a better means of teaching physics than traditional methods.

Nor is there substantial research on context-based instruction in other areas of science. The research done in other areas of science implementing context-based instruction, such as biology and chemistry, is similar to the work done in physics with a good number of studies failing to assess achievement (e.g. Bennett, Grasel, Parchmann, & Waddington, 2005; Holman, 1991). The very few studies that assess achievement and include a comparison group provide inconclusive results with some evidence of better achievement (Bloom & Harpin, 2003) and some evidence of no differences in achievement (Barber, 2001; Barker & Millar, 1996) when compared to traditional instruction. However, the research assessing achievement has serious methodological problems including a failure to pretest (e.g. Bloom & Harpin, 2003), lack of random assignment (e.g. Barker and Millar, 1996), and even failure to include a traditional instruction comparison group (e.g. Burton, Holman, Pilling, & Waddington, 1995). Well designed studies testing the effectiveness of context-based instruction on science achievement needs to be done before conclusions can be made about the efficacy of this approach for improving science learning.

While there is good reason to believe that context-based instruction will improve learning, there is also reason to believe that it may not. With context-based instruction, it is expected that students will be able to remember more of what they have learned because it has become meaningful to them. For instance, Lye, Fry, and Hart (2001) interviewed high school physics instructors and found that the instructors felt that students would retain more information "when they have it tied to a context rather than when it is just remember the rules" (p.19). However, we need to go beyond perceptions of possible improvement in learning to documenting significant differences in students receiving context-based instruction. There is concern among researchers that teaching material within a specific context will prevent students from being able to generalize their knowledge outside the context in which it was initially learned (Rayner, 2005). There is evidence that context-based instruction in mathematics has been found to suppress transfer of knowledge to other contexts (Bassok, 1997). Future research should examine how students' understanding and application of central concepts at the end of a physics course in a classroom implementing context-based instruction is being taught, not because there is evidence that it is better than traditional methods, but because there is evidence that traditional methods do not work.

The changes in strategy use connected to context-based instruction need to be more rigorously assessed. The studies examining context-based instruction used questionnaires to assess the strategies students were using to learn the material and solve the problems. The students' actual strategy use was not documented. Future research needs to look at students' actual strategy use during problem solving. It would be particularly helpful to determine whether context-based instruction supports the move from the working backward strategy characteristic of novices, to the working forward strategy characteristic of experts (e.g. Priest & Lindsay, 1992). These strategies should be assessed when comparing context-based and traditional instruction. Further, group work was frequently used during context-based instruction, making it difficult to determine whether improved strategy use was the result of the use of context or the use of group work. Research in this area needs to untangle the contributions of group work with the contributions of context to the types of strategies students use during

problem solving. It may be that context plays no role in promoting higher level strategy use, and that group work is the critical variable.

There is no research examining how well context-based instruction communicates higher level concepts that are typically taught in more advanced courses. Context-based instruction may be particularly effective for novices, but may become less effective in higher level physics where students are required to understand and apply more complex concepts. We need to know if and when context-based physics is effective and when it should not be used. The few studies in the field provide no information that would guide the use of this form of instruction beyond the beginner level.

Conclusion

While there is little evidence supporting the use of context-based instruction to improve physics achievement, there is also little evidence that it does not improve achievement. While we know that this instructional method is useful in improving student motivation, its influence on problem solving and achievement in physics is still unclear. A tremendous amount of work needs to be done in this area.

Further, if context-based physics instruction proves to be effective in improving learning, females may benefit the most from this type of instruction. The largest gender differences in achievement and participation have been found to exist in physics. Males have been found to take more physics courses, have higher physics achievement, have a more positive attitude toward physics, and are more likely to major in physics (Benbow & Minor, 1986). Gender differences in hands-on experience influence differences in knowledge in science, with males having greater hands-on experiences in science than females, particularly in physics (Jones,

Howe, & Rua, 2000). Context-based physics instruction may provide females with some of the hands-on experiences they need to increase their knowledge of physics.

In addition, females, more than males, feel that feel that physics is irrelevant to them and to their future goals (Murphy & Whitelegg, 2006). Integrating context into physics material may be particularly beneficial for females by providing examples and experiences that make physics relevant. Whitelegg and Edwards (2001) interviewed 38 students across three high schools and found that the use of context in physics was particularly valued by the females. Females are more likely to participate in physics courses that use context-based instruction (Wilkinson, 1999), which may be particularly helpful in bringing females into physics courses.

When context-based instruction was integrated in high school physics in Australia, it was found that in the first year, there was a 25% increase in numbers of students taking physics, which was linked to the changes in the physics curriculum (Wilkinson, 1999). This is important given the decline of participation and interest by all students in physics (Murphy & Whitelegg, 2006). The critical issue with context-based instruction at this point is determining whether it improves achievement along with motivation to learn.

A Traditional Physics Problem:

A 5.0-kg block slides 0.5 m up an inclined plane to a stop. The plane is inclined at an angle of 20 degrees to the horizontal, and the coefficient of kinetic friction between the block and the plane is 0.60. What is the initial velocity of the block?

The Traditional Problem Transformed into a Context-Based Problem:

You visit Solleftea, a very hilly, Swedish town. When you are driving up a steep hill, a small boy runs out in the street in front of you. You slam on the breaks and skid to a stop. The boy, who had chased a ball, runs away with the ball under his arm. A policeman watching the accident comes up to you and points out that the speed limit is 50 km/h and he gives you a ticket for speeding.

When you have calmed down from this shaking event you start wondering if you really drove too fast. You can distinguish the skid marks on the street and you measure them to be 18.2 m. You also estimate that the street makes an angle of 20 degrees with the horizontal. In the owners manual of the car you find that the mass of your car is 1570 kg. You own mass is 58 kg. A witness tells you that the boy had a mass of 30 kg and that he crossed the 5 m wide street in 3.0 seconds. You contact a tire manufacturer and he informs you that the coefficient of kinetic friction between your tires and the street surface is .60. The coefficient of static friction is 0.8. You also measure the contact area between a tire and the street. It is 1.2 dm^2 .

Will you fight the ticket in court?

Figure 5: Traditional and context-based physics problem.

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APPENDIX A

PHYSICS PACKET

Physics Course: _____

Gender:

INSTRUCTIONS

Students:

Included in this packet is a questionnaire, five physics problems, and four categorization tasks designed to measure your physics motivation and knowledge of physics. The entire packet takes approximately 30-40 minutes to complete. You will need to work individually to answer all of the questions and problems. Before starting, please sign the consent form to turn in with the rest of the packet.

The questionnaire assesses your motivation in physics. Please answer all of these questions, and answer as honestly as possible. Your professor will not see your responses on the questionnaire, but you will need to answer all of the questions in order to receive full credit.

There are also five physics problems that you will need to solve. Please solve these problems showing ALL of your work. Finally, there are four sets of categorization tasks. Please categorize the problems into pairs, and describe in as much detail as possible the basis for your categorization. You may use your book and notes to solve the problems and complete the categorization tasks.

You will need to complete the entire packet to receive full credit. Again, you should work on your own to complete the packet.

In order to better understand what you think and feel about physics, please respond to each of the following statements from the perspective of:

"When learning physics....."

- 01. I enjoy learning physics. O Never O Rarely O Sometimes O Usually O Always
- 02. The physics I learn relates to my personal goals. O Never O Rarely O Sometimes O Usually O Always
- 03. I like to do better than other students on physics tests. O Never O Rarely O Sometimes O Usually O Always
- 04. I am nervous about how I will do on physics tests. O Never O Rarely O Sometimes O Usually O Always
- 05. If I am having trouble learning physics, I try to figure out why. O Never O Rarely O Sometimes O Usually O Always
- 06. I become anxious when it is time to take a physics test. O Never O Rarely O Sometimes O Usually O Always
- 07. Earning a good physics grade is important to me. O Never O Rarely O Sometimes O Usually O Always
- 08. I put enough effort into learning physics. O Never O Rarely O Sometimes O Usually O Always
- 09. I use strategies that ensure I learn physics well. O Never O Rarely O Sometimes O Usually O Always
- 10. I think about how learning physics can help me get a good job. O Never O Rarely O Sometimes O Usually O Always
- 11. I think about how the physics I learn will be helpful to me. O Never O Rarely O Sometimes O Usually O Always
- 12. I expect to do as well as or better than other students in physics courses. O Never O Rarely O Sometimes O Usually O Always
- 13. I worry about failing physics tests. O Never O Rarely O Sometimes O Usually O Always
- 14. I am concerned that the other students are better in physics. O Never O Rarely O Sometimes O Usually O Always
- 15. I think about how my physics grade (in a course) will affect my overall grade point average. O Never O Rarely O Sometimes O Usually O Always

- 16. The physics I learn is more important to me than the grade I receive. O Never O Rarely O Sometimes O Usually O Always
- 17. I think about how learning physics can help my career. O Never O Rarely O Sometimes O Usually O Always
- I hate taking physics tests.
 O Never O Rarely O Sometimes O Usually O Always
- I think about how I will use the physics I learn.
 O Never O Rarely O Sometimes O Usually O Always
- 20. It is my fault, if I do not understand physics. O Never O Rarely O Sometimes O Usually O Always
- 21. I am confident I will do well on physics labs and projects. O Never O Rarely O Sometimes O Usually O Always
- 22. I find learning physics interesting. O Never O Rarely O Sometimes O Usually O Always
- 23. The physics I learn is relevant to my life. O Never O Rarely O Sometimes O Usually O Always
- 24. I believe I can master the knowledge and skills in physics courses. O Never O Rarely O Sometimes O Usually O Always
- 25. The physics I learn has practical value for me. O Never O Rarely O Sometimes O Usually O Always
- I prepare well for physics tests and labs.
 O Never O Rarely O Sometimes O Usually O Always
- 27. I like physics that challenges me. O Never O Rarely O Sometimes O Usually O Always
- 28. I am confident I will do well on physics tests. O Never O Rarely O Sometimes O Usually O Always
- 29. I believe I can earn a grade of "A" in a physics course. O Never O Rarely O Sometimes O Usually O Always
- 30. Understanding physics gives me a sense of accomplishment. O Never O Rarely O Sometimes O Usually O Always

Please solve the problems below. Show **all** of your work. Write as neatly and clearly as possible. As you work through each problem, show all of your work, including the equations you are using.

- 1. A block of mass 7 kg starts sliding down a plane of length 5 m, inclined at an angle of 30 degrees to the horizontal. If the coefficient of friction between the block and the plane is 0.2, find the velocity vt of the block when it reaches the bottom of the plane.
- 2. An airplane flies horizontally with a speed of 300 m/s at an altitude of 400 m. Assume that the ground is level. What horizontal distance from a target must the pilot release a bomb so as to hit the target?
- 3. A 0.15 kg steel ball is dropped onto a steel plate where its speed just before impact and after impact are 4.5 m/s and 4.2 m/s, respectively. If the ball is in contact with the plate for .03 seconds, what is the magnitude of the average force (in N) applied by the plate on the ball?
- 4. An escalator is 30.0 meters long and slants 30 degrees relative to the horizontal. If it moves at 1.00 m/s, at what rate does it do work in lifting a 50.0 kg man from the bottom to the top of the escalator?
- 5. A 1.0 kg block is released from rest at the top of a frictionless incline that makes an angle of 37 degrees with the horizontal. An unknown distance down the incline from the point of release, there is a spring with k = 200 N/m. It is observed that the mass is brought momentarily to rest after compressing the spring 0.20 m. What distance does the mass slide from the point of release until it is brought momentarily to rest?

Part I. Please categorize the four problems into pairs of two based on which problems are best related. Do not solve the problems. Once you categorize the problems, please explain in as much detail as possible why you feel those two particular problems fit or go together.

- 1. A jet is taking off from the deck of an aircraft carrier. Starting from rest, the jet is catapulted with a constant acceleration of $+31 \text{ m/s}^2$ along a straight line and reaches a velocity of +6.2 m/s. Find the displacement of the jet.
- 2. A football game customarily begins with a coin toss to determine who kicks off. The referee tosses the coin straight up with an initial speed of 6.00 m/s. In the absence of air resistance, how high does the coin go above its point of release?
- 3. A diver run horizontally with a speed of .120 m/s off a platform that is 10.0 m above the water. What is his speed just before striking the water?
- 4. You are driving in a convertible with the top down. The car is moving at a constant velocity of 25 m/s, due east along flat ground. You throw a tomato straight upward at a speed of 11 m/s. How far has the car moved when you get a chance to catch the tomato?

Pair 1 = ____, ____

Please describe in detail, why did you categorize these problems as a pair?

Pair 2 = ____, ____

Part II. Please categorize the four problems into pairs of two based on which problems are best related. Do not solve the problems. Once you categorize the problems, please explain in as much detail as possible why you feel those two particular problems fit or go together.

- 1. A 12.0 kg lantern is suspended from the ceiling by two vertical wires. What is the tension in each wire?
- 2. A supertank of mass $m = 1.50 \times 10^8$ kg is going straight and being towed by two tugboats. One tugboat is moving north-east at a 30 degree angle and the other tugboat is moving south-east at a 30 degree angle. The tensions in the towing cables apply the forces T_1 and T_2 at equal angle of 30 degrees with respect to the tanker's axis. In addition, the tanker's engines produce a force drive D, whose magnitude is D=75.0 $\times 10^3$ N. Moreover, the water applies an opposing force R, whose magnitude is R = 40.0 $\times 10^3$ N. The tanker moves forward with an acceleration that points along the tanker's axis and has a magnitude of 2.00 $\times 10^{-3}$ m/s². Find the magnitudes of T_1 and T_2 .
- 3. A 1,300 kg car is moving due east with an initial speed of 27.0 m/s. After 8.00 seconds the car has slowed down to 17.0 m/s. Find the magnitude and direction of the net force that causes the car to slow down.
- 4. A jet plane is flying with a constant speed along a straight line, at an angle of 30 degrees above the horizon. The plane has weight W whose magnitude is 86,500 N, and its engines provide a forward thrust T of magnitude T = 103,000 N. In addition, the lift force L (directed perpendicular to the wings) and the force R of air resistance (directed opposite to the motion) act on the plane. Find L and R.

Pair 1 = ____, ____

Please describe in detail, why did you categorize these problems as a pair?

Pair 2 = ____, ____

Part III. Please categorize the four problems into pairs of two based on which problems are best related. Do not solve the problems. Once you categorize the problems, please explain in as much detail as possible why you feel those two particular problems fit or go together.

- 1. A force acting on an object is given by $F_x = (8x 16)$ N, where x is in meters. Find the net work done by this force as the object moves from x=0 to x=3.
- 2. A student removes a 10.5 kg amplifier from a shelf that is 1.85 m high. The amplifier is lowered at a constant speed to a height of 0.75 m. What is the work done by (a) the person and (b) the gravitational force that acts on the amplifier?
- 3. The force acting on a particle increases, decreases, and then increases again. How would you determine the total work done by the force?
- 4. A 2.40×10^2 N force is pulling an 85.0 kg refrigerator across a horizontal surface. The force acts at an angle of 20 degrees above the surface. The coefficient of kinetic friction is .20, and the refrigerator moves a distance of 8.00 m. Find the work done by the pulling force and the work done by the kinetic frictional force.

Pair 1 = ____, ____

Please describe in detail, why did you categorize these problems as a pair?

Pair 2 = ____, ____

Part IV. Please categorize the four problems into pairs of two based on which problems are best related. Do not solve the problems. Once you categorize the problems, please explain in as much detail as possible why you feel those two particular problems fit or go together.

- 1. A 50.0-kg skater is traveling to the right at a speed of 3.00m/s. From a different point, a 70.0-kg skater is moving straight ahead at a speed of 7.00 m/s. They collide and hold on to each other after the collision, managing to move off at an angle with a speed of $v_{\rm f}$. Find the speed $v_{\rm f}$ assuming friction can be ignored.
- 2. A ball with $m_1 = .0250$ kg and a velocity $v_{01} = +5.00$ m/s collides head on with a ball of mass $m_2 = .0800$ kg that is initially at rest ($v_{02} = 0$ m/s). No external forces act on the balls. If the collision is inelastic (that is, they stick together), what is the velocity of the balls after the collision?
- 3. Kevin has a mass of 87-kg and is skating with in-line skates. He sees his 22-kg younger brother straight ahead skating straight towards him. Kevin grabs his brother, holds on, and rolls off at a speed of 2.4 m/s. Ignoring friction, find Kevin's speed just before he grabbed his brother.
- 4. A 2,000 kg car moving east at 10.0 m/s collides with a 3,000 kg car moving north. The cars stick together and move as a unit after the collision north of east and at a speed of 5.22 m/s. Find the speed of the 3,000 kg car before the collision.

Pair 1 = ____, ____

Please describe in detail, why did you categorize these problems as a pair?

Pair 2 = ____, ____