THE USE OF QUALITATIVE REPRESENTATIONS WITH RANKING TASK EXERCISES IN PHYSICS

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By
Peter M. Vreeland
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Examining Committee Members:

Joseph DuCette, Advisory Chair, Educational Psychology
Catherine Schifter, Curriculum, Instruction & Technology in Education
Michael Smith, Curriculum, Instruction & Technology in Education
Thomas Walker, Curriculum, Instruction & Technology in Education
John Pecore, Curriculum, Instruction & Technology in Education

ABSTRACT

This study examined the use of ranking task exercises in physics as a means to elicit student's quantitative and/or qualitative understanding of four different physics concepts. Each ranking task exercise in physics asked students to examine several different scenarios that contain a number of quantitative features and then arrange the scenarios in an ordered sequence according to some other quantitative feature. In this study, students completed four different ranking task exercises as part of their coursework in their high school physics class. The responses of students to these ranking task exercises were scored, analyzed, and categorized according to the extent to which a student's response was primarily quantitative or primarily qualitative in nature.

The results show that while students relied on a combination of both qualitative and quantitative representations as they completed the exercises, the majority of students used qualitative representations in their solutions to the ranking task exercises in physics. While the students' qualitative and quantitative representations supported the students' rankings of the scenarios in each ranking task exercise, the qualitative representations used by the students provided insight into the student's current understanding of the physics concepts being investigated. The findings suggest that regardless of the representation used by the student to complete the ranking task exercise, students had difficulty in correctly ranking the scenarios in all of the ranking task exercises used in this study. While the students used both quantitative and qualitative representations in their solutions to ranking task exercises in physics that contained two quantitative variables, the study found that students relied exclusively on qualitative representations in

their solutions to the ranking task exercise in physics that contained four quantitative variables.

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CHAPTER 1

INTRODUCTION

"Science is built up of facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house." - Henri Poincare

In physics education research, questions about how educators and students should take a 'collection of facts' about the physical world and turn them into a coherent and meaningful body of knowledge and understanding about physics concepts have served as the central questions in a number of physics education research studies. These studies have been based on the premise that systematic research about the teaching and learning of physics can reveal how students learn ideas in physics and provide insights that can guide improvements in physics instruction (Heron & Meltzer, 2005). In a comprehensive discussion of physics education research, Redish and Steinberg (1999) developed three questions designed to provide a comprehensive framework for the research of the teaching and learning of physics. By gaining insight into "what is involved in understanding and using physics", "what do students bring to physics classes", and "how do students respond to what they are taught", Redish and Steinberg (1999) assert that physics instructors will be able to create learning environments that foster valuable learning experiences for their students (p. 24).

While the primary emphasis of physics education research has been on increasing student understanding of physics content, studies have shown that most students, including high performing students, struggle to learn important concepts in physics

(Alvermann & Hynd, 1989; Champagne, Klopfer & Anderson, 1980; Peters, 1982). In particular, the typical performance of students on the Force Concept Inventory (Hestenes, Wells & Swackhamer, 1992; McDermott & Redish, 1999), a test widely used in physics education research to gauge students' conceptual understanding of Newtonian mechanics, is so low that it is often cited as evidence that students do not develop a sound conceptual understanding of important physics concepts even after receiving physics instruction (Hestenes, 1998; Jolly, 2009). Through his research, Hestenes (1998) has established that a disconnect often exists between how students discuss physics concepts and their ability to successfully apply these concepts in different problem solving situations. Hestenes (1998) found that in a typical university physics course "nearly 80% of the students could state Newton's Third Law at the beginning of the course, while the force concept inventory data showed that less than 15% of them fully understood it at the end" (p. 466).

Problem Statement

Studies in physics education research have consistently shown that gaps exist between the objectives of traditional physics courses and the actual level of conceptual understanding attained by students in these courses (Eryilmaz, 2002; Heron & Meltzer, 2005; Mualem & Eylon, 2010; O'Kuma, Maloney & Hieggelke, 2000; Peters, 1982; Redish & Steinberg, 1999). An overview of the literature reveals that there are key conceptual elements, knowledge hierarchies, and problem solving skills necessary for students to learn, foster, and develop in order to understand and use physics in a manner consistent with the objectives of physics courses (McDermott & Redish, 1999; McDermott 2001). In particular, students must understand the relationships between physics concepts, knowledge, and problem solving at a level deeper than the simple identification, application, and manipulation of the appropriate equation used to solve a problem if students are going to develop a substantive understanding of the physics concepts they are trying to learn (Redish & Steinberg, 1999). In describing what it means to understand physics, Peters (1982) asserts that “students should be able to approach a physical concept from all directions, from the observable phenomena to the verbal, symbolic, and mathematical representations of that concept” (p. 501). Studies in physics education research, however, indicate that many students fail to see these connections and focus instead on the surface characteristics of the concepts they encounter and rely on the manipulation of equations to develop solutions to physics exercises and questions (Redish & Steinberg, 1999).

The true nature of the gaps in student understanding of physics may not be apparent to physics students and instructors, however, because of the ways in which quantitative problems and problem solving are used in traditional physics courses to assess and evaluate student understanding of physics concepts.

Quantitative problems and problem solving are key features of virtually all branches of physics and, as a result, are often central themes in many high school and university level physics courses (Bolton, 1997; Ogunleye, 2009). Indeed, the role of problem solving in traditional physics instruction is considered the “sine qua non” of physics understanding (Hestenes, Wells & Swackhamer, 1992, p. 151). Problem solving in a traditional physics course often involves the completion of problems containing quantitative (numerical) information about a situation and physics instructors often devote substantial time to reviewing equations and teaching students problem solving methods and techniques (McDermott, 2001). Student performance on these types of standard quantitative problems is then often used as the primary measure for assessing student understanding of physics concepts (Halloun & Hestenes, 1987; McDermott, 2001).

There is a growing body of research that suggests, however, that students' performance on physics exercises that involve quantitative problem solving may not reflect their understanding of the underlying physics principles and concepts and may not then be a valuable method for evaluating and assessing students' understanding of physics concepts (Bowden et al., 1992). Studies have shown that students may successfully solve these quantitative problems not by applying sound reasoning based on their understanding of physics concepts, but rather through the application and manipulation of the appropriate algorithms without the complementary understanding of the physics concepts from which the algorithms were initially developed (Henderson, Yerushalmi, Kuo, Heller & Heller, 2004; Kim & Pak, 2002; McDermott, 2001; Ogilvie, 2009; Singh, 2008).

In a study conducted using both conceptual and algorithmic questions, Nakhleh (1993) found that 65 % of the students correctly answered the algorithmic (quantitative) questions but only 35 % of the students correctly answered the corresponding conceptual (qualitative) questions. A similar study found that when students in an undergraduate physics course were given both an algorithmic problem and a conceptual problem addressing the concept of single slit diffraction, 70 % of the students were able to correctly complete the quantitative problem while only 10 % of the students were able to correctly complete the corresponding qualitative problem (McDermott, 2001). These findings and similar findings from other studies have led physics education researchers to begin to examine and question the role of quantitative exercises and problem solving in fostering and developing student understanding of physics concepts.

While lectures in physics are typically used to address both physics concepts and problem solving approaches (McDermott & Redish, 1999), the use of quantitative problems and extended problem solving practice with those quantitative problems as a means to reinforce students' conceptual understanding of the material presented in the lectures may not help students develop the corresponding conceptual understandings contained in the quantitative problem solving exercises. In a recent study, students continued to demonstrate common difficulties with their understanding of several physics concepts despite having completed over 1,000 textbook-style quantitative problems related to those physics concepts (Kim & Pak, 2002). A possible explanation for this disconnect between the students' conceptual understanding and the problem solving activities may be the way in which physics students approach the traditional quantitative problems they encounter in physics courses.

Ogilvie (2009) states that "many students believe that problem solving (in physics) is being able to apply set procedures or algorithms to tasks and that their job as students is to master an ever-increasing list of procedures" (p. 1). Students complete the problems by drawing on their understanding of an equation rather than the related physics concepts (Ogilvie, 2009). In some cases, the portion of time in a lecture spent on problem solving and working out quantitative problems during the lecture is interpreted by students in such a way to make the manipulation of equations a central element of developing an understanding of physics concepts (Bowden et al., 1992).

The rote memorization of these problem solving algorithms without the accompanying conceptual understanding and the discrepancy between student performance on quantitative questions and their performance on similar qualitative questions has led some researchers to the conclusion that student performance on quantitative problems is an inadequate criterion for gauging students' functional understanding of physics concepts (Hestenes, Wells & Swackhamer, 1992; McDermott, 2001). In general, the reliance on any one technique or question type to assess student understanding in physics may not accurately portray students' mastery of physics concepts and some researchers assert that other techniques and question types should be incorporated into physics instruction to increase students' problem solving and physics reasoning abilities (Bartiromo, Finley & Etkina, 2010; Maloney, Hieggelke & Kanim, 2010). With a growing understanding of the role of problems and exercise in physics education, some researchers have indicated that students should have experience in interpreting physics concepts in a variety of different contexts and under different conditions if they are going to develop a substantive understanding of physics concepts (Lawson & McDermott, 1987).

While there are several physics education studies that examined the role of various instructional approaches in promoting students' understanding of important physics concepts (Duit, 2007), an examination of the assessment exercises used in physics classes and how students respond to them may also provide insight to physics education researchers into how physics assessments can be used to improve students' understanding of those concepts and help them achieve the goals of a physics course.

A review of the literature reveals that qualitative questions, questions that address students' conceptual understanding, may place more of an emphasis on conceptual learning and rely more on the students' qualitative understanding of the physical sciences than quantitative questions and these qualitative questions may serve as valuable learning opportunities for physics students (Hestenes, Wells & Swackhamer, 1992; Mualem & Eylon, 2010; Yap & Wong, 2007). According to Yap and Wong (2007), qualitative problems are distinct from quantitative problems in that qualitative (or conceptual) problems involve the use of investigation, inquiry, and process skills while quantitative (or mathematical or computational) problems involve the use of mathematical models, equations, or formulas to arrive at a solution. While a quantitative problem and a qualitative problem may be related to the same physics concept, the qualitative problem tends to rely more on students' conceptual understanding while the quantitative problem tends to rely more on the student's mathematical manipulation of variables (Hung & Jonassen, 2006).

The role of the force of friction in determining the motion of an object, for example, can be explored using either qualitative or quantitative questions. A physics question may begin with a description of a situation where a man pulls on a dog's leash but the dog doesn't move. In a qualitative question students would be asked to explain how the forces acting on the dog keep the dog at rest (Mualem & Eylon, 2010). The students could make statements about the normal force, the dog's weight, the force of friction, the force on the leash and how these forces balance to keep the dog at rest. While the statements may make comparisons between the size of each force, the primary focus would be on how the forces are balancing each other rather than a calculation of the size of each force. In a quantitative question students would be given additional information about the mass of the dog and the coefficient of static friction and then asked to determine the maximum force of friction acting on the dog (Mualem & Eylon, 2010). The students would rely on the friction equation and use the values provided in the question to calculate the force of friction. In each of the questions, the students are asked to address the role of forces in the motion of objects. While a qualitative approach requires students to identify and discuss the different forces involved in the situation, the quantitative approach relies on the students' ability to apply the appropriate equation and then solve that equation for the missing quantity.

As researchers continue to investigate activities that foster students' conceptual understanding in physics, a growing number of instructors have begun to include more qualitative problems in their courses (Yap & Wong, 2007). Research studies examining the role of both quantitative and qualitative problems in physics instruction have started to emerge in the physics education literature.

Physics education research into physics problem solving reveals that strong problem solvers rely on a well-developed knowledge structure as they work through physics problems (Bolton & Ross, 1997; Ogilvie, 2009). Further research reveals that students who are effective problem solvers often rely on both a qualitative and quantitative understanding of physics concepts to develop a solution to a physics question (Jonassen, 2003). One study in particular looked at both the role of quantitative understanding and qualitative understanding in physics problem solving and examined how students' qualitative understanding and quantitative understanding interact and influence each other as the students complete physics exercises (Ploetzner, Fahse, Kneser & Spada, 1999).

In their study investigating the difference between quantitative questions and qualitative questions, Ploetzner, Fahse, Kneser, and Spada (1999) developed a physics program where students received either quantitative instruction (mathematical equations and relationships) or qualitative instruction (conceptual ideas and relationships). The students who received qualitative instruction were then paired with students who received quantitative instruction and the student pairs were then asked to collaboratively solve problems after they completed two units in a physics course. The problems the students were asked to solve were beyond the competence of either group of physics students.

The findings indicate that during the collaborative problem solving exercises, the students who initially received the qualitative instruction gained significantly more from their partner who received quantitative instruction when attempting to solve the problems than the students who initially received quantitative instruction gained from their partner who initially received qualitative instruction (Ploetzner, Fahse, Kneser & Spada, 1999). While quantitative and qualitative problems can often address the same physics principles, the researchers concluded that the "complementarity of qualitative and quantitative problem representations is not a symmetric complementarity"(p 181). They posit that "qualitative problem representations seem to be a necessary prerequisite for the appropriate construction and use of quantitative problem representations" (p 181) but quantitative representations are not a prerequisite for the successful application of a qualitative representation.

Ploetzner, Fahse, Kneser, and Spada (1999) explain this lack of complementarity by noting "knowledge about qualitative physics seems to encode a rather expanded and highly related set of qualitative aspects (while) knowledge about quantitative physics seems to encode a rather small set of quantitative aspects" (p 181). With this growing body of research about the role of qualitative reasoning and representations in physics education, questions emerge about what types of activities and exercises engage students in qualitative reasoning and what are some of the characteristic features of these activities, questions, and problems.

Yap and Wong (2007) studied the use of qualitative questions in physics and have described the design of qualitative physics problems. They assert "the real issue is whether we can identify quantitative problems which can produce higher order thinking skills on the part of the student and through which we can then recognize the lack of conceptual learning or student understanding" (p. 51). They concluded that problems that help identify potential alternative conceptual views, that allow instructors to assess conceptual difficulties and understanding, and that provide meaningful conceptual reinforcement are certainly useful in helping students develop an understanding of physics concepts (Yap & Wong, 2007).

Ploetzner, Fahse, Kneser, and Spada (1999) maintain that qualitative problems should elicit information from students about the essential problem features and allow them to elaborate on any important distinctions they drew between those features. Bartiromo, Finley, and Etkina (2010) emphasize how multidimensional problems that require students to include written explanations provide opportunities to measure students' deep understanding while discouraging students from using a plug and chug approach to solving physics problems.

These findings and conclusions from studies in physics education research have lead various physics education groups to alter the format of traditional quantitative physics problems to create activities and problems that engage students in making sense of the underlying physics concepts rather than just searching for the right answer (Maloney, Hieggelke & Kanim, 2010). One such collection of activities and problems, referred to as TIPERs (Tasks Inspired by Physics Education Research), are designed to strengthen students' conceptual understanding of topics covered in an introductory physics course (Maloney et al., 2010). The TIPERs are designed to address those concepts and ideas that research in physics education has identified as problematic for students (Maloney et al., 2010). While the TIPERs use a variety of different activities to engage students in learning physics (Henderson & Dancy, 2009), one of the TIPERs activities draws on both the quantitative and the qualitative aspects of physics problems.

Ranking task in exercises in physics (RTEP) engage students in physics reasoning as they consider a number of similar scenarios and are asked to rank them in an order based on a particular quantitative element that appears in each scenario (O'Kuma, Maloney & Hieggelke, 2000). The RTEP presents student with a set of scenarios. The number of scenarios in each RTEP changes from one ranking task to next but most of the RTEPs include six to eight scenarios. Each scenario differs from the other scenarios in some quantitative way or ways. The students are then asked to rank the scenarios based on some physical quantity and provide an explanation for why they ranked the scenarios in the order in which they did. Each RTEP contains elements that are both quantitative and qualitative in nature and can be approached as a qualitative exercise, quantitative exercise, or a combination of both a quantitative and qualitative exercise (O'Kuma et al., 2000).

RTEPs have many of the characteristics that physics education researchers have identified as some of the essential elements of qualitative questions. These exercises allow instructors to assess conceptual difficulties and understanding (Yap & Wong, 2007), allow students to elaborate on important distinctions in the problem (Ploetzner, Fahse, Kneser & Spada, 1999), and they require students to provide written explanations in their solutions to these exercises (Bartiromo, Finley & Etkina, 2010).

While RTEPs (O'Kuma, Maloney & Hieggelke, 2000) have been developed to foster conceptual understanding in physics students, a review of physics education literature reveals that no study has been conducted that explores the type of reasoning students use while they complete these exercises. With a growing body of research about the importance of fostering qualitative reasoning in students studying physics, an analysis of how students complete RTEPs would provide insight into the characteristics of physics questions and exercises that elicit qualitative reasoning in physics students.

In their framework for the research of the teaching and learning of physics, Redish and Stienberg (1999) posit that by gaining insight into "what is involved in understanding and using physics", physics instructors will be able to create learning environments that foster valuable learning experiences for their students (p 24). This study aims address this question in part and contribute to the physics education research literature on the role of qualitative and quantitative reasoning in physics by examining how students approach these RTEPs and determine what types of explanations and representations students tend to rely on as they complete these activities. With a clear understanding of the types of reasoning used by students as they complete the RTEPs, physics researchers will be able to develop physics exercises and problems that elicit students' qualitative reasoning about physics concepts and ideas.

Purpose of the Study

The purpose of this study was to determine the understanding students have of physics concepts, the type of representations (qualitative representations, quantitative representations, a combination of qualitative and quantitative representations, or alternate representations) students use when asked to complete RTEPs, and the predominate reliance, if any, on a particular type of representation when completing these activities. This study also examined the relationships that exist between the type of representations used by the student and the number of quantitative variables contained in the RTEPs. In addition, the study examined the representations used by students who successfully complete the RTEPs and determined if students who successfully complete the exercises tend to rely on one type of representation over the over. The study concludes with an examination of any relationships that exist between the students' perceived confidence in their ranking of the scenarios in the RTEPs and the degree to which the students accurately ranked the scenarios. A sample RTEP appears in Figure 1.

Research Questions

The research questions for this study are

1. What student understandings of kinematics, dynamics, the conservation of energy, and the conservation of momentum are revealed in students' responses to RTEPs?

2. To what extent does the number of quantitative variables in a RTEP influence the type of explanation (qualitative representation, quantitative representation, or other) that students use to complete the RTEPs?

3. How do the type(s) of explanation (qualitative, quantitative, or other) students who correctly rank the scenarios use when completing RTEPs compare to those who incorrectly rank the scenarios in a RTEP?

4. What is the relationship between the students' score on the RTEPs and the students' rating on how sure they are that their ranking of the scenarios provided in the activity is correct?

Need for the Study

In physics education research, one of the goals is to identify instructional strategies and activities that facilitate student understanding in physics (McDermott, 2001). In their research on problem solving in physics, Yap and Wong (2007) identify the need for introductory physics qualitative problems that provide insight into student reasoning. RTEPs, by integrating both qualitative and quantitative elements in their design, meet these criteria established in the research by addressing the different quantitative and qualitative aspects of a student's understanding of physics concepts. RTEPs also provide insight into the type of reasoning used by students as they engage in explaining and utilizing various physics concepts to complete the exercises.

The findings of this study provide physics instructors and curriculum designers with information about the potential applications and student benefits to be realized from incorporating RTEPs into instructional programs. By coupling varying amounts of computation in the different RTEPs with conceptual understandings and requesting that students provide a ranking of the various scenarios rather than specific quantitative answers, the authors of the RTEPs have left open the question of what type of representations will the various RTEPs elicit from students as they try to complete the exercises (O'Kuma, Maloney & Hieggelke, 2000). The research on physics education has demonstrated the importance of fostering conceptual and qualitative understanding in physics students and the research questions presented in this study are designed to provide insight into the role of RTEPs in promoting such conceptual understanding in physics students.

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

This chapter provides an overview of the physics education research related to RTEPs and outlines the findings of several studies addressing student learning and understanding of physics concepts, the characteristics of traditional physics instruction and problem solving, and the role of quantitative and qualitative reasoning in physics instruction and physics courses. The design and features of RTEPs are outlined and the rationale for using them in physics education is discussed. The rule assessment technique, which serves as a theoretical framework for the development of the RTEPs, is discussed and the application of the rule assessment technique to study time, distance, and speed concepts is examined and related to the use of RTEPs in the classroom. The use of qualitative and quantitative questions in physics instruction and the students' subsequent development of both qualitative and quantitative reasoning are discussed. The elements of traditional physics instruction and the role of problem solving in physics instruction is also discussed. The chapter concludes with an overview of physics education research and the findings related to the use of RTEPs and the development of quantitative and qualitative understanding of physics concepts.

Ranking Task Exercises in Physics

The authors of the RTEPs developed the exercises to encourage students to approach physics problem solving in a different way. The authors note that in the context of traditional problem solving, students are expected to read through the problem, identify the relevant quantitative variables necessary to calculate the answer, and use those quantitative variables in an equation or set of equations to determine the answer to the question (O'Kuma, Maloney & Hieggelke, 2000). The authors also noticed that often all of the quantitative variables given in the problem are needed in the calculation of the right answer. The authors contend that presenting quantitative information and variables in this way leads students to use these numerical values and equations in inappropriate ways (O'Kuma et al., 2000).

The authors of the RTEPs elaborate on this by noting that students often do not understand the equations that they are using and simply rely on plugging the numerical values into whatever equation is available to determine the answer to any particular exercise (O'Kuma et al., 2000). Hammer (1994) observed that often physics textbooks, in an attempt to provide students with problem solving guidance, present this 'plug and chug' approach as a legitimate problem solving technique and a way to learn and understand physics concepts. A shortcoming of this approach is that often students will utilize an equation that, while containing the appropriate variables, does not relate to the physical situation that they are considering (O'Kuma et al., 2000). While this approach to solving problems in physics may lead students to the right answer, it does not necessarily distinguish between students who simply know how to complete calculations and those students who have an actual understanding of the physics concepts involved in the problem.

Interviews with physics students have revealed genuine differences in how physics students approach physics questions. Hammer (1994) asserts that these interviews indicate that some students try to learn physics by relying on the application of knowledge and the related equations while other students try to learn physics through the "reorganization of their intuition" (p.152). The design of the RTEPs allows different students to use different approaches to develop their solutions and provides insight into what type of approach students adopt as they encounter physics topics and work to complete the exercises.

The design of the RTEPs is different from the traditional physics problem in the ways in which students are expected to interact with the quantitative information that is presented in the problem (O'Kuma, Maloney & Hieggelke, 2000). The RTEPs are designed to elicit students' thinking about the behavior of a physical system rather than recalling and applying a set of equations or facts. The structure of each RTEP requires students to think about physical systems in an unusual manner and the description of each situation contains few clues about how the question should be approached (O'Kuma et al., 2000). With qualitative information represented as quantitative values in the RTEPs, students can rely on either a quantitative representation involving the use of memorized equations to complete the exercise or a qualitative representation involving conceptual thinking and ideas to complete the exercises. The major aim of this study is to identify the types of representations that RTEPs elicit from students and the students' understanding of physics concepts associated with those representations as they consider the physical situations presented in each RTEP and work to rank the scenarios and explain their reasoning.

The RTEPs are designed as paper and pencil activities to help students develop a substantive and legitimate understanding of some of the concepts in physics (O'Kuma, Maloney & Hieggelke, 2000). The format of the RTEPs is different from the format of traditional physics exercises. Traditional physics exercises are usually presented as multiple choice questions, word problems, and short response or essay questions (McDermott, 2001). While the RTEPs address the same physics topics that traditional physics exercises address, the authors of the RTEPs have reframed the questions to encourage students to think about situations in an unusual manner (O'Kuma et al., 2000).

Each RTEP has five elements (O'Kuma, Maloney & Hieggelke, 2000). The first element is a description of the situation and includes information about the criteria the students will be basing their ranking on (e.g., time in air for a projectile) and the parameters of the problem (e.g., neglect air resistance, the initial velocity of all of the objects is the same). The second element is a set of labeled diagrams showing the different scenarios to be compared in the exercise. The labeled diagrams include quantitative information about each scenario and indicate to the students how each scenario is unique and different from the other scenarios in the exercise. The third element is a place for students to record their ranking of each scenario based on a specific quantitative variable identified in the exercise. The students are asked to rank items based on that specific quantitative variable in either an ascending or descending order. In some of the RTEPs, two or more of the scenarios will have the same value for the quantitative variable being considered. In these situations, students are instructed to rank the scenarios in order and indicate in which scenarios the quantitative value being addressed is the same. Additionally, the RTEPs have a place on the page for students to mark that indicates that all of the scenarios have the same value for the specific quantitative variable being considered. The fourth element is a place for students to record their explanation or rationale for ranking the scenarios the way they did. The fifth element is a place for students to respond to the question “How sure were you of your ranking?” on a scale from one to ten (O’Kuma et al., 2000). A sample RTEP is provided in Figure 1.

RTEPs are distinct from other types of traditional problems in that by placing the question in a novel and unfamiliar context, students can not rely on the memorized or rote response often used in a traditional question. Students will need to consider the situation and think about the physics concepts in another way (O’Kuma, Maloney & Hieggelke, 2000). Physics education research supports the development of activities that create novel problem solving situations that require explanations dependent on the underlying physics concepts rather than the application of memorized equations to arrive at a solution (Bowden et al., 1992). As an assessment tool, RTEPs achieve this by providing students with the opportunity to explain their thinking and reasoning as they complete the RTEPs and by providing instructors with some insight into the way students approach a physics problem (O’Kuma et al., 2000).

The results from conceptual and problem-solving physics tests indicate that the use of RTEPs and other similar research based activities in a physics class can result in an increase in student understanding when compared to the understanding of students in a physics class where more traditional activities and assessments are utilized as part of the course (Hake, 1998). In their taxonomy of introductory physics problems, Teodorescu, Bennhold, and Feldman (2008) identified RTEPs as problems that require students to rely on both their declarative and procedural knowledge of physics concepts while engaging them in the cognitive processes of retrieval, comprehension, and analysis.

In a survey of the use of research-based instructional strategies used by instructors in college level physics courses, Henderson and Dancy (2009) found that 38.7 % of the respondents indicated that they were familiar with RTEPs while 15.4 % of the respondents indicated that they were currently using RTEPs in their introductory physics course at either a two year or four year college.

The authors of the RTEPs, by designing the tasks in an alternative way that is distinct from traditional physics exercises, have provided an additional avenue for physics education researchers to explore the ways in which students think about, learn, and explain physics concepts.

Rule Assessment

The development and design of the RTEPs was inspired by research into conceptual learning and a technique known as rule assessment (O'Kuma, Maloney & Hieggelke, 2000). The rule assessment technique was developed to assess an individual's conceptual understanding and determine how an individual's current knowledge influences his or her ability to learn (Siegler, 1982). The rule assessment technique is not a method specifically designed for determining how students learn physics concepts but rather it is a general technique for determining where along a developmental progression or sequence students may be as they acquire, develop, and modify their understanding of a new concept (Siegler, 1982).

Siegler (1982) states that

> The rule assessment approach is based on two assumptions: first that conceptual development can be characterized as a sequence of increasingly powerful rules for solving problems, and second, that we can

> discern what rules people are using by presenting them with items that yield different patterns of predictions for alternative rules. (p.272)

Studies in physics education have supported the first assumption and have found that student understandings will fit into a hierarchy with those understandings at the top of the hierarchy having more explanatory power than the understandings found further down the hierarchy (Bowden et al., 1992).

Siegler (1982) used the rule assessment technique to address three elements of conceptual development in students. The first element is the students' existing knowledge and the knowledge phases a student goes through as a concept is developed and learned (Siegler, 1982). The second element is the students' ability to learn and examines students' development differences and the influences of those differences on students' ability to learn (Siegler, 1982). The third element is the students' method of encoding stimuli and addresses how students at different developmental stages encode information (Siegler, 1982).

Through his work with the rule assessment technique, Siegler (1982) has drawn eight conclusions about the ways students develop concepts. Of the eight conclusions, one directly addresses the role of RTEPs as a means for assessing students' understandings of different physics concepts. Siegler (1982) asserts that with a clear understanding of a student's current level of conceptual understanding, the most effective instructional path for developing the concept can then be determined. When the rule assessment technique is applied to the development and evaluation of assessment items, researchers gain insight into students' thinking not by determining the number of correct responses the student has provided but rather by examining the pattern of answers that the student provides (Siegler, 1982). While there is only one correct ranking of the scenarios in any given RTEP, the order in which the students rank the scenarios and the accompanying explanations provide insight into the students' conceptual understanding of physics.

By designing activities that would allow students to apply a number of different rules to the situation, Siegler (1982) asserts that both right and wrong responses will reveal what rules the students are using as they complete the activity. In a discussion of the analysis of the reasoning used by physics students, Viennot (1985) asserts students completing a number of these activities provide instructors with an increasingly detailed understanding of the rules students are relying on as they complete these activities. One of the instructional aims inherent in the design of the RTEPs is to use these scenarios to elicit and reveal what reasoning the students are using as they complete the exercises (O'Kuma, Maloney & Hieggelke, 2000).

While the rule assessment technique developed by Siegler (1982) does not specifically address whether or not a student relies on a quantitative or qualitative rule, the technique has been used to study how students use qualitative rules as they develop an understanding of time, speed, and distance concepts (Siegler & Richards, 1979). In their study, Siegler and Richards (1979) set out to determine what knowledge states would lead students to develop an understanding of the concepts of time, speed, and distance and also determine in what order the students would master the concepts of time, speed, and distance (Siegler & Richards, 1979). In the study, students were shown the beginning position and the end position of two different trains. The students were then given information about when each train started moving and stopped moving. The students were then asked a series of questions about the differences in the speed, distance traveled, and time taken to travel between the beginning and end points for each of the trains. The students weren't asked to determine the speed, distance traveled, or time taken to travel between the beginning and end points for each of the trains but rather asked to determine which train had moved faster, traveled farther, or took more time to get from the beginning position to the end position.

In a RTEP, students are also asked to consider situations that differ in the specific value for two variables and they have to decide and explain how those variables influence the behavior of interest in the various situations (O'Kuma, Maloney & Hieggelke, 2000). As with the work of Siegler and Richards (1979) studying how students develop time, distance, and speed concepts, students were asked to complete the RTEPs by making comparisons between the scenarios and ranking the scenarios in either an ascending or descending order with respect to some physical quantity. The students are not asked to calculate or determine specific values in order to complete the RTEPs.

In the studies using the rule assessment technique, Siegler (1976) carefully constructed the questions so that the pattern of incorrect responses provided by any of the study's participants aligned with a particular set of rules. By doing this, Siegler (1976) was able to infer what rules the participant's were relying on by examining the pattern of responses provided by the participants. In their design of the RTEPs, O'Kuma, Maloney, and Hiegglke (2000) incorporated the same approach but also asked students who were completing the RTEPs to accompany their rankings with an explanation.

Throughout their study, Siegler and Richards (1979) determined that students at different developmental stages were using different qualitative rules to answer the questions about the distance each train had moved, the speed of each train, and the time it took the trains to travel between the beginning position and the final position. They also found a hierarchy within the different rules in which simple rules were modified to incorporate more sophisticated thinking that addressed the important distinctions in the concepts studied.

The pattern of student responses to the questions about each train allowed Siegler and Richards (1979) to determine which qualitative rule the students were relying on as they answered the questions. The comparison of two trains rather than the calculation of the speed, distance traveled, or time taken to get from the beginning point to the end point of a single train allowed Siegler and Richards (1979) to determine what qualitative rules students relied on as they completed the tests. In a similar fashion, the comparison of several different scenarios in a single RTEP rather than the calculation of specific values for any single scenario can be used by researchers and instructors to identify whether students are relying on quantitative rules or qualitative rules as they work to complete the activity.

A number of studies in educational research have used comparison questions to determine how students interpret and apply various concepts (Stavy & Tirosh, 2000). Piaget's (1965) work with children and their reliance on the relationship between the height of liquid in a container and the volume of liquid in that container is an example of how the comparison of two situations allows researchers to evaluate what rules students use as they answer questions. In Piaget's (1965) work with the volume of a liquid, careful attention was given to the selection of containers used in the study so that researchers could isolate the rules the students were using as they developed their answers. In a similar way, Siegler (1982) maintains that the use of the rule assessment technique with the careful and deliberate construction of questions would allow researchers to not only recognize students' correct and incorrect answers but also allow them to determine what rules the students relied on as they considered the question and arrived at their answer. The RTEPs mirror this design by keeping key features of each scenario the same while varying the particular quantitative elements of interest in the ranking task (O'Kuma, Maloney & Hieggelke, 2000). RTEPs provide an opportunity for students to explain the rules they use to rank the scenarios and the focus of this study is on how students express these rules and whether students express these rules and their associated understanding of the physics concepts as either quantitative or qualitative representations.

Quantitative and Qualitative Reasoning in Physics

The distinction between qualitative and quantitative representations in physics lies in the nature of the reasoning a student is expected to engage in while considering and developing their answer to a question or exercise. Qualitative reasoning is identified in the physics education research literature as the type of reasoning associated with a robust and substantive understanding of physics (McDermott, 2001; Ogilvie, 2009). Quantitative reasoning, while certainly an important part of understanding and applying physics concepts, involves the use of equations and algorithms and has often been relied on as the primary type of reasoning employed by introductory physics students as they encounter and try to comprehend new physics concepts (Bowden et al., 1992; Leonard, Dufresne & Mestre, 1996).

Qualitative representations differ from quantitative representations in that they address physics concepts, rather than equations, and elaborate on the relationships between the physics concept and the phenomena being considered (Hung & Jonassen, 2006). They describe how a particular physics concept is applied to develop a solution to a physics question, problem, or exercise (Leonard, Dufrense & Mestre, 1996). Qualitative reasoning about a physics concept involves using knowledge about the conditions under which a concept can legitimately be applied, the attributes associated with the concept, and the values that the concept's attributes may have (Ploetzner et al., 1999). The qualitative representations of a physics concept may include verbal, written, pictorial, and physical representations of the physics concept under consideration (Van Heuvelen & Zou, 2001).

When discussing the concept of kinetic friction in a physics problem, a student relying on qualitative reasoning would state that there is force on an object due to kinetic friction when the object moves on a non-frictionless surface and that the magnitude of force is determined in part by the normal force exerted on the object (Ploetzner et al., 1999). A free-body diagram indicating the number, size, and direction of the forces acting on an object would serve as one type of qualitative representation of the concept of kinetic friction (Van Heuvelen & Zou, 2001).

Quantitative reasoning about a physics concept involves using knowledge about interaction and motion and the mathematical representations of concept and its relationship to other concepts (Ploetzner et al., 1999). The quantitative representation of a physics concept would include mathematical representations of the concept expressed as either an equation or algorithm that would then be used to arrive at a quantitative answer (Van Heuvelen & Zou, 2001).

When discussing the concept of kinetic friction, a student relying on quantitative reasoning would indicate that the magnitude of the kinetic force of friction would be the product of the coefficient of friction and the normal force. The kinetic friction equation with the appropriate values substituted into the equation would serve as a quantitative representation of the concept of kinetic friction (Van Heuvelen & Zou, 2001). The students would then complete the necessary steps to calculate the force of kinetic friction in the situation described in the problem.

As students complete physics problems and exercises, they are often asked to describe the reasoning they relied on to develop their answers (Leonard, Dufresne & Mestre, 1996; Thacker, Kim & Trefz, 1994). Henderson (2004) states that in addition to helping students learn physics and instructors teach physics, the process of showing their reasoning while working through a problem is an essential element of the scientific process. By developing these descriptions as they complete physics questions and exercises, students have the opportunity to practice accurately describing some natural phenomena while identifying and highlighting the relevant facts and principles and then demonstrating how those facts and principles lead to specific solutions (Henderson, 2004).

While both qualitative and quantitative reasoning can lead to correct solutions, research in physics education indicates that the use of qualitative approaches to physics problems and exercises allows students to develop more of a hierarchal understanding of physics concepts and principles. These hierarchal understandings have more explanatory power than the strictly quantitative approaches that result in the production of correct answers without the corresponding conceptual understanding (Bowden et al., 1992; Leonard et al., 1996; Thacker et al., 1994). While students may get the right answer using quantitative methods, Bowden (1992) found that the capacity to get the right answer to a quantitative physics question or exercise has a low correlation to the corresponding qualitative understanding of the physics concept being investigated.

In order to address the limitations of quantitative problem solving in helping students achieve the objectives of a physics course, McDermott (2001) recommends an increased reliance on the use of qualitative questions and posits that the use of this type of question is essential in both the teaching and learning of physics. The goal of teaching introductory physics is to help students learn major concepts and principles and then apply these concepts to solve problems (Leonard, 1996). Qualitative problem solving strategies that allow students to identify the major physics principles and concepts, articulate the rationale for using those principles and concepts, and apply those principles and concepts to construct a solution facilitate the achievement of that goal (Leonard, 1996).

Research addressing the role of qualitative questions has shown that the use of qualitative questions, reasoning, and representations is an effective instructional approach (McDermott, 2001). In their study of students' conceptual understanding of causual reasoning in physics, Hung and Jonassen (2006) found that students receiving qualitative instruction gained more knowledge about physics concepts than students who received quantitative instruction on the same physics concepts. The findings of this study and other similar studies reveal that while teaching knowledge about quantitative aspects might initially help students solve problems, teaching knowledge about qualitative aspects helps build a comprehensive understanding of physics topics (Mualem & Eylon, 2010; Ploetzner et al., 1999).

These findings suggest that physics education materials that allow students to develop a qualitative understanding of physics concepts can promote learning and strengthen students' conceptual understanding (Maloney, Hieggelke & Kanim, 2010). While physics education research has highlighted the limitations of traditional quantitative problems, Maloney, Hieggelke, and Kanim (2010) have found that relying on a variety of assessment techniques is an effective way to engage physics students in meaningful learning that goes beyond simple rote memorization. These tasks, while containing quantitative information, are structured to elicit students' natural ideas and promote conceptual understanding and sense-making of the physics concepts they are studying (Maloney et al., 2010). One example of this type of task is a RTEP.

While the physics education research literature indicates the importance of qualitative reasoning and representation in helping students develop a substantive understanding of physics concepts, the use of any particular representational format does not necessarily indicate the students have applied the corresponding physics concepts in a consistent or correct manner. In a study of the use of different representational formats used by physics students while solving problems, Meltzer (2005) found that there were no significant differences between the type of representational format used by the student and the error rates of the students on the physics problems. In some cases Meltzer (2005) found students provided different answers to the same questions when asked to use different representational formats to complete the problem. These findings imply that the reliance on one type of representational format during physics instruction may not reflect a student's understanding of physics concepts. The use of alternate problem types, like the RTEPs, may elicit both the quantitative and qualitative reasoning a physics student may be using to solve physics problems.

Physics education research findings have highlighted the importance of qualitative reasoning and representations in fostering student understanding of physics concepts. The research also indicates that activities that engage students in qualitative reasoning and have them create representations of their ideas as the explore concepts results in meaningful learning of physics concepts. The focus of this study was to determine the role of RTEPs in promoting student understanding of physics concepts by examining student responses to RTEPs. This study was structured to identify the types of reasoning and representations (quantitative, qualitative, or other) students rely on while completing RTEPs and describe how the structure of the RTEPs influence the type of reasoning students engage in while completing the task. The students' accuracy in completing the task, and the relationship between student scores on the RTEPs and their rating of their own accuracy in completing the exercises was also investigated.

Problem Solving in Physics

With a growing consensus on the need to move from traditional lecture based courses towards instructional methods that promote student engagement and exploration of physics ideas and concepts, physics education researchers have begun to identify and address the types of instructional methods and activities students should become actively engaged with while they are studying physics. McDermott (2001) asserts that the materials used in a physics course should help students develop an understanding of physics that allows them to interpret and use their knowledge of physics concepts in situations different from those in which it was initially acquired. A review of the literature on the teaching and learning of science reveals that the majority of the research is conducted in the domain of physics and much of that research focuses on the identifying practices or instructional methods that influence and support a student's understanding of physics concepts (Duit, 2007; Hammer, 1996). While improving instructional practices may lead to an increase in students' understanding of physics concepts, research into the types of instructional activities physics students should be engaged in is lacking (McDermott, 2001).

In defining what it means to understand problem solving in relationship to physics concepts and ideas, Peters (1982) writes that:

> We do not mean routine problem solving by substitution into formulas, nor do we mean the rote memorization of facts and procedures. We do mean that a student should be able to approach a physical concept from all directions, from the observable phenomena to the verbal, symbolic, and mathematical representations of that concept. The student should be able to describe what the concept is *not* as well as what it is. The student should be able to distinguish between closely related concepts, noting their similarities and differences. (p. 501)

Peters' definition of understanding in physics and physics problem solving makes it clear that success in physics requires more than the ability to engage in and complete the quantitative manipulation of physical quantities. It is clear that students need to develop a facility with the qualitative nature of physics concepts as well as the corresponding mathematical and problem-solving aspects that accompany physics concepts (Peters, 1982).

Physics concepts, which are often expressed in mathematical terms, naturally lend themselves to mathematical analysis and treatment. Mulhall and Gunstone (2008) note that "such is the importance of mathematics in representing physics relationships that it is often referred to as the 'language of physics'" (p. 436). With such a clear connection to mathematics, most traditional physics courses have incorporated a strong emphasis on the use of formulas to solve problems in addition to the facts, definitions, and concepts associated with the study of physics (Mulhall & Gustone, 2008; Uhden, Karam, Pietrocola & Pospiech, 2012).

In most physics courses, developing proficiency in problem solving has long been recognized as one of the primary educational objectives in these introductory science courses (Teodorescu, Bennhold & Feldman, 2008). Mulhall and Gunstone (2008) reiterate that point by noting how traditional physics teaching relies on students acquiring a number of facts and equations and then using those facts and equations to solve problems. As a matter of fact, the role of problem solving in physics courses is so well established that problem solving in physics has been the subject of a number of physics education research studies. McDermott and Redish (1999) found that several researchers have investigated physics problem solving with a particular focus on how students solve problem in classical mechanics. The role of problem solving as a skill has been addressed so frequently that it has transcended the physics classroom and has been recognized in a broader sense such that Ogilvie (2009) posits that "progress in our technological society absolutely requires that individuals entering the workforce have strong problem-solving skills" (p. 1).

Physics students engaged in problem solving in a physics course are often presented with quantitative information about some phenomena and asked to develop a solution that produces a quantitative answer. The quantitative information described in the problem usually provides the students with numerical values for certain physical quantities (e.g., velocity, time, etc.) and asks the student to calculate some other physical quantity (e.g., acceleration). When approaching these problems, Ogilvie (2009) states that many physics students believe that problem solving is little more than the application of algorithms to a given task and through the acquisition and accumulation of physics equations and algorithms, they will become more proficient problem solvers in physics.

McDermott (2001) argues, however, that quantitative problem solving is not a reliable indicator of conceptual understanding. Student success on these quantitative problems may be achieved without the corresponding conceptual knowledge. McDermott found that students could acquire the correct solutions using only memorized algorithms without the complimentary conceptual understanding of the physics principles involved. Oftentimes students presented with quantitative problems can simply use formula-centered translation strategies rather than relying on conceptual understanding of physics principles to solve the problems (Jonassen, 2003). These formula-centered translation strategies rely on the application of a series of algorithms to develop the solution to a problem rather than on an understanding of the underlying physics concepts that physics education research has shown to be a necessary component of understanding physics concepts and the related problem solving approaches.

A review of the physics education literature reveals that studies in physics problem solvers often compare the performance of novice physics problem solvers to the performance of expert physics problem solvers on physics exercises (Bassok, 1990; Clement 1982; Mason & Singh, 2011). In their study, Mason and Singh (2011) found that novice physics problem solvers focused on the quantitative surface features of the problem while expert physics problem solvers relied on the underlying physics concepts to develop their solutions. Bassock (1990) points out that the skills an introductory physics student uses to solve one problem type tend to focus on the content in the problem and not on the structure of the problem. As a result, physics students may succeed in solving a number of physics problems that are similar in content but have difficulty transferring their understanding between different problem types that require an understanding of the underlying structure of the problem (Bassock, 1990). In a study of the role of qualitative reasoning in problem solving, Clement (1982) found that an inadequate or incorrect qualitative understanding of the physics concepts involved limits the success of students in physics problem solving situations. The implication of these findings is that exercises that draw students to the structure of the problem may help students develop an understanding of the related physics concepts.

In describing the features of successful problem solving and its relationship to conceptual understanding, Jonassen (2003) writes:

> Successful problem solvers need to construct a conceptual model of the problem and base their solution plans on their models. It is the quality of their conceptual models that most influences the ease and accuracy with which the problem can be solved. (p.269)

When instructors rely on the results of quantitative exercises and problem sets as the sole indicators of student understanding, Clement (1982) warns that students can mask their conceptual shortcomings of important physics principles by demonstrating physics proficiency through the application and manipulation of the correct equations.

Physics education research has shown that when presented with problems that ask for precise quantitative solutions, many students approach the problems exclusively on the basis of algebraic equations (Kim & Pak, 2002; Ploetzner, Fehse, Kneser & Spada, 1999; Yap & Wong, 2007). McDermott (2001) posits that instructors assume that the teaching of physics problem solving and the associated skills with it will also serve help students foster a conceptual framework of important physics concepts. However, McDermott goes on to state that most students do not develop any meaningful conceptual framework using this approach.

Research does reveal that, from a students' perspective, the reliance on a strictly quantitative approach often gets the students lost in a search for equations with no means at hand to guide them toward the successful and efficient use of the equations to produce a solution (Hammer, 1994; Mualem & Eylon, 2010; Ploetzner et al., 1999). While there is a growing body of research on the importance of qualitative reasoning in developing student understanding of physics concepts, the physics education research literature is lacking in regards to the type of assessment activities and problem types that facilitate the development of students' qualitative understanding of physics concepts (Eryilmaz, 2002; Maloney, Hieggelke & Kanim, 2010; McDermott, 2001; Redish & Steinberg, 1999).

Studies in physics education have examined the influence of the format of assessment activities on student understanding of physics concepts (Bonham, Deardroff & Beichner, 2003). In their study comparing the role of traditional paper-based homework problems and web-based homework problems, Bonhan, Deardorff, and Beichner (2003) found that the format of homework problems had no effect on the students' understanding of physics concepts. Other studies have focused on what ideas and concepts students bring to class and how instructors should engage these ideas and concepts to promote physics understanding (Hammer, 1996; Reddish & Steinberg, 1999). This study was designed to contribute to the literature on physics education research by examining how RTEPs elicit different types of student reasoning as they interact and consider the information presented in the RTEPs.

Current Physics Education Research

A number of physics education research studies have identified a gap that exists between what the students are expected to learn in a physics course and the students' actual performance and level of physics understanding after completing a physics course (Heron & Meltzer, 2005; McDermott, 2001; Redish & Steinberg, 1999). Crouch and Mazur (2001) found the results of several studies reveal that the traditional structure of physics courses does not promote students' understanding of fundamental physics concepts. Hake (1998) points out that, even with skillful instructors teaching these courses, students gain little conceptual understanding of the material presented. In their review of physics education studies, Hung and Jonassen (2006) found that "a survey of more than 5000 physics students at 30 institutions showed that the conceptual understanding of students enrolled in physics courses was unsatisfactory" (p. 1601).

When considering possible reasons for the limited success of students in physics courses, researchers have examined the nature and structure of the discipline of physics, the beliefs students have about the nature of motion, the traditional methods used to teach physics, and the structure and design of physics courses. While the types of physics questions and exercises have certainly been part of a number of physics studies, the nature of those physics questions and exercises that students have been asked to complete has not been addressed in the physics education literature (McDermott, 2001).

Mulhall and Gunstone (2008), in discussing different views about the teaching of physics, assert that physics is often regarded as a difficult, abstract, and highly mathematical subject to teach. In describing the reasons physics is a difficult subject, Clement (1982) identifies a combination of higher order thinking skills, mathematical reasoning, and the abstractness of the course content as some of the factors that make physics a difficult subject. The results of one study indicate that in addition to being considered abstract and complicated, some students consider physics to be counterintuitive and incomprehensible (Duit, 2007).

Researchers have also considered the beliefs students have about the nature of motion as they begin to study physics and recognize that those existing beliefs influence the extent to which students can develop understandings consistent with currently accepted ideas in physics. In discussing physics education research studies, Hake (1998) describes how students' initial ideas about physics concepts, while having a substantial influence on how students acquire new ideas, are unlikely to be addressed in conventional physics instruction.

In describing their rationale for developing some of their diagnostic and assessment instruments in physics education, Maloney, O'Kuma, Hiegglke, and Van Heuvelen (2001) write that existing students ideas "often called alternative conceptions of common sense science, differ from accepted scientific ideas" and that "it is difficult for students to change their initial ideas" (p.S12). While these studies focus on the role of student beliefs in the teaching and learning of physics, Meltzer asserts that it is challenging to research students' current understanding of physics topics because their understandings of physics topics are constantly shifting and undergoing change.

In discussing the relationship between existing student beliefs and physics instruction, Halloun and Hestenes (1985) posit that students entering a physics course possess a mindset about physical phenomena that is drawn from their everyday interactions with the world and students rely on this mindset to interpret the material they are presented with in physics class. They go on to observe, however, that most physics instruction does not address the students' initial mindset. The instructional strategies and practices used to teach traditional physics classes generally treat students as passive receivers of information, focus on knowledge transmission, and have an emphasis on traditional problem solving (Dancy & Henderson, 2006).

In this type of educational setting, physics education research has shown that the traditional physics class leaves most students confused about the basic concepts of mechanics, electricity and magnetism, optics, heat, and thermodynamics (Redish, Saul, & Steinberg, 1998). A further review of the literature shows that traditional introductory physics courses with passive lectures, recipe labs, and algorithmic problems in exams are of limited value in enhancing students' conceptual understanding of the subject (McDermott & Redish, 1999).

The structure of physics courses may also contribute to the limited success students experience when trying to learn and understand physics concepts. Redish and Steinberg (1999) state that

> One source of difficulty is that even though more than 95% of students in introductory physics never take another physics class, introductory courses are often variations on courses designed for the professional physicist. They treat many topics superficially to provide a context for the later study of physics and

> they emphasize mathematical manipulations and structures that lay the groundwork for more advanced study. (p. 24)

While physics education research has identified effective methods and materials for physics instruction, the dissemination and implementation of these methods has been limited in two ways. The physics instructors often modify the methods as they are implemented and these modifications may actually eliminate the essential components of the method and there are also time constraints that limit the ability for instructors to make the major instructional changes necessary to implement the new method (Dancy & Henderson, 2010).

While physics education research has documented obstacles to student success in physics, it has also identified some of the features of programs that promote student understanding. One of those features is the reliance on student interactivity over the more traditional lecture based methods (Dancy & Henderson, 2006). In their evaluation of physics education research curricula, Dancy and Henderson (2006) have found prevalence of methods and materials designed to promote student interactivity. Dancy and Henderson (2006) define student interactivity by identifying five dimensions of student interactivity. The five dimensions focus on increase student engagement during each class and are (1) students to teacher discourse, (2) student to student discourse, (3) conversations that focuses on students' ideas, (4) students recording their own ideas, and (5) students are physically active as they interact with equipment or materials (Dancy & Henderson, 2006).

Hake (1998) frames the concept of interactivity as interactive engagement and defines it as "methods designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussions with peers and/or instructors" (p. 65). Hake (1998) maintains that the results from conceptual and problem-solving tests indicate that this type of student engagement results in more effective learning of physics concepts.

The physics education research literature discusses the role of qualitative and quantitative reasoning in physics and highlights the importance of qualitative reasoning in fostering students' conceptual understanding of physics. The literature details the difficulties students have with developing a firm understanding of physics concepts as they rely on algorithms, concepts, and their own ideas about the physical nature of the world to discuss and solve different physics problems, questions, and exercises. While curriculum guides, instructional practices, and assessment techniques are all components of a sound educational program in physics, this study focused on how students interact with one particular assessment technique and determined how students relied on their understanding of physics to approach and solve one particular type of physics exercise.

CHAPTER THREE

METHODOLOGY

Introduction

With a body of research indicating that a student's responses to quantitative exercises in physics may not be sufficient for evaluating student understanding of physics concepts and that there is a need for qualitative exercises that help identify and foster students' conceptual understanding of physics, this dissertation focused on describing what types of representations (quantitative or qualitative) students used to complete RTEPs. This study was a single case, descriptive case study that relied on a methodology designed to identify, describe, and analyze the salient features of the students' responses to four RTEPs and determine the extent to which students used quantitative representations or qualitative representations to complete the exercises (Yin, 2003).

Context of the study

This study was conducted in a suburban, mid-Atlantic public high school and examined the responses of 36 students to four different RTEPs. The students who participated in the study were enrolled in one of four sections of the honors-level physics course offered at the high school during the 2010-2011 school year. The students participating in the study were selected because

- they were enrolled in a physics course in which RTEPs were used,
- they agreed to participate in the study after attending an information session, and
- they were at least 18 years old (as required by the Institutional Review Board).

While approximately 100 students were enrolled in the honors level courses and all of these students completed the RTEPs as part of the course, the Institutional Review Board's review and approval of the study required that only students of legal age would be allowed to participate in the study. As the researcher and a high school physics teacher, I was not the instructor of any honors-level physics courses at the high school or the instructor of any of the students who participated in the study.

The honors-level physics course at this high school is a first year course in algebra-based physics and the students enrolled in these courses were in either 11^{th} or 12^{th} grade. The honors physics classes met each day for a 48 minute period and met for two additional 48 minute lab periods during the high school's six day rotating cycle. The students in the study completed the prerequisite coursework in algebra II and chemistry.

The instructors for the honors-level physics course used similar approaches to teach each of their courses. The teachers collaborated on the writing of the curriculum guide for the course and relied on the same resources to instruct the students and assess student progress and understanding. Each unit of study began with an introduction to the topic that included the identification of the new concepts and their definitions, relevant examples that demonstrated the concepts, and any equations related to those concepts.

In their classes, a significant amount of time (when compared to the traditional physics classroom) was spent developing concepts without relying on equations. As the unit progressed, the students were asked to solve sample problems and complete other formative assessment activities related to the concepts covered in the unit. The RTEPs used in this study were administered during this portion of each unit. The unit concluded with a review of the concepts presented in the unit and the completion of summative assessments by the students that included problem sets and the end of unit quizzes/tests. The textbook used in the course, the second edition of Holt Physics written by Serway and Faughn, covered the traditional content of a high school physics and provided students with a mix of conceptual questions, sample problems, and a set of quantitative problems and exercises at the end of each chapter.

The students attended a short informational meeting that addressed their questions about participating in the study and the students who agreed to participate in the study completed and returned consent forms to their physics instructor. The consent forms were then delivered to the researcher. Of the 36 students who participated in the study, 15 students were male and 21 students were female with two African American/Black students, three Asian students, two Hispanic/Latino students, 28 White students, and one student reporting more than one race.

Each of the four RTEPs used in the study came from a major unit of study in the honors-level physics course. The State's standards aligned system identifies a curriculum framework for each of the subject areas taught in the State. The curriculum framework for physics contains four major units and the honors-level physics course at the high school was designed around those units. The units were the kinematics unit, the dynamics unit, the conservation of energy unit, and the conservation of momentum unit.

The "car and boat trailer" RTEP was part the forces and Newton's laws unit (dynamics) and involved the application of Newton's third law of motion to the motion of an object (see Appendix A). The students were given information about the boat's mass and the car's final velocity and asked to rank the scenarios according to the difference in size between the force the car exerted on the trailer and the force the trailer exerted on the car. Students with an understanding of Newton's third law of motion should recognize that forces occur as interactions and the forces between each car and boat trailer would be the same regardless of the car's mass or final velocity and would rank the scenarios accordingly. Some students may incorrectly reason that a large force on the trailer from the car would result in a different force being exerted on back on the car and arrive at a different and inaccurate ranking of the scenarios.

The "car's impulse" RTEP was part of the conservation of momentum unit and involved analyzing the changes in an object's momentum (see Appendix B). The students were given information about the before and after velocity of a car and asked to rank the scenarios according to the impulse that produced the change in the car's velocity. Students with an understanding of impulse should recognize the directional aspect of momentum and would rank the scenarios accordingly. Some students may incorrectly reason that the car's speed, regardless of direction, was the only relevant quantity and arrive at a different and inaccurate ranking of the scenarios.

The "pendulum" RTEP was part of the conservation of energy unit and involved analyzing changes in an object's potential energy and kinetic energy (see Appendix C). The students were given information about the length of the pendulum and the mass of the pendulum bob and asked to rank the scenarios according to the speed the pendulum bob reached at the bottom of its swing. Students with an understanding of the conservation of energy should recognize that the speed of the ball at the bottom of the swing depends solely on the height or vertical distance that the pendulum swings through and would rank the scenarios accordingly. Some students may incorrectly reason that the mass of the pendulum would also influence its speed and arrive at a different and inaccurate ranking of the scenarios.

The “projectile” RTEP was part of the kinematics unit and involved analyzing the two dimensional motion of a projectile (see Appendix D). The students were given information about each projectile’s mass, launch angle, launch velocity, and horizontal velocity and asked to rank the scenarios according to the horizontal distance traveled by each projectile. Students with an understanding of the behavior of moving objects in two dimensions should recognize that the projectile’s horizontal velocity and the time the projectile is in the air determines the horizontal distance traveled by a projectile and would rank the scenarios accordingly. Some students may incorrectly reason that the mass of the projectile will in some way influence the horizontal distance traveled by the projectile and arrive at a different and inaccurate ranking of the scenarios.

The majority of RTEPs written by Thomas O’Kuma, David Maloney, and Curtis Hieggelke (2000) incorporated two quantitative variables in each RTEP. In this study, three of the RTEPs contained two quantitative variables and one of the RTEPs, the “projectile” RTEP, contained four quantitative variables. The study of projectiles is an extension of one-dimensional motion and involves the consideration of horizontal motion variables as well as the consideration of vertical motion variables. In order to assess the students’ understanding of both the horizontal and vertical motions of a projectile, the “projectile” RTEP included four quantitative variables relating to the horizontal and vertical motion of a projectile.

In all of the RTEPs used in this study, any incorrect ranking of the scenarios provided by a student offers some insight into the reasoning the student relied on as they completed the activity. The explanation that accompanies each ranking of the scenarios provides further insight into the students' reasoning about the concepts and will help the physics instructor identify what concepts or ideas the students are relying on to complete the exercises. With an understanding of the students' current thinking about a particular physics concept, the physics teachers would have opportunities to re-teach or review the important physics concept with the students before moving on to any new material involving that concept.

All of the RTEPs used in this study were written by Thomas O'Kuma, David Maloney, and Curtis Hieggelke and published in Ranking Task Exercises in Physics (2000).

Data Collection

The students completed each RTEP during the corresponding unit as one of the formative assessment activities assigned by their physics instructor. For example, the "car's impulse" RTEP was completed during the unit on the conservation of momentum and the students' performance on the RTEP was used by the physics instructor to monitor student progress and guide future lesson planning. The students were given as much time as they needed to complete each RTEP and were allowed to ask their physics instructor questions to clarify their understanding of the instructions. The students submitted their completed assignments to their instructors and the instructors reviewed the completed RTEPs as part of their formative assessment process.

The RTEPs completed by the students in this study were not graded by the physics instructors. Ranking task exercises were routinely assigned in each of the honors-level physics courses and the instructors maintained the practice of not grading any of the formative assessment activities used in the course. A review of the literature conducted by the physics teachers on the role of grading in formative assessment indicated that grading of assignments often inhibited student performance and the grades received by students on their assignments may not accurately reflect the extent to which students understand the course material (Clymer & Wiliam, 2007; Pulfrey, Buchs & Butera, 2011).

After the physics instructors were done with the completed RTEPs, they reviewed the list of students who agreed to participate in the study and removed their papers from the papers submitted to each instructor. The physics instructors then removed each student's name from their completed RTEP and replaced it with a number that served as a unique identifier for each student. The unique identifier served as a means to track student completion of the RTEPs. With the names removed and replaced with a number, the physics instructors then submitted the completed assignments to the researcher.

Data Analysis

As part of this study, students completed four separate RTEPs. Each completed RTEP contained four pieces of data for analysis. The first piece of data for analysis was the student's ranking of the scenarios in the RTEPs. The data are ordinal data and were used to gauge the accuracy of the student's responses to the ranking task in physics activity. The second piece of data was the explanation the student used to describe their reasoning for ranking the scenarios the way they did. The data are nominal data and were used to determine the type of representation the student uses to explain their reasoning.

The third piece of data was the students rating on how sure they are that their ranking of the scenarios provided in the activity is correct. These data are interval data and were used to correlate with their rating on the activity with their accuracy of their ranking of the scenarios in the activity. The fourth piece of data was the number of quantitative variables that appear in the RTEPs. This data are interval data and were used to determine any relationships that exists between the number of variables in a RTEP and the type of explanation provided by the students.

The data gathered from the RTEPs were used to develop answers to the research questions for this study.

Research Question 1 Data Analysis

1. What student understandings of kinematics, dynamics, the conservation of energy, and the conservation of momentum are revealed in students' responses to RTEPs?

The researcher and another experienced physics teachers reviewed the completed RTEPs and evaluated the student's explanation and categorized their explanation as either primarily qualitative (conceptual in nature), primarily quantitative (computational in nature), or other explanation type using the following categories. The categories outlined below were developed based on the researcher's experience using RTEPs with students in high school physics classes. The representations were then reviewed and the students' understandings from both the qualitative and quantitative representations were identified and described.

The following categories include a title for each category and a description of the type of student representation that would fall into that category. Figure 1 shows a sample RTEP. In the following sections, example student responses are included to clarify the each of the ten classifications used in the study. Figure 2 shows a sample coding sheet used by the reviewers to collect data from their review of the RTEPs completed by the students.

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Ranking Task Exercises in Physics

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Figure 1: Sample Ranking Task Exercise in Physics

Cars – Impulse During a Change of velocity
(2 appropriate variables – 0 extraneous)

ID:____

Ranking

Most Positive 1_____ 2_____ 3_____ 4_____ 5_____ 6_____ 7_____ 8_____ Most Negative

Or, the impulse on these cars is the same (but not zero) for all of these._________
Or, the impulse on these cars is zero for all of these._________
Or, it is not possible to determine the impulse on these cars for all of these._________
Answer

Most Positive (1___**A**_ 2___**E**_) 3___**D**_ (4__**B**__ 5__**F**__ 6__**G**__) 7__**C**_ 8__**H**_ Most Negative

Reasoning

	Qualitative representation using only the appropriate variables			*Quantitative representation using only the appropriate variables*
	Qualitative representation using both appropriate and extraneous variables			*Quantitative representation using both appropriate and extraneous variables*
	Qualitative representation using only the extraneous variable			*Quantitative representation using only the extraneous variable*
	Qualitative representation using no variables			*Quantitative representation using no variables*

	Dual representation using both qualitative and quantitative explanations			*Alternate representation*

Supporting
Evidence:____
____

How sure were you of your ranking? ________________ on a 10 point scale

Reviewer:_________________________________

Figure 2: Sample Data Collection and Coding Sheet

Type of Student Representation

Qualitative representation using only the appropriate variables.

A student's explanation of the RTEP identified or described a physics concept and the student incorporated the appropriate variable in his or her explanation. The student did not address any extraneous variable in his or her explanation or include an explanation of why an extraneous variable does not need to be taken into account. In the sample RTEP provided, a student's explanation that states that all rising objects decelerate at the same rate (concept) and that the height is determined by the vertical component of the velocity (appropriate variable) would have been classified as a qualitative representation using only appropriate variables. The explanation ignored the mass of the rocket (extraneous variable) or stated that the mass of the rocket wasn't relevant as presented in the Law of Falling Bodies.

Qualitative representation using both appropriate and extraneous variables.

A student's explanation of the RTEP identified or described a physics concept and the student incorporated both the appropriate variable and the extraneous variable in his or her explanation. In the sample RTEP provided, a student's explanation that states that rising objects decelerate at a rate (concept) and that the height is determined by the vertical component of the velocity (appropriate variable) and the mass of the rocket (extraneous variable) would have been classified as a qualitative representation using both appropriate and extraneous variables.

Qualitative representation using only the extraneous variable.

A student's explanation of the RTEP identified or described a physics concept and the student incorporated only the extraneous variable in his or her explanation. The student did not address any appropriate variable or include an explanation of why an appropriate variable does not need to be taken into account. In the sample RTEP provided, a student's explanation that states that heavier objects have a larger force on them than lighter objects (concept) and that the height is determined by the mass of the rocket (extraneous variable) would have been classified as a qualitative representation using only extraneous variables. The explanation would have ignored the vertical velocity of the rocket (appropriate variable) or stated that the vertical velocity of the rocket does not need to be taken into account.

Qualitative representation using no variables.

A student's explanation of the RTEP identified or described a physics concept and the student did not incorporate any variables in his or her explanation. The student did not address the variables in their explanation or include an explanation of why the variables do not need to be taken into account. In the sample RTEP provided, a student's explanation that states that everything falls at the same rate (concept) and that rockets will all reach the same height would have been classified as a qualitative explanation using no variables. The representation would have ignored the vertical velocity of the rocket (appropriate variable) and the mass of the rocket (extraneous variable) or stated that the vertical velocity of the rocket or the mass of the rocket does not need to be taken into account.

Quantitative representation using only the appropriate variables.

A student's explanation of the RTEP identified or described a physics equation and the student incorporated the appropriate variable in his or her calculation. The student did not address any extraneous variable or include an explanation of why an extraneous variable did not need to be taken into account. In the sample RTEP provided, a student's explanation that relies on a kinematic equation (equation) and uses the vertical velocity of the rocket (appropriate variable) to calculate the height would have been classified as a quantitative representation using only appropriate variables. The explanation ignored the mass of the rocket (extraneous variable) or stated that the mass of the rocket isn't relevant as presented in the Law of Falling Bodies.

Quantitative representation using both appropriate and extraneous variables.

A student's explanation of the RTEP identified or described a physics equation, or equations, and the student incorporated the appropriate variable and the extraneous variable in his or her explanation. In the sample RTEP provided, a student's explanation that relies on a kinematic equation and a force equation (equations) and uses the vertical velocity of the rocket (appropriate variable) and the mass of the rocket (extraneous variable) to calculate the height would have been classified as a quantitative representation using only appropriate variables.

Quantitative representation using only the extraneous variable.

A student's explanation of the RTEP identified or described a physics equation and the student incorporated only the extraneous variable in his or her calculation. The student did not address any appropriate variable or include an explanation of why an appropriate variable did not need to be taken into account. In the sample RTEP provided, a student's explanation that uses a force equation (equation) and that the height is determined by the mass of the rocket (extraneous variable) would have been classified as a quantitative representation using only extraneous variables. The explanation did not address the vertical velocity of the rocket (appropriate variable) or state that the vertical velocity of the rocket did not need to be taken into account.

Quantitative representation using no variables.

A student's explanation of the RTEP identified or described a physics equation and the student did not incorporate any variables in his or her explanation. The student did not address the variables or include an explanation of why the variables do not need to be taken into account. In the sample RTEP provided, a student's explanation that used a constant acceleration equation (equation) and stated rockets will all reach the same height would have been classified as a quantitative representation using no variables. The representation ignored the vertical velocity of the rocket (appropriate variable) and the mass of the rocket (extraneous variable) or stated that the vertical velocity of the rocket or the mass of the rocket did not need to be taken into account.

Dual representation using both qualitative and quantitative explanations.

A student's explanation of the RTEP identified or described both a physics concept and physics equation and the student incorporated variables in some way in his or her explanation. In the sample RTEP provided, a student's explanation that uses the law of falling bodies (concept) and an kinematic equation (equation) and uses the vertical velocities of the rockets (variable) to determine the heights would have been classified as a dual representation using both qualitative and quantitative explanations.

Alternate representation.

A student's explanation of the rank task exercise in physics identified no concepts or equations in his or her explanation. In the sample RTEP provided, a student's explanation that arranges the scenarios in alphabetical or numeric order without any reference to a physics concept or equation would have be classified as an alternate representation.

A Cohen's Kappa was used to assess interrater reliability during this component of data analysis. The interrater reliability for the raters was Kappa = 0.91. Of the 140 student responses, the raters reported identical categorizations of 130 of the student responses. For the purpose of including and analyzing the all student responses and answering the research questions in the study, the raters met and reviewed the 10 student responses that they had categorized differently. After discussing the salient features of each of the student responses, the raters arrived at consensus categorization for each of those student responses. The data analyzed in this study were then compiled from 140 student responses comprised of the initial categorizations of the 130 student responses in which the raters had independently agreed on and the consensus categorization of the 10 student responses the raters had agreed on after reviewing and discussing the student responses.

Once all of the student explanations for each RTEP were categorized, the results were analyzed using descriptive statistics that indicated the frequency at which the students used each type of representation. A discussion of the data and the findings from this analysis of the students' representations and understanding of the physics concepts is contained in chapter four of this study.

Research Question 2

2. To what extent does the number of quantitative variables in a RTEP influence the type of explanation (qualitative representation, quantitative representation, or other) that students use to complete the RTEPs?

I determined the number of quantitative variables in the RTEP and use descriptive statistics to indicate the frequency at which the different representations were used with RTEPs that had different numbers of qualitative variables. A discussion of the data and findings from this analysis of the students' representation is contained in Chapter Four of this study.

Research Question 3

3. How do the type(s) of explanation (qualitative, quantitative, or other) students who correctly rank the scenarios use when completing RTEPs compare to those who incorrectly rank the scenarios in a RTEP?

I scored the RTEPs and paired the type of representation used by the student to the student's score on the RTEP. A crosstabs analysis was used to determine if students who correctly complete the RTEPs used one type of representation more often than students who did not correctly complete the RTEPs. A discussion of the data and findings from this analysis is contained in Chapter Four of this study.

Research question 4

4. What is the relationship between a student's score on the RTEPs and the student's rating on how sure they are that their ranking of the scenarios provided in the activity is correct?

I paired a student's score on each RTEP with the students rating on how sure they are that their ranking of the scenarios in the activity is correct. A correlation was completed to determine if there was a correlation between the students score on each RTEP and their corresponding rating on how confident they were about the accuracy of their ratings. The results of the analysis are presented and discussed in Chapter Four of this study.

CHAPTER FOUR

FINDINGS

Introduction

The purpose of this study was to determine the understanding students have of four different physics concepts, the type of representations (qualitative representations, quantitative representations, a combination of qualitative and quantitative representations, or alternate representations) students use when they are asked to complete RTEPs, and determine if students tend to rely predominately on a particular type of representation when completing these activities. During the study, physics students (n=36) in a high school honors-level physics course completed four different RTEPs. The physics teachers used the RTEPs as an assessment tools and students were asked to complete each RTEP during the physics unit that corresponded to the topic presented in each RTEP. The RTEPs completed by the students were scored and their responses were categorized based on the type of representation they used and the types of variables they addressed in their responses. The research questions in this study were answered using the following:

- type of representation the students used to complete each of the RTEPs,
- the students explanations for their ranking of the scenarios,
- students' scores on the each of the RTEPs, and
- students' ratings of how sure they were of their ranking of the scenarios in each of the RTEPs.

In this study, 36 students were each asked to complete four different ranking tasks. Each ranking task exercise had three distinct elements for the students to complete. The totals for the rankings provided, the representations provided, and the "How sure" ratings provided would be 144 for each of the three elements of the ranking task exercises used in the study if every student completed every element of the ranking task exercises. The number of responses for each element is shown in Table 1.

Table 1

Summary of data collected in this study

Ranking task exercise in physics	Rankings Provided	Representations Provided	"How sure" Ratings Provided
Ranking Task Exercises			
Accelerating car and boat trailer	33	29	33
Car impulse	36	35	36
Pendulum	36	25	36
Projectile	36	36	36
Totals	141	125	141

The missing elements from the data can be accounted for, in part, with the following explanations.

During the accelerating car and boat trailer exercises, three students were absent and did not return to school until after the physics instructors had moved on to another part of the unit on forces. The physics instructors had excused the students from completing the accelerating car and boat trailer ranking task exercise. This accounts for three of the missing rankings provided, representations provided, and "How sure" ratings provided.

The pendulum ranking task exercise, while having the expected number of rankings and “How sure” ratings, provided only 25 of the expected 36 representations. Possible explanations for the lack of explanations to this RTEP are that the pendulum ranking task exercise had very little physical space on the page for a student to write his or her explanation and the instructions to provide an explanation does not stand out in a clear way from the surrounding text. These factors may have resulted in students overlooking this part of the exercise. An examination of this ranking task exercise shows that the students had less than one line of space to provide their representations (see appendix C) while the other ranking task exercises had provided students with more than one line of space to provide their representations (see appendix A, B, and D).

While these explanations address some of the missing data, there are four missing representations from the data that may be attributed to students overlooking the instruction to provide an explanation for their rankings.

Research Question 1 Findings

1. What student understandings of kinematics, dynamics, the conservation of energy, and the conservation of momentum are revealed in students’ responses to RTEPs?

The first research question addressed the type of explanation students used while completing the RTEPs and the students’ understanding of the concepts of associated with their explanation. The students’ explanations were categorized according to the nature of their reasoning and the types of variables the students included with their representations. Table 2 summarizes the representations used by the students on each of the RTEPs.

Table 2

Frequency of representations used by students completing each RTEP

Reasoning	Task 1 (n=29)	Task 2 (n=35)	Task 3 (n=25)	Task 4 (n=36)
Qualitative Representation				
Using only appropriate variables	-	17	4	-
Using appropriate and extraneous variables	-	-	12	5
Using only extraneous variables	15	-	3	30
Using no variables	1	-	-	1
Quantitative Representation				
Using only appropriate variables	-	6	-	-
Using appropriate and extraneous variables	-	-	4	-
Using only extraneous variables	10	-	-	-
Using no variables	-	-	-	-
Dual Representation				
Using Qualitative and Quantitative	1	2	-	-
Alternate Representation				
Using alternate representation	2	10	2	-

Note. Tasks 1 to 4 are the RTEPs completed by the students. Task 1 – Accelerating car and boat trailer; Task 2 – Car Impulse; Task 3 - Pendulum; Task 4 – Projectile.

For each of the RTEPs used in this study, the majority of the students used qualitative representations in their solutions to the RTEPs. The projectile RTEP elicited only qualitative representations with the other RTEPs eliciting a combination of qualitative and quantitative representations. While the accelerating car and boat trailer RTEP did elicit the largest number of quantitative representations in the study (10 quantitative representations), it still elicited more qualitative representations (16 qualitative representations) than quantitative representations. When presented with these RTEPs, the majority of the students relied on qualitative representations to explain their reasoning.

This particular finding answers the question about the type of representations RTEPs elicit from students as they complete the activities. While RTEPs can be approached using either a quantitative or qualitative explanation, the RTEPs used in this study predominately elicited qualitative representations from the students. Physics education research has identified qualitative reasoning as an important aspect of developing a robust and substantive understanding of physics concepts. Physic instructors who incorporate qualitative reasoning into their physics instruction and use RTEPs as an assessment tool should expect an increase in the number of students who use qualitative reasoning to complete these exercises.

The following sections contain a detailed analysis of the quantitative and qualitative representations used by the students on each of the RTEPs used in this study.

Ranking Task Exercises in Physics

The accelerating car and boat trailer.

The accelerating car and boat trailer RTEP required students to consider six different scenarios in which a car was pulling a boat (See Appendix A). In the scenarios, each of the trailers had a different mass and the cars pulling the trailers each reached a different final velocity. In each scenario, the car exerted a force on the trailer to accelerate it while the trailer exerted a force back on the car. The students were asked to rank the scenarios based on the difference between the magnitude of the force that the car exerted on the trailer and the magnitude of the force that the trailer exerted on the car as the car and trailer accelerated from rest to a final velocity.

A review of both the quantitative and qualitative representations used by the students reveals that many students ranked the scenarios by comparing the magnitude of the boat trailer/car forces *between* each scenario rather the differences between the force of the boat trailer on the car and the force of the car on the boat trailer *within* each scenario. This reveals that most of the students were not attempting to answer the question presented in the RTEP but rather a variation of this question. In this variation, the students appeared to be comparing the size of the forces between the different boat trailer combinations rather than the difference between each boat and trailer in the different scenarios. In order to answer this alternate question, however, students would have needed additional information from each scenario to calculate the forces between the car and the boat trailer. The RTEP would have had to include some information about the time it took the car to reach its final velocity for students to correctly calculate the magnitude of the forces in each scenario.

Quantitative representations

The quantitative representations used by the students to complete this exercise used the numerical values for the physical quantities included in the RTEP in some type of calculation. The students completed a number of different types of calculations in their quantitative representations. These calculations included the

- boat trailer's mass times the car's final velocity,
- boat trailer's mass to car's final velocity as a ratio, and
- differences between the boat trailer's mass and the car's final velocity.

The students who calculated a product for this RTEP by multiplying the boat trailer's mass by the car's final velocity for each scenario ranked the scenarios with the highest products as the ones exerting the largest forces and those scenarios with the smallest products as the ones exerting the smallest forces.

The students who calculated a ratio for this RTEP by dividing the boat trailer's mass by the car's final velocity ranked the scenarios with the highest quotients as the ones exerting the largest forces and those scenarios with the smallest quotients as the ones exerting the smallest forces.

The students who calculated a difference for this RTEP by subtracting the car's final velocity from boat trailer's mass ranked the scenarios with the highest differences as the ones exerting the largest forces and those scenarios with the smallest differences as the ones exerting the smallest forces.

While none of these quantitative representations resulted in the correct ranking of the scenarios, the students using quantitative representations completed the mathematical operations correctly and ranked the scenarios in a consistent manner. It is important to point out that while neither the boat trailer's mass nor the cars' final velocity were needed to correctly rank the scenarios, all of the quantitative representations utilized both of these numbers to complete this RTEP. The students completing these calculations indicated that all of the variables included in the scenario were needed to correctly rank the scenarios.

An analysis of these students' quantitative representations reveals that, in an attempt to identify a suitable criterion to rank the items by, the students performed some mathematical operation using the quantitative data in each scenario to derive one number they could then use to rank the scenarios. The student representations did little to communicate the rationale for using that number and did not provide insight into why that number was important in the context of the scenarios under consideration. In most instances, the calculated quantity in these quantitative representations did not correspond to any quantity used to describe the physics concepts related to Newton's laws of motion or forces.

Qualitative representations

The qualitative representations used to complete this RTEP incorporated the application of a rule to rank the scenarios in the correct order. As a qualitative representation, the rule described how changes in one quantity would produce changes in another quantity. While the phrasing of the rule varied between the representations, the rule the student's applied incorporated some statement of the role of the boat trailer's mass and the car's final velocity in determining how much force was exerted on the trailer as the car pulled the trailer forward.

The rule stated that large forces acting on large masses would move the object at a slow speed. One student expressed this rule by writing that "I looked at the mass and velocity differences. Since (scenario) D has such a great mass and small velocity, I thought the force would be the greatest."   Another student stated this rule by writing that "the heavier and slower that it is going will have a greater force." The students using this rule indicated that the trailers with the largest mass would have the greatest difference in forces while the trailers with the smallest masses would have the smallest differences in forces. When the trailer masses were the same, the students indicated the scenarios with the smallest final velocities would exert larger forces than scenarios with larger final velocities.

As with the quantitative representations, students who used qualitative representations were consistent in the applications of the rule and ranked the scenarios according to the rule they identified in their representation.

A review of the student responses to this RTEP reveals that only one student, using a qualitative representation, correctly ranked the scenarios and indicated that the forces between the car and the trailer in each scenario would be identical and the differences between all of the force pairs in each of the scenarios was the same. The student wrote that "I feel that both forces would be the same because each action creates an equal and opposite reaction." All of the other students, using either qualitative or quantitative representations, incorrectly indicated that the difference in the magnitude of the force pairs in at least one of the scenarios would be greater than the differences in the magnitude of force pairs in the remaining scenarios.

An analysis of the student's qualitative representations reveals that the students thought the mass of the trailer and the car's final velocity were related and that a change in one of those quantities would produce changes in the other quantity. In particular, these responses suggested that the students thought the trailers mass would determine the car's final velocity and changes in mass would result in changes in the car's final velocity. These representations focused on the role of mass in determining the car's final velocity without recognizing that it is the force that causes the mass to accelerate and not a moving mass that produces a force.

An analysis of both the qualitative representations and the quantitative representations provided by the students revealed that most of the students did not understand the concept that forces always occur as interactions and the each force in those interactions would be equal in size. These students would most likely not be able to correctly apply Newton's third law of motion to future physics exercises and assignments without further review or re-learning of this physics concept.

Car impulse

The car impulse RTEP required students to consider eight different scenarios in which a car's velocity changed from a before velocity to an after velocity (See Appendix B). The students were shown the before and after velocities of eight different cars and were asked to rank the scenarios based on the magnitude and direction of the impulse that produced that car's change in velocity.

Quantitative representations

The quantitative representations used by the students to complete this exercise incorporated the numerical values for the cars' initial and final velocity. The calculations included the

- difference between car's final velocity and its initial velocity,
- sum of the car's initial velocity and its initial velocity, and
- difference between the absolute values of the car's final and initial velocity.

In these quantitative representations, the students used either the sum or difference between the final and initial velocities as the only basis for ranking the scenarios.

The students who calculated the difference between the car's final and initial velocity ranked the scenarios with the greatest difference as the scenario with the most positive impulse and the scenario with the smallest difference as the scenario with the most negative impulse. The students who calculated the sum of the car's final and initial velocities ranked the scenario with the greatest sum as the scenario with the most positive impulse and the scenario with smallest sum as the scenario as the most negative impulse. The students who calculated the absolute value of the difference between the cars final and initial velocity ranked the scenarios with the greatest difference as the scenario with the most positive impulse and the scenario with the smallest difference as the scenario with the most negative impulse.

While only one of these quantitative representations resulted in the correct ranking of the scenarios, all of the students using quantitative representations completed the mathematical operations correctly and rank the scenarios accordingly. Only the students who calculated the difference between car's final velocity and its initial velocity ranked the scenarios in the correct order.

An analysis of these students' quantitative representations suggested that the students recognized that a change in the cars velocity was related to the impulse that acted on the car but, in most cases, did not treat the car's velocity as a vector quantity.

Qualitative representations

The qualitative representations used to complete this RTEP incorporated some statement relating the change in velocity to the impulse given to the car. The statements equated the change in velocity to the impulse delivered to the car noting that a larger impulse would result in a larger change in velocity. One student indicated that "the change in velocity was proportional to the impulse." Some of the qualitative representations noted that since the mass of all the cars was the same, the mass of the car did not need to be included and focused on the car's change in velocity.

As with the quantitative representations, students who used qualitative representations were consistent in the application of the statements about impulse and ranked the scenarios according to the statements they made about the relationship between the change in velocity of the car and the impulse delivered to the car.

A review of the responses to this RTEP reveals that ten of the students correctly ranked the scenarios and indicated that the cars with the greatest change in velocity would experience the greatest impulse. Of all the RTEPs completed by the students in this study, this RTEP elicited the largest number of correctly ranked scenarios. Of the ten representations used by the students to correctly rank the scenarios, six of the representations were qualitative in nature, one of the representations was quantitative in nature, two of the representations were alternative in nature, and one of the correct rankings was not accompanied with any type of representation.

An analysis of the students' qualitative representations revealed that the students recognized that larger changes in velocity would result from larger impulses acting on the car but, in most cases, did not properly incorporate the direction the car was moving before and after the impulse was delivered to the cars in their explanations. One student who did correctly addressed the directional nature of velocity wrote " I looked at the differences between the starting and ending velocities, taking into consideration their direction."

An analysis of both the qualitative representations and the quantitative representations suggested that most of the students did not understand the vector nature of velocity and were unable to correct rank the scenarios. The vector nature of velocity is incorporated into a number of physics concepts and students may continue to struggle to understand these concepts without an understanding of the vector nature of velocity.

The pendulum

The pendulum RTEP required students to consider six different scenarios with pendulums released from various heights (See Appendix C). Each of the pendulums had a different arrangement of string length and pendulum bob mass. The students were asked to rank the scenarios based on the maximum speed the different pendulum bobs reached at the bottom of their swings after they were released.

A review of the 25 student responses to this RTEP reveals that 19 of the students relied on a qualitative representation to complete the exercise, four of the students relied on quantitative representations, and two of the students accompanied their rankings of the scenarios with alternative representations.

Quantitative representations

The quantitative representations used by the students to complete this exercise incorporated both the mass of the pendulum bob and the length of the pendulum string into their calculations. Unlike the quantitative representations in the other RTEPs used in this study, all of the quantitative representations were identical in how the students calculated the maximum speed of the pendulum. In each quantitative representation, the students multiplied the mass of the pendulum by the length of the pendulum string and used the product of those two numbers to rank the scenarios. The scenarios with the highest pendulum mass and string length products were ranked as the scenarios with the greatest maximum speed while the scenarios with the smallest pendulum mass and string length products were ranked as the scenarios with the least maximum speed.

While none of these quantitative representations resulted in the correct ranking of the scenarios, the students completed the mathematical operations correctly and ranked the scenarios accordingly. It is important to note that the product of a pendulum's mass and length is not a meaningful number in this context and would not provide any direct information about the maximum speed of the pendulum bob.

An analysis of these students' quantitative representations suggested that the students associated increased pendulum lengths and increased pendulum mass with an increased speed for the pendulum bob at the bottom of its swing and that an increase in either the pendulum's length or an increase in the mass of the pendulum bob would result in an increase in the speed of the pendulum bob at the bottom of its swing.

Qualitative representations

The qualitative representations used by students to complete this exercise incorporated statements about the

- mass of the pendulum bob,
- length of the pendulum string, and
- initial angle the pendulum string made with the vertical before it was released.

The qualitative representations described how changes in pendulum bob's mass, the pendulum string's length, and/or the release angle would change the pendulum bob's maximum speed. Some qualitative representations relied on changes in only one of these variables while other qualitative representations relied on a combination of variables to change the pendulum bob's maximum speed.

Unlike the quantitative representations provided by students for this RTEP, some of the qualitative representations discussed the role of the initial angle the pendulum string made with the vertical. While the initial angle the pendulum string made with the horizontal is a quantitative variable in this type of problem, the instructions and accompanying images with each scenario indicate that the pendulum strings in all of the scenarios are at the same initial angle with the vertical.

A number of the qualitative representations described how changes in only one of the variables would change the pendulum bob's maximum speed. The statements related changes in the pendulum's mass, length, or release angle to changes in the pendulum bob's maximum speed. In describing his or her reasoning, one student wrote that "mass doesn't matter, only string length matters." Another student wrote that "the longest string will take the most time to move and it will be then be the slowest pendulum."

The qualitative representations that addressed the pendulum's mass or release angle indicated that increases in mass or release angle would increase the pendulum bob's maximum speed. While changes in the pendulum's mass would not produce any changes in the pendulum bob's maximum speed, it is important to point out that changes in the release angle would result in changes in the pendulum bob's maximum speed. An increase in release angle would increase the pendulum bob's maximum speed if the length of the pendulum remained the same.

In this RTEP, however, all of the pendulums were released at the same angle. One qualitative representation used by a student indicated that an increase in release angle would increase the pendulum bob's maximum speed and since all of the release angles were the same, the student ranked all of the scenarios as having the same maximum speed. The student explained this reasoning with the statement that "the angle is the same, the length and mass do not matter." While this representation is partially correct in this exercise, it is incomplete in that the student did not correctly account for the role of the pendulum string length in changing the pendulum bob's maximum speed.

The qualitative representations describing how changes in both the pendulum's length and mass would produce different maximum pendulum bob speeds relied on different combination of those two variables to determine the pendulum bob's maximum speed. One student wrote "The greater the distance and mass, the greater the speed." Another student concluded " The less string and more mass will have more speed." The combinations that produced the greatest maximum speed for the pendulum bob were

- increased pendulum mass coupled with increased string length,
- increased pendulum mass coupled with decreased string length,
- decreased pendulum mass with increased string length, and
- decreased pendulum mass with decreased string length.

When the students applied these statements to the RTEP, however, it is unclear how they interpreted these statements as they ranked the scenarios.

In some cases, students relying on identical qualitative representations ranked the scenarios in different orders. It appears that when these students encountered scenarios where the change in one variable (e.g. mass) would increase the pendulum bob's maximum speed while the change in the other variable (e.g. length) would decrease the pendulum bob's maximum speed, the students relied on one variable more than the other to rank the scenarios. Their qualitative representations however, did not indicate that a change in one of the variables was more influential than a change in the other variable in determining the maximum speed of the pendulum bob.

The qualitative representations that contained statements about how changes in pendulum length resulted in changes in the pendulum bob's maximum speed were the only representations that would lead to the correct ranking of the scenarios. Of the four representations that addressed this idea, only one student correctly identified and applied the relationship to the RTEP and ranked the scenarios in the correct order. The other qualitative representations that contained statements about how changes in pendulum length resulted in changes in the pendulum bob's maximum speed either had the relationship reversed (short pendulum lengths producing greater speeds) or neglected to indicate that scenarios with identical pendulum lengths would produce identical maximum pendulum bob speeds.

It is also noteworthy that of all the RTEPs completed in the study, the pendulum RTEP exercise had 11 papers that were submitted without any type of representation provided by the student. This was the largest number of papers without any representation for any of the RTEPs completed in the study and may be due to the comparatively small space provided on the page in this exercise for students to write their explanation for their rankings of the scenarios.

An analysis of the student's qualitative representations reveals that most of the students thought that each quantitative variable in the RTEP had some influence on the speed of the pendulum bob at the bottom of its swing and that a change in any one of those variables would change the speed of the pendulum bob at the bottom of its swing.

An analysis of both the qualitative representations and the quantitative representations revealed that most of the students incorporated the mass of the pendulum bob into their reasoning about the speed of the pendulum bob at the bottom of its swing. While pendulums with identical lengths and different masses would have different potential and kinetic energies as the pendulum swings back and forth, they would have the same velocities at the bottom of their swings when released from the same angle. Students with an understanding of the individual concepts of kinetic energy and potential energy that then do not also understand the relationship between these energies when energy is transferred from one form to another will most likely have limited success in applying these concepts to a wide range of physical situations.

Projectile

The projectile RTEP required students to consider six different scenarios in which a projectile was launched from a cannon (See Appendix D). The students were asked to rank the scenarios based on the horizontal distance traveled by the projectile while it was in the air. In each scenario, the students were given information about the mass of the projectile, the angle at which the projectile was launched, the projectile's launch velocity, and the projectile's horizontal velocity.

A review of the representations used by the students reveals that all of the students relied on a qualitative representation to rank the scenarios. While all of the other RTEPs used in this study elicited more qualitative representations than quantitative representations, this RTEP was the only RTEP to elicit only qualitative representations. This is also the only RTEP used in the study in which all of the students who completed the exercise had incorrectly ranked the scenarios.

Qualitative representations

The qualitative representations used by students to complete this exercise incorporated statements described how the horizontal distance traveled by the projectile would be influenced by changes in the

- mass of the projectile,
- launch angle,
- projectile's launch velocity, and
- projectile's horizontal velocity.

Some qualitative representations relied on how changes in only one of these variables would change the horizontal distance traveled by the projectile while other qualitative representations relied on how changes in different combinations of variables would change the horizontal distance traveled by the projectile. As with the other qualitative representations used by students in this study, the students described how changes in one or some of the variables would change the horizontal distance traveled by the projectile.

The qualitative representations that relied on only one variable to rank the scenarios identified either the projectile's launch angle or the projectile's launch velocity as the variable that influenced the horizontal distance traveled by the projectile. The qualitative representations that used the projectile's launch angle to determine the horizontal distance travelled by the projectile indicated that an increase in launch angle would decrease the horizontal distance travelled by the projectile. One student wrote "the greater the angle, the less horizontal distance." Another student wrote " I looked at the angle size. If the angle size is really large, the ball will go high but not far." The qualitative representations that used the projectile's launch velocity to determine the horizontal distance traveled by the projectile indicated that an increase in launch velocity would increase the horizontal distance traveled by the projectile.

The remaining qualitative representations described how changes in the projectile's mass, launch angle, launch velocity, and/or horizontal velocity relied on different combinations of these variables to determine the horizontal distance traveled by the projectile. Unlike the qualitative representations the students provided in the other RTEPs used in this study, the qualitative representations used in the projectile RTEP often indicated that one of the variables would be more influential than the other variables in determining the horizontal distance traveled by the projectile. One student wrote “I looked at the angle and then the mass of the object.” Another student wrote “First I looked at the kg of the ones that had the same velocity and angle. The lighter ones would travel further. Then I looked at the angles and knew 45 was the best degree to throw the furthest.”

A review of the qualitative representations reveals that 19 of the representations identified the projectile’s mass, launch angle, and launch velocity as the variables that would influence the horizontal distance traveled by the projectile. A unique feature of all of these qualitative representations is that they all began with the rule that projectiles launched at 45 degrees would produce the maximum horizontal distance traveled by the projectile. These representations provided this as an absolute statement and did not qualify it in any way. A student wrote “I knew that to achieve the greatest distance, the angle would have to be 45 degrees.”

While objects launched at 45 degrees will travel the maximum horizontal distance, this statement will only hold true if the horizontal distance traveled by the projectile is compared to the horizontal distance of other projectiles launched at different angles with the same launch velocity. In the projectile RTEP, the six different scenarios had three different launch velocities and limited the generalizability of the maximum range occurring at 45 degrees statement that these students relied upon.

Within these representations, the qualitative representations that identified the launch angle as the primary influence on the horizontal distance travelled by the projectile differed on how the projectile’s mass and launch velocity would then influence the horizontal distance travelled by the projectile. While all of the students using these representations ranked the scenarios with a 45 degree launch angle as the scenarios which produced the largest horizontal distance travelled by the projectile, the students ranked the remaining scenarios according to either the projectile's mass or launch velocity. One student wrote "First I looked at the 45 degree ones because that is the best possible angle. Then I chose between the two [scenarios] by mass." Ten of the qualitative representations indicated that an increase in mass would decrease the horizontal distance traveled by the projectile and ranked the remaining scenarios accordingly. The other nine qualitative representations suggested that an increase in launch velocity would increase the horizontal distance traveled by the projectile and ranked the remaining scenarios accordingly.

The remaining qualitative representations used either a combination of the projectile's launch angle and another variable from the exercise or relied on only the projectile's launch angle to rank the scenarios. The qualitative representations using two variables relied on the projectiles launch angle and either the projectile's mass or launch velocity. These qualitative representations either stated the same 45 degree rule that appeared in other qualitative representations or stated that increases in the projectile's launch angle would result in increased horizontal distance travelled by the projectile.

The qualitative representations that identified the projectile's mass as the other variable that influenced the horizontal distance travelled by the projectile stated that increases in the projectile's mass would decrease the horizontal distance travelled by the projectile and ranked the remaining scenarios accordingly. The qualitative representations that identified the projectile's launch velocity as the other variable that influenced the horizontal distance travelled by the projectile stated that increases in the projectile's launch velocity would increase the horizontal distance travelled by the projectiles and ranked the remaining scenarios accordingly.

The horizontal distance travelled by the projectile depends on the projectile's horizontal velocity and the time the projectile is in the air. Since all of the scenarios had the same horizontal velocity, the only quantitative variable that the students needed to consider was the time the projectile was in the air. None of the qualitative representations used by the students accurately discussed the relationship between the horizontal distance travelled by the projectile and the appropriate variable.

An analysis of the students' qualitative representations reveals that the students, while understanding that the different quantitative variables would influence the horizontal distance travelled by the projectile, did not understand how the horizontal velocity of the projectile and the time the projectile was in the air were the only two quantities that determined the horizontal distance travelled by the projectile. The understanding of the independence of an object's horizontal and vertical motion and the relationship between those motions is an essential concept in the study of all two dimensional motions and students without a conceptual understanding of these relationships will be limited in their ability to analyze and understand this type of motion.

Research Question 2 Findings

2. To what extent does the number of quantitative variables in a RTEP influence the type of explanation (qualitative representation, quantitative representation, or other) that students use to complete the RTEPs?

Each RTEP contained a number of quantitative variables the students used to develop a solution and complete the activity. The quantitative variables provided specific quantitative information about the physical quantities in each scenario. Three of the RTEPs contained two quantitative variables and one of the RTEPs contained four quantitative variables. The second research question examined how the type of representation used by the students on the RTEPs varied with the number of quantitative variables in each RTEP. Table 3 summarizes the types of representations used by the students on the RTEPs with different numbers of quantitative variables.

Table 3

Frequency of representations used by students on activities with a different number of variables

Reasoning	2 variables (n=89)	4 variables (n=36)
Qualitative Representation		
Using only appropriate variables	21	-
Using appropriate and extraneous variables	12	5
Using only extraneous variables	18	30
Using no variables	2	1
Quantitative Representation		
Using only appropriate variables	6	-
Using appropriate and extraneous variables	4	-
Using only extraneous variables	10	-
Using no variables	-	-
Dual Representation		
Using Qualitative and Quantitative	3	-
Alternate Representation		
Using alternate representation	14	-

Note. The RTEPs contained a different number of quantitative variables. The two variable RTEPs were Accelerating Car and Boat Trailer, Car Impulse, and Pendulum exercises; The four variable RTEP was the Projectile exercise.

While the RTEPs with two variables elicited various types of representations, the RTEP with four variables elicited only qualitative representations.

Ranking Task Exercise in Physics

Accelerating car and boat trailer.

The accelerating car and boat trailer RTEP provided two variables with each scenario, the mass of the trailer and the final velocity of the car. Because the students were asked to rank the scenarios by only the differences in magnitude of the forces between the car and the boat trailer in each scenario, both the trailer's mass and the car's final velocity were extraneous variables and were not needed by the student to successfully rank the six scenarios in the RTEP.

The quantitative representations relied on both variables in the RTEP to rank the scenarios and used a comparison of the trailer's mass and the car's final velocity to determine in which scenarios the force between the car and trailer were the greatest. The qualitative representations also incorporated both variables in the explanation and relied on both variables to determine the order in which the scenarios should be ranked. The only exception to this pattern was the one qualitative representation that correctly indicated that the force difference in all of the scenarios was the same. In this representation, neither the trailer's mass or car's final velocity was mentioned.

Car impulse.

The car impulse RTEP provided two variables with each scenario, the velocity of the car before and the velocity of the car after the impulse was delivered. Unlike the accelerating car and boat trailer RTEP, students needed to consider and incorporate both of these variables in their solution in order to successfully rank the eight scenarios in the RTEP.

As discussed earlier in this chapter, this particular RTEP elicited the largest number of correct rankings of all the RTEPs used in this study. The initial and final velocity were the only quantitative variables included in the exercise and, as a result, were incorporated in the responses of students who used both quantitative and qualitative representations. Without any extraneous quantitative variables in the RTEP that would lead to an incorrect ranking of the scenario, students who incorporated all of the variables from the exercise in their representation would be able to correctly rank the scenarios if they described or manipulated the quantitative values appropriately.

Pendulum.

The pendulum RTEP provided two variables with each scenario, the mass of the pendulum bob and the length of the pendulum. While ranking the scenarios, the students needed to incorporate only the length of the pendulum into their solution and ignore the mass of the pendulum or explain why the mass of the pendulum was unnecessary in their solution to successfully rank the six scenarios.

Unlike the car impulse RTEP, students needed to address only one of the two variables provided in the scenarios. The inclusion of an extraneous variable in this problem and the incorporation of this variable in the students' representations led many students to incorrectly rank the scenarios in this RTEP.

While the RTEPs with two variables did elicit both quantitative and qualitative representations, more students responded to the RTEPs with qualitative representations than with quantitative representations. When the RTEP included four quantitative variables, the students relied exclusively on qualitative representations to rank the scenarios.

Projectile.

The projectile RTEP provided students with four variables in each scenario. The projectile's mass, the projectile's initial velocity, the projectiles horizontal velocity, and the projectile's launch angle were included in each of the six scenarios in this RTEP. While ranking the scenarios, the students needed to incorporate the projectile's launch angle and initial velocity into their solution and ignore the projectile's mass and horizontal velocity or explain why the projectile's mass and horizontal velocity was unnecessary in their solution to successfully rank the six scenarios.

Unlike the other RTEPs, the projectile raking task elicited only qualitative representations and is the only RTEP in which no one student ranked the scenarios in the correct order. The students' responses did not identify or rely on any algorithms but instead relied on variations of statements indicating that the maximum horizontal distance traveled by the projectile was achieved when the projectile was launched at an angle of 45 degrees or some other relationship between the variables contained in the scenarios.

An analysis of the students' responses reveals that when presented with two variables in a RTEP, most students will in some way incorporate both of those variables into their explanation regardless of whether or not each variable influences the physical quantity they are investigating. The analysis also reveals that an increase in the number of quantitative variables in the RTEP elicited more qualitative representations from students as they completed the exercises.

A review of the student responses to the RTEPs reveals that in both the quantitative and qualitative representations, the majority of the students incorporated all of the variables in their representations. This finding is consistent with the physics education literature on problem solving and the students' reliance on algorithms rather than sound reasoning to complete physics problems (Bowden et al., 1992; McDermott, 2001). When the RTEP included two variables, the students who accompanied their rankings with quantitative representations used both of those variables to complete some type of calculation. The calculations involved the addition, subtraction, multiplication, or division of the quantitative variables provided in the scenarios. When confronted with four variables, all of the students accompanied their rankings with a qualitative representation. With four variables to address in their representations, a quantitative representation involving the inclusion of four variables in some type of calculation may have presented the students with too many possibilities for how to complete the calculations and, as a result, led students to consider using a qualitative representation on this particular RTEP.

Research Question 3 Findings

3. How do the type(s) of explanation (qualitative, quantitative, or other) students who correctly rank the scenarios use when completing RTEPs compare to those who incorrectly rank the scenarios in a RTEP?

While students relied on both qualitative representations and quantitative representations to explain their rationale for ranking the scenarios in the RTEPs, a review of their responses indicates that very few students were able to correctly rank the scenarios. Table 4 identifies the number of correct responses to each of the RTEPs.

Table 4

Number of correct responses to the RTEPs

Ranking task exercise in physics	Number of correct responses	Total number completed
Accelerating car and boat trailer (Task 1)	1	33
Car impulse (Task 2)	10	36
Pendulum (Task 3)	1	36
Projectile (Task 4)	-	36

The RTEP that had the largest number of correct responses was the car impulse ranking task with 10 correct rankings. The accelerating car and boat trailer RTEP and the pendulum RTEP each had one correct ranking. The projectile RTEP had no correct rankings. The number of and type of representation used by students who ranked the scenarios correctly appears in Table 5.

Table 5

Frequency of representations used by students who correctly ranked the scenarios.

Ranking task exercise in physics	Qualitative representations	Quantitative representations	Other representations
Accelerating car and boat trailer	1	-	-
Car impulse	6	1	2
Pendulum	1	-	-
Projectile	-	-	-

Note: While there were 10 correct rankings for the car impulse RTEP one of the ten correct rankings of the scenarios was not accompanied with any type of representation. The student did not write anything in the space provided for their explanation of their rankings.

A review of the types of representations used by the students that resulted in the correct ranking of the scenarios indicates that 8 of the 12 representations used by the students were qualitative in nature. A qualitative representation was used on each of the correct rankings of the scenarios in the accelerating car and boat trailer RTEP and the pendulum RTEP. In the car impulse RTEP, six of the representations used by the students were qualitative in nature while one of the representations was quantitative in nature. The remaining two correct scenario rankings were accompanied with alternate representations.

While there were correct rankings of the scenarios in three of the four RTEPs, the majority of the rankings provided by the students in the RTEPs were incorrect. Of the 141 RTEPs completed by the students in this study, only 12 of the exercises correctly ranked the scenarios in the correct order.

Research Question 4 Findings

4. What is the relationship between a student's score on the RTEPs and the student's rating on how sure they are that their ranking of the scenarios provided in the activity is correct?

After completing the RTEPs, students were asked to indicate on a scale from 1 to 10 how sure they were of their ranking with 1 indicating that they basically guessed and 10 indicating that they were very sure of their ranking of the scenarios in the RTEPs they completed. The number of each of the 10 ratings and the average of rating for each RTEP appears in Table 6.

Table 6

The frequency and average of each "How Sure" rating on the RTEPs

"How Sure" Rating	Task 1 (n=32)	Task 2 (n=36)	Task 3 (n=36)	Task 4 (n=36)
Rating of 1 – Basically Guessed	2	3	-	2
Rating of 2	6	2	4	2
Rating of 3	2	3	4	7
Rating of 4	5	6	8	6
Rating of 5 - Sure	5	7	7	5
Rating of 6	4	3	3	7
Rating of 7	5	4	6	4
Rating of 8	2	5	2	3
Rating of 9	1	-	1	-
Rating of 10 – Very Sure	1	3	1	-
Average	4.75	5.31	5.06	4.72

Note. Tasks 1 to 4 are the RTEPs completed by the students. Task 1 – Accelerating car and boat trailer; Task 2 – Car Impulse; Task 3 - Pendulum; Task 4 – Projectile. On the Task 1 - accelerating car and boat trailer ranking task, one of the student responses was not accompanied by "how sure" ratings.

An analysis of the data indicates that very few students were able to correctly rank the scenarios in the RTEPs and the "how sure" ratings do not correlate to the accuracy of their rankings of the scenarios. While the students were not asked to provide an explanation for their "how sure" ranking on each RTEP, slightly more than half of the students indicated that they were somewhere between "Sure" and "Very Sure" with the accuracy of their rankings of the scenarios. The one exception is task four, the projectile RTEP, in which slightly more than half of the students indicated that they were somewhere between "Basically Guessed" and "Sure" with the accuracy of their rankings of the scenarios.

Task two, the “car impulse” RTEP, had the highest number of students who correctly ranked the scenarios and also had the largest number of “how sure” ratings between “Sure” and “Very Sure.” The “projectile” RTEP, task four, was the one RTEP in which no student was able to correctly rank the scenarios and slightly more than half of the students provided “how sure” ratings between “Basically Guessed” and “Sure.”

Conclusion

The purpose of this study was to determine the understanding students have of four different physics concepts, the type of representations students use when they are asked to complete RTEPs, and determine if students tend to rely predominately on a particular type of representation when completing these activities. A review of the findings from this study reveals that

- very few students ranked the scenarios in the RTEP correctly,
- students relied more on qualitative representations than quantitative representations to complete the RTEPs,
- the qualitative representations used by the students revealed their understanding of physics concepts,
- the qualitative representations used by students contained statements that connected their reasoning to their rankings,
- RTEPs with two variables elicited both qualitative and quantitative representations while the RTEP with four variables elicited only qualitative representations, and

- the quantitative representations incorporated all of the variables in the exercise regardless of whether or not they were appropriate or extraneous variables.

CHAPTER FIVE

DISCUSSION AND CONCLUSION

Discussion

The purpose of this study was to determine the types of representations (qualitative representations, quantitative representations, a combination of qualitative and quantitative representations, or alternate representations) students use when they are asked to complete RTEPs and to describe the students' understanding of physics concepts that were revealed in their explanations as they completed these activities. In this study, the relationship that exists between the number of quantitative variables contained in the RTEPs and the types of representations used by the students to complete each of the RTEPs is also described. An analysis of the student responses finds that very few of the students, using either a qualitative and quantitative representation to complete the RTEPs, were able to rank the scenarios in the correct order. While the literature on physics education research shows that most physics students struggle to understand and apply physics concepts to physics problems, the results of this study reveal how profound and widespread this lack of conceptual understanding can be in high school physics students. The findings of this study have implications for the role of RTEPs in the teaching, learning, and assessment of important physics concepts, knowledge, and skills.

The first research question addressed the type of representations used by the students as they completed the RTEPs. A review of all of the representations used by students on the RTEPs reveals that the students relied more on qualitative representations than quantitative representations when they explained their ranking of the scenarios in the

RTEPs. Asking the students to rank the scenarios according to a specific physical quantity rather than asking them to calculate the value for that specific physical quantity led a majority of the students to think about and describe their solution in a qualitative rather than quantitative manner. These qualitative representations illustrated how students thought about physics ideas on a conceptual level and are the type of student assignments that research in physics education has identified as activities that promote students' understanding of physics concepts (Yap & Wong, 2007).

The authors of the RTEPs (O'Kuma et al., 2000) wanted to give students an opportunity to explain their thinking rather than rely on rote memorization to complete the RTEPs. By designing RTEPs that required students to explain their reasoning, the authors created a situation in which students wrote qualitative responses that had more explanatory power than the quantitative responses that explained the same phenomena (Bowden et al.,1992; Leaonard et al., 1996; Thacker 1994). The qualitative representations used by the students on the RTEPs in this study were consistent with the research on qualitative reasoning in that their representations revealed both the students' understanding of physics concepts and how they applied that understanding to the scenarios they considered.

The qualitative representations used by the students in this study did incorporate the quantitative information provided in each scenario but did not rely on the use of any physics equations or algorithms to arrive at their rankings of the scenarios in the exercises. The qualitative representations relied on statements, concepts, or ideas about the physical quantities involved in the exercise to develop their rankings of the scenario. The design of RTEPs was based on rule assessment theory with the goal of using students' responses to each RTEP to determine what rules the students were relying on to complete the RTEP (Siegler, 1982). An analysis of the students' qualitative responses to the RTEPs provides insight into not only what rules they were using but also how students interpreted and applied those rules. The students' qualitative responses to the RTEPs clearly communicated how the students were applying their understanding of physics to the scenarios in each of the RTEPs. This insight into how students think about physics concepts is an important component physics of teaching and learning (Hammer, 1996; Redish & Steinberg, 1999). The use of RTEPs is one method for engaging students in thinking about physical phenomena and eliciting students' conceptual understanding of physics topics related to those phenomena.

The quantitative representations used by the students in this study included the results of calculations and those results were used to rank the scenarios in each of the RTEPs. While the students completed their calculations correctly, the quantitative representations did not include any explanation of how they used the results of those calculations to rank the scenarios in the exercises. The quantitative representations seemed to infer that when the results of the calculations were large, the specific physical quantity under consideration was also large. The resulting rankings were the arranging of the scenarios based on these calculations in either an ascending or descending order without any discussion of why any scenario should be ranked above another scenario.

The literature describes how students will often rely on formula-centered strategies and 'plug and chug' approaches for problem solving and how these strategies are often used without an understanding of the underlying physics concepts (Jonassen, 2003; Ploetzner et al., 1999). In this study, students using quantitative representations did rely on algorithms to rank the scenarios and complete their quantitative representations. However, the algorithms used by the students usually didn't correspond to the physics equations that were appropriate for the material being considered and, in some cases, the algorithms did not correspond any real physics equations. In the "pendulum" RTEP, the students using quantitative representations multiplied the mass of the pendulum bob by the length of the string creating an equation of mass times length. That equation would not be found in a physics textbook. In the "accelerating car and boat trailer" RTEP, many students using quantitative representations calculated the momentum of the trailer by multiplying the mass of the trailer by the velocity when the RTEP was asking them to consider forces.

The qualitative representations seemed to address and identify the students' current understanding of the physical systems under consideration in each of the RTEPs while the quantitative representations provided little insight into what the students understood about the physics concepts in each of the RTEPs. In both the qualitative and quantitative representations the students were consistent in the application of any rules, concepts, or equations they included in their representations. This analysis is consistent with the physics education literature that suggests that the incorrect rankings were not the result of difficulties with the application of any rules, concepts, or equations, but rather the lack of a comprehensive understanding of the underlying physics concepts and algorithms necessary to successfully complete these RTEPs (Bassock, 1990; Mason & Singh, 2011). Physics instructors need to rely on activities and assessments that go beyond the applications of rules and equations and engage their students in learning experiences that engage and challenge their conceptual understanding of physics concepts. Physics education researchers need to continue to identify and design activities that distinguish between students who can recognize and apply simple rules to physics problems and those students who explain the relationship of important physics concepts to a wide range of physical situations.

The second research question examined the relationship between the number of variables in the RTEPs and the type of representations used by the students to complete the exercises. The findings from the study suggest that the number of variables in each exercise, the use of extraneous variables in each exercise, and the number of different physical quantities represented in the exercises influenced how students relied on either a qualitative or quantitative representation to complete the exercises. While the RTEPs with two variables elicited both qualitative and quantitative representations, the RTEP with four variables, the "projectile" RTEP, elicited only qualitative representations. While the number of quantitative variables could have influenced how students responded to the RTEP, the conceptual nature of two-dimensional motion and the difficulties students have with the associated concepts may have also influenced the students' choice of a qualitative representation over a quantitative representation.

The use of both extraneous and appropriate variables in the RTEPs gave students the opportunity to identify the role, or lack of a role, the various physical quantities had in determining the behavior of the system under consideration in each RTEP. In most of the qualitative representations and in all of the quantitative representations, the students incorporated all of the variables presented in the RTEP into the representation they used to rank the scenarios. The inclusion of extraneous variables in their representation may help explain why so many of the students' submissions did not correctly rank the scenarios in the RTEPs. The inclusion of a variable that had no effect on the behavior of the system may have led students down a line of reasoning that would not result in the correct ranking of the scenarios. This lack of a critical analysis of the role of the variables in physics problems has been cited as a weakness in the design of traditional quantitative physics problems (Halloun & Hestenes, 1987; O'Kuma et al., 2000).

The tendency for students to include all of the variables in their representation may also explain why the car impulse RTEP had the largest number of correct rankings. Since the car impulse RTEP contained only appropriate variables and did not incorporate any extraneous variables in the scenarios, the students would have needed to address both of the appropriate variables to correctly rank the scenarios. With only appropriate variables in the problem, it was just a matter of selecting the correct concept, rule, or algorithm to rank the scenarios in the correct order. The students who subtracted the initial velocity of the car from the final velocity of the car and ranked them in order largest difference to the smallest difference ranked the scenarios in the correct order. The other RTEPs used in this study incorporated at least one extraneous variable and, as a result, when students included the extraneous variable in their representation, they did not rank the scenarios in the correct order.

While the number of variables in the RTEPs appears to have led students to rely on a particular qualitative or quantitative representation, the types of variables in the RTEPs appear to have influenced the type of calculation used in the quantitative representations. In the car impulse RTEP, the students were given two different speeds to consider as they ranked the scenarios. The speeds were the car's initial speed and the car's final speed and both speeds were measured in identical units. A review of the quantitative representations used on the car impulse RTEP reveals that the students relied exclusively on finding either the sum of or difference between the car's final and initial speed to rank the scenarios. The students did not multiply or divide the car's initial and final speeds to develop a ranking of the scenarios.

In the pendulum RTEP, the students were given information about the length of the pendulum's string and the mass of the pendulum bob. Unlike the car impulse RTEP, these variables represented to entirely different physical quantities and were not measured in the same units. All of the quantitative representations used by the students were identical in the calculation they used to arrive at their rankings of the scenarios. In each quantitative representation, the students multiplied the pendulum's mass by the length of the pendulum's string to rank the scenarios.

While many of these quantitative representations used by students in the car impulse and pendulum RTEPs did not result in the correct ranking of the scenarios, the students use of addition and subtraction to combine quantities with identical units and the use of multiplication to combine numbers with different units is consistent with a fundamental and basic understanding of the ways numbers can manipulated and combined in the physical sciences. In the physical sciences, the addition or subtraction of numbers with different units does not result in number with any physical significance. The only way to combine numbers with identical units in the physical sciences and still have them have some physical significance is to either use addition or subtraction to combine them. When the numbers have different units, multiplying or dividing them will result in the calculation of physical quantities with some physical significance while adding or subtracting the quantities will not. A review of these responses reveals that while the students may have had a functional understanding of how to combine and manipulate physical quantities, they lacked the conceptual understanding necessary to combine these numbers in a way consistent with the behavior of these objects in a physical system.

Physics instructors interested in knowing if their students can identify extraneous variables in a physical situation could assign RTEPs that contain extraneous variables to their students and the students' responses to these exercises would reveal whether or not they understood the role that the quantitative variables had in the behavior they were asked to evaluate. Additionally, physics instructors interested in eliciting more quantitative representations from their students should select and assign RTEPs to their students that involve several quantitative variables.

The third research question investigated the relationship between the type of explanation each student used and the accuracy of their ranking of the scenarios in the RTEPs. With so many students incorrectly ranking the scenarios in the RTEPs, the poor performance of students on the RTEP cannot be attributed to the students' reliance on either quantitative or qualitative representations. This finding is consistent with Meltzer's (2005) research where no significant difference existed between the type of students' representational format used by a student and their error rate on physics problems and McDermott's (1991) research indicating students often do not develop a sound conceptual understanding of physics concepts even after receiving instruction on those topics.

The fourth research question examined the relationship between the students' performance on the RTEP and the corresponding "how sure" ratings they provided with the exercise. A review of students "how sure" ratings reveals that many of the students were unable to correctly assess their own understanding of these physics concepts. With the number of incorrect responses on the RTEPs, one would expect the majority of the "how sure" ratings to be low numbers but a review of the ratings provided by the students reveals a spread of "how sure" ratings across the 10 point rating scale. This means that some of the students thought that they were correct in the rankings of the scenarios when actually they were incorrect. This suggests that students either did not accurately reflect on the work they did on the RTEP or the students haven't fostered a metacognitive awareness of the limitations of their own understanding of physic concepts. This finding supports the claim that students incorrectly consider problem solving in physics as the procedural application of equations without the corresponding understanding of the underlying physics principles (Ogilvie, 2009). By correctly completing the procedures, students may have thought that they had also correctly ranked the scenarios.

Implications

The findings of this study have implications for the curriculum, instruction, and assessment used in physics education. The literature review presented in Chapter 3 supports the shift to conceptual approaches to teaching physics and this shift would require the curriculum of physics courses to identify the explicit conceptual understandings that the students need to attain along with descriptions of how students should demonstrate their understanding of those physics concepts. The results of this study highlight the lack of conceptual understanding these students developed during their study of the physics unit and suggest that a physics curriculum that places a primary importance on conceptual understanding is a necessary component in physics education.

Physics education research and the findings of this study reveal that physics instruction needs to explicitly address conceptual reasoning if we expect students to engage in conceptual reasoning while completing physics exercises and problems. Fink and Mankey (2010) caution, however, that the separation of physics instruction into a conceptual component and a problem solving component may result in students relying on two different and separate understandings physics concepts as they complete their assignments. These different understandings may result in inconsistencies in students reasoning or incompatible ideas when the students attempt to merge their both their conceptual and problem solving understandings together. An instructional sequence that has students complete the “pendulum” RTEP and then conduct a lab activity that replicates the “pendulum” RTEP with actual pendulums and the associated data measurements and calculations provides students with an opportunity to uses both qualitative and quantitative approaches simultaneously to investigate the conservation of energy.

The assessment of students understanding of physics concepts needs to match the objectives identified in the curriculum of the course. The results of this study reveal that although the instructors attempted to foster conceptual reasoning and qualitative representations in their students by using RTEPs in each unit, the students did not have the conceptual understanding to develop a viable qualitative representation of the concepts studied. The results of assessments like the RTEPs provide important feedback to both the instructor and the students about the students’ progress towards the objectives of the course. The careful use of assessments in physics can provide feedback that can be used to inform students about the level of understanding of physics concepts, identify students' beliefs about the behavior of various physical systems and phenomena, and provide guidance on how to adjust instruction to foster the students understanding of important physics concepts.

Conclusion

Physics education researchers conduct studies to identify instructional strategies and activities that promote student understanding of physics (McDermott, 2001). A review of the literature indicates that the completion of traditional physics problem sets by physics students that rely on the use and manipulation of various equations and algorithms may not be an effective means to engage students in the meaningful learning of physics topics. There has been a call for physics activities that engage students in activities that reveal how they think about and apply the physics concepts they are learning in physics class (Yap & Wong, 2007). The designers of the RTEPs left open the question of what type of representations students would rely on as they completed these activities. This study finds that the RTEPs developed by O'Kuma, Maloney, and Hiegglke (2000) and used in this study tended to elicit qualitative explanations from students that revealed their understanding of physics concepts and illustrated how the students connected their reasoning to the ranking of the scenarios.

The findings reveal that many of the students were unable to rank the scenarios in the correct order. The difficulties encountered by the students in ranking the scenarios correctly were attributed to their limited understanding of both the physics concepts and the relationships between the variables in the different scenarios. The students did not appear to have difficulty with the manipulation of the variables in the exercises or with the consistent application of the statement or rules the students relied on to complete the exercises.

One area that emerged during the study for further research was the role of extraneous variables in the exercises the students completed. A review of the student submissions in this study revealed most of the students incorporated all of the variables into their representations regardless of whether it was an appropriate or extraneous variable. While the physics education research literature addresses the use of variables in problem solving approaches and method, there is little research about the role extraneous variables have in students' approaches to problem solving in physics.

With a growing awareness of the importance of conceptual reasoning in fostering genuine physics understanding and the struggles students have while trying to develop this understanding, physics education researchers need to continue to investigate, design, and evaluate instructional activities and assessments that help students go beyond using equations and algorithms to solve physics problems. Physics students need opportunities to explore physics concepts and identify how those concepts relate to the physical phenomena they encounter in their physics classes. The research presented in this study has identified how students rely on qualitative representations while completing RTEPs and by incorporating the RTEPs in their instruction, physics teachers can create opportunities for students to discuss and investigate the conceptual ideas that form the basis of genuine physics understanding. While quantitative physics problems may always be part of physics teaching and learning, they should not be the sole criterion for engaging and evaluating student understanding. Qualitative physics instruction, activities, and assessments are fundamental and necessary components of any physics program designed to promote and foster meaningful physics understanding.

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APPENDIX A
ACCELERATING CAR AND BOAT TRAILER RANKING TASK EXERCISE IN PHYSICS

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Ranking Task Exercises in Physics

APPENDIX B
CAR IMPULSE RANKING TASK EXERCISE IN PHYSICS

APPENDIX C
PENDULUMS RANKING TASK EXERCISE IN PHYSICS

APPENDIX D
PROJECTILE RANKING TASK EXERCISE IN PHYSICS