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Investigating Teachers' Content Knowledge and Pedogogical Content Knowledge in a Middle School Physical Science Curriculum on Force and Motion

Daniel Patrick Laverty
University of Maine

INVESTIGATING TEACHERS' CONTENT KNOWLEDGE AND PEDAGOGICAL CONTENT KNOWLEDGE IN A MIDDLE SCHOOL PHYSICAL SCIENCE CURRICULUM ON FORCE AND MOTION

By

Daniel Patrick Laverty

B.S. University of Maine, 2005

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Advisory Committee:

John R. Thompson, Associate Professor of Physics, Cooperating Associate Professor of STEM Education; Co-Advisor

MacKenzie R. Stetzer, Assistant Professor of Physics, Cooperating Assistant Professor of STEM Education; Co-Advisor

Michael C. Wittmann, Professor of Physics, Cooperating Professor of STEM Education

THESIS ACCEPTANCE STATEMENT

On behalf of the Graduate Committee for Daniel Laverty we affirm that this manuscript is the final and accepted thesis. Signatures of all committee members are on file with the Graduate School at the University of Maine , 42 Stodder Hall, Orono, Maine.

Dr. John R. Thompson, Associate Professor of Physics, Cooperating Associate Professor of STEM Education 12/11/15

Dr. MacKenzie R. Stetzer, Assistant Professor of Physics, Cooperating Assistant Professor of STEM Education 12/11/15

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By Daniel Patrick Laverty

Thesis Co-Advisor: Dr. John R. Thompson
Thesis Co-Advisor: Dr. MacKenzie R. Stetzer

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Teaching is a profession that requires the incorporation of many types of knowledge in order to create effective instructional experiences that promote student learning. Teachers need to blend their knowledge of the content with the methods for delivering that content and an understanding of their students' thinking. With increasing concern in the United States over student achievement in science and mathematics, there is ongoing discussion about which elements of teacher knowledge most directly correlate with effective instruction. How do specific strands of teacher knowledge blend to influence student learning outcomes? This study explores the roles of teacher content knowledge (CK) and pedagogical content knowledge (PCK), particularly teacher knowledge of student ideas (KSI), in the context of a middle-school physical science curriculum on force and motion. The study takes place within the Maine Physical Sciences Partnership (MainePSP). The primary focus of the MainePSP is the professional development of physical science instructors in grades 6-9 via curriculum renewal using common instructional resources across multiple school districts in rural Maine.

Teachers and their students were given multiple-choice assessment items to examine teachers' CK as well as the learning gains of their students. To measure teacher KSI, teachers were additionally asked to predict if a significant portion of their students (>10%) would select a multiple-choice option on a certain assessment item and to articulate student reasoning for selecting that choice. For both the CK and the KSI surveys, teacher performance varied widely, between 10% and 90% of the maximum score on each survey represented, with little to no correlation between CK and KSI scores. Overall results from the student assessment indicate that students come into the curriculum with incorrect ideas about force and motion, but are on par with comparable populations seen in the literature. Furthermore, there was little shift in student understanding of force and motion concepts after instruction of the curriculum. Additionally, teacher CK and KSI were not strong predictors of student performance when related to the narrow learning gains observed. We discuss possible factors to which this lack of correlation may be attributed, including the implementation process and elements of the curriculum itself, and also the resolution of the KSI instrument. Recommendations for future research are provided.

DEDICATION

This thesis is dedicated to my wife Jessica, and daughter Kaya. Thank you for your unending patience and faith in me. I love you both more than words can tell.

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CHAPTER 1

INTRODUCTION

The education system that has served the United States for over the past two centuries finds itself stuck in a cycle of perpetual reform. International assessments such as the Program for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMMS) continually place U.S. student achievement behind that of students in other developed nations despite the many initiatives undertaken at both the federal and state levels (OECD, 2012; Mullis, Martin, & Arora, 2012). What can be done to increase U.S. student achievement? Reform efforts have increasingly focused on the teacher as a key variable in student learning. Standards for teacher certification, pre-service training and, more recently, measures of teacher effectiveness have all been incorporated into models that attempt to bridge the gap between U.S. students' achievement and that of their peers in other nations.

If the teacher is such a deciding factor in student achievement then just what types of knowledge make an effective teacher? Is it mastery of content that allows for deep understanding of a content area, or is it pedagogical skills that are not specific to any one subject? Research into the knowledge required for teaching has indicated that there is another domain of knowledge that is a blend of both pedagogical practice and specific to each content area and topic. This is the domain of pedagogical content knowledge (PCK), or the content specific knowledge required to teach a certain subject (Shulman, 1986). Since PCK was first proposed as a theoretical construct in the 1980s, it has blossomed into a wide field of research in many different subject areas. Much work has been undertaken to further delineate domains of teacher knowledge and methods have been developed for measuring these different domains; however, these models and methods are still not complete. Further research and refinement of methods are required to validate the theoretical construct of PCK.

Results of this research can be an important tool to inform educational reform efforts and to indicate where resources should be focused for teacher training and certification. Where does this teacher knowledge come from? Research has suggested that teacher knowledge comes from two sources: teachers' own teaching practices and their own education or professional development (van Driel et al., 1998). If it can be determined which domains of knowledge are the most closely linked to student learning outcomes, then methods can be developed to help teachers acquire and expand on these domains.

This study aims to measure specific domains of teacher knowledge and assess their respective effects on student learning within a middle-school physical science curriculum on force and motion. In particular, we are interested in the interplay of two types of teacher knowledge, Teacher Content Knowledge (CK) of a subject and their knowledge of the understanding that their students bring to the learning of that subject. Teacher CK refers to teachers' understanding of the subject beyond the realm of teaching or instruction. Teacher Knowledge of Student Ideas (KSI) refers to their understanding of common student difficulties and preconceptions. The specific research question addressed by this study is: *What* *are the relative effects of teacher content knowledge and teacher knowledge of student ideas on students learning in a middle-school physical science curriculum?* The results of this and other similar studies are necessary to inform teacher pre-service training and professional development.

Chapter 2 of this thesis examines the literature supporting PCK research, starting with its original conception as a theoretical construct through further efforts to define a comprehensive framework of teacher knowledge. It then looks at studies that have sought to quantify and measure PCK in the field of science education– most importantly, those that have focused on teacher KSI. Chapter 2 ends with a review of the literature surrounding student difficulties in Newtonian force and motion from early education through the college level and instruments that have been developed to probe this understanding.

Chapter 3 describes the context of the study, including the setting and populations. It also details the methods used for compiling and administering the surveys to both students and teachers.

In Chapter 4 the results of the respective survey instruments are detailed as well as a discussion of the relevance of any levels of correlation between the different measures. The results of this study do not suggest a strong relationship between either teacher CK or KSI on student learning. The assessments found little correlation overall between the three measures. This lack of correlation is examined in Chapter 4; possible reasons for an overall lack of student learning gains are discussed in the conclusion in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

Teaching requires many different types of knowledge. Instruction that leads to student learning not only requires deep content knowledge of a subject in order to present that content to students, but also knowledge surrounding that content that relates to how it is learned (Grossman, 1990). It is not enough to be an expert in a certain field; teaching requires much more. It extends beyond simply understanding content and knowing the techniques of classroom management. This type of "teacher knowledge" is a specific type of knowledge, which blends content understanding with an understanding of learning and learners, specific to the subject being taught. This knowledge at the intersection of content, students, and learning is the realm of Pedagogical Content Knowledge, or the Knowledge for Teaching.

2.1. Pedagogical Content Knowledge

In his 1986 publication, *Knowledge Growth in Teaching*, Lee Shulman first introduced and outlined the concept of pedagogical content knowledge (PCK) and proposed a theoretical framework for its development. By introducing the concept of PCK, Shulman initiated an ongoing conversation and line of research that has attempted to bridge what he described as the gap between the content teachers are required and expected to know and the tools they should possess to make that knowledge accessible to students. These are not simply the tools of classroom management but rather knowledge of strategies and student ideas that are particular to the content being taught. Shulman described PCK as "the most useful ways of representing and formulating the subject that make it comprehensible to others." PCK includes the knowledge of student difficulties and preconceptions that are specific to a topic as well as the effective methods to address them. PCK is the intersection of content knowledge and pedagogical knowledge specific to a content area. Shulman argued that both expertise in a field and the skills and knowledge of pedagogical practice together are necessary for effective teaching.

Rather than attempting to categorize the way in which teachers organize their classroom, divide time, plan lessons, etc., Shulman looked to understand where teachers' knowledge comes from and the ways in which novice teachers transform from successful college students to successful teachers. How do teachers make decisions about how to teach a topic? How will they choose to represent an idea or address student misconceptions? How do they adapt their knowledge of subject matter into forms that are comprehendible to students?

Shulman recognized that to be able to speak about the relationships between content knowledge and pedagogical knowledge, a framework for teachers' knowledge must be established. In an attempt to create such a framework, Shulman proposes three categories of knowledge: Content Knowledge, Pedagogical Content Knowledge, and Curricular Knowledge. Content Knowledge refers to the structure of subject matter both substantive, as the organization of facts and ideas, and syntactic, as the set of rules and norms that support the content. Why is an idea held to be true and how is it distinguished from alternative explanations? It is not only *knowing* that something is true but also *understanding* why it is true. Content knowledge should also include an understanding of the organization of content and which concepts or ideas are most central and relevant to a subject matter.

Pedagogical Content Knowledge is the content knowledge beyond subject matter that Shulman describes as the content knowledge for teaching. PCK includes all the strategies and representations that make for effective teaching of a content area. This includes a large body of examples, demonstrations, analogies, and explanations that are specific to the content being taught and that allow for effective learning by the student. It is not simply a list of strategies but knowledge of how and when to employ them. PCK also includes the understanding and knowledge of student ideas and what makes a subject difficult or easy for students. This includes common misconceptions and methods for recognizing and addressing them.

Curricular Knowledge refers to a knowledge of the curricular materials available and variety of programs and resources for teaching a certain subject area. This includes an understanding of alternative methods and practices for instruction. Shulman posited that future teacher education efforts will need to adjust to take into account the connections between content and process. These programs should build out from the research base on student ideas and difficulties particular to subject matter.

2.2. Further Defining Domains of Teacher Knowledge

Subsequent research into the content-specific knowledge needed for teaching has expanded into many different subject areas since Shulman's initial proposal. Further research has also expanded and redefined Shulman's initial categories of teacher knowledge.

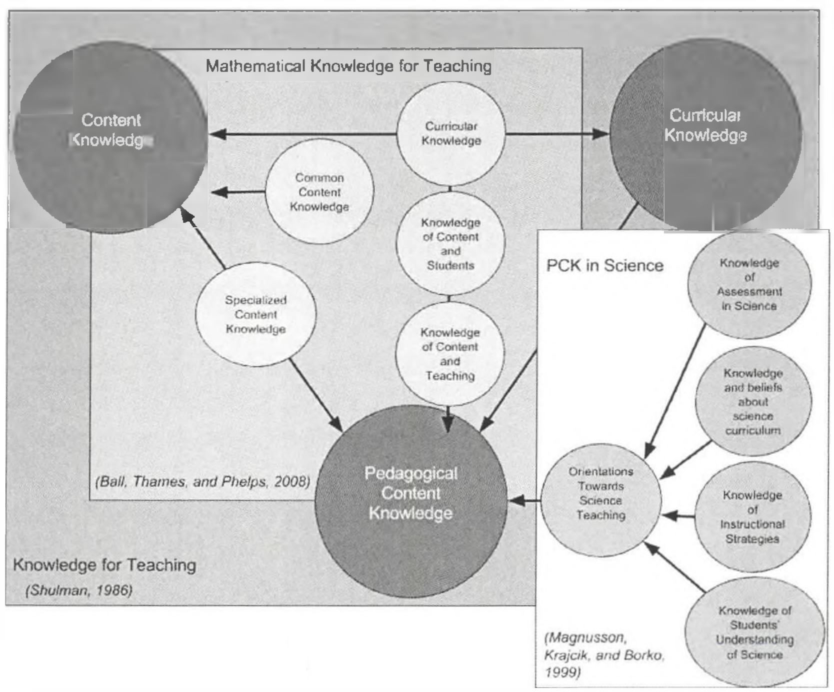
One of the largest efforts in PCK research has occurred in the field of mathematics education. In their research into teacher knowledge in mathematics Ball, Thames, and Phelps (2008) argue that PCK lacks a firm foundation and its development has suffered because of this neglect. They contend that after 20 years of research and exhaustive citation in the research community, PCK still lacks definition and an empirical base. This lack of grounding limits its usefulness. "Without empirical testing, the ideas remain, as they were 20 years ago, promising hypotheses based on logical ad hoc arguments about the content believed to be necessary for teachers."

Ball et al. point to the extensive list of citations as evidence of interest and validation of PCK in the research community. They claim that Shulman's original article (1986) and the one following in the *Harvard Education Review*, appearing in 1987, have been cited in over 1,200 journal articles, appearing in over 125 different publications in subjects such as science, engineering, mathematics, nursing, history, business, communication, religion, music, special education, English, social studies, physical education, etc. The idea of PCK caught on like a wildfire.

Ball et al. then question, with all this attention on PCK, what have we learned? Much of the PCK research, following its introduction in the 1980s, has focused on teachers' orientations towards subject matter and how that orientation influences the way they present content to students. This includes how teachers' backgrounds shaped their approach to subject matter. How does a teacher whose focus is biology approach the teaching of physics, and how is it different from that of a teacher with a physics background? Another line of research has focused on teachers' knowledge and recognition of student ideas and misconceptions (e.g., Hill, Ball and Schilling, 2008; Thompson, Christensen and Wittmann, 2011; Sadler, Sonnert, Coyle, Cook-Smith and Miller, 2013). Other researchers have developed interview-based and observational methods for assessing teachers' PCK (e.g., Grossman, 1990; Lee, Brown, Luft, Roehrig, 2010; Moru and Qhobela, 2013). In mathematics, this has been used to investigate the ability of teachers to create explanations for procedural knowledge, such as having the ability to explain why we must multiply by the reciprocal when dividing fractions, or being able to explain the borrowing subtraction algorithm. Although this body of research is well established, Ball et al. argue that Shulman's basic call to develop a coherent theoretical framework for content knowledge for teaching has been disregarded. They claim that this feature has been overlooked. "Scholars have used the concept of pedagogical content knowledge as though its theoretical foundations, conceptual distinctions, and empirical testing were already well defined and universally understood."

Shulman did not attempt to quantify or list skills and knowledge that would be required of teachers in a specific subject matter. His work was more of an attempt to establish a framework that could inform both the research and policy community and could bring attention to the "missing paradigm." Shulman listed three categories that were specific to teacher content knowledge: Content Knowledge, Curricular Knowledge, and Pedagogical Content Knowledge. Ball and colleagues further refine two of these categories by suggesting that Shulman's Content Knowledge can be further broken down into Common Content Knowledge (CCK) and Specialized Content Knowledge (SCK) and that Pedagogical Content Knowledge can be further divided into Knowledge of Content and Students (KCS) and Knowledge of Content and Teaching (KCT). These subdivisions are meant to elaborate, not replace, Shulman's original taxonomy.

Figure 2.1. Domains of Teacher Knowledge



Common Content Knowledge (CCK) is the mathematical knowledge that is used in settings other than teaching. This includes the ability to recognize errors, make correct calculations and pronounce terms correctly. CCK is mathematical knowledge required for teaching but not unique or exclusive to it.

Specialized Content Knowledge (SCK) is the mathematical knowledge that is used for and exclusive to teaching. This may include the ability to recognize the nature of student errors and interpretations. This goes beyond the required procedural knowledge of math that an engineer or accountant must possess to include a deeper understanding and ability to communicate that understanding to students.

Knowledge of Content and Students (KCS) combines knowledge of mathematics with knowledge of students. This includes anticipating student ideas and misconceptions. It also includes interpreting student understanding as it evolves and through student language.

Knowledge of Content and Teaching (KCT) combines knowledge of mathematics with knowledge of teaching. KCT is about instructional decisions. This category includes the knowledge of sequencing and the design of instruction, the evaluating of advantages and disadvantages between different representations, and the ability to present examples that are effective for creating deeper understanding among students.

Why is this refinement and remapping of the domains of knowledge for teaching so important? It is necessary when studying the relationship between students' achievement and teachers' content knowledge to be able to assess whether one domain has a greater effect over another. Secondly, another advantage is being able to assess whether different teacher preparation or professional development programs have greater effects on certain domains. Third, a clearer notion of these categories might inform teacher support materials and curriculum development.

2.3. PCK in Science Education

In the field of science education, Magnusson, Krajcik, and Borko (1999) describe PCK as a transformation of several types of teacher knowledge. They argue that effective teaching requires the integration of knowledge from various domains. This "integrated and differentiated knowledge," as Magnusson et al. refer to it, provides the ability to organize and present lessons under the real time constraints of the classroom, allowing for "deep and integrated understanding" by students. Based upon the work of Shulman (1986) and Grossman (1990), Magnusson expands upon the existing framework outlined by Grossman to conceptualize PCK to consist of five discrete, but related, components:

1. Orientation towards science teaching
2. Knowledge and beliefs about science curriculum
3. Knowledge of students' understanding of science
4. Knowledge of assessment in science
5. Knowledge of instructional strategies

Orientation towards science teaching plays a central role in the PCK framework and includes teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level. This is the general way in which a teacher views the teaching of science and the objectives of instruction. A teacher's orientation is not defined by the strategy they use but rather by his or her purpose for employing it, as some orientations may use similar approaches to presenting materials but with different purposes. The next category of teacher knowledge, *knowledge and beliefs about science curriculum* was considered separate from PCK by Shulman. This domain includes the goals and objectives of curriculum relating to relevant standards and the vertical position of their subject within the progression of student learning. It also includes the teacher knowledge of specific programs and materials. Magnusson argues for its inclusion in a PCK framework, citing that it is knowledge of the curricular materials that divides the content specialist from the pedagogue, which is a defining factor of PCK.

Teacher *knowledge of students' understanding of science* includes both the knowledge of prerequisite ideas and skills that students will need to learn a topic and also areas of student difficulty. It also includes teachers' knowledge of varying approaches that students will use to learn specific content depending on the developmental level and learning style of an individual student. Effective teachers will recognize the varying needs of their students and have knowledge of varying strategies that will be best suited for a type of learner in a specific subject area. Student difficulties may arise from the abstractness of a concept and the inability of students to ground concepts in any common experience. Other areas of difficulty may have to deal with students' ability to plan and solve problems. Other student difficulties may arise from direct misconceptions that students hold, which will inhibit their ability to learn concepts that may seem counterintuitive.

Studies that have looked at teachers' knowledge of student difficulties have found that even when teachers have some knowledge of student difficulties, they often lack knowledge that will help students overcome them. One issue surrounding this research is that often teachers are found to hold some of these misconceptions as well as their students. The research, conducted by the University of Maryland's Middle School Probeware Project (Magnusson, 1994), found that teachers' lack of awareness of student errors, or the need to address them, might have contributed to students still holding these common misconceptions after instruction. Simply being aware of common misconceptions is not enough to ensure that they are addressed in a productive way. Teachers require strategies to confront them.

The domain of *knowledge of assessment in science* includes both teacher knowledge of what parts of student learning are most important to assess in a certain content area and also by what means those parts are assessed. Teachers should recognize which aspects of scientific literacy are more appropriately addressed in a content area and what are the advantages and disadvantages of different assessment methods.

The last domain proposed by Magnusson et al., *knowledge of instructional strategies,* is a broad category that includes both the strategies that teachers possess to make content accessible to students and also how they make decisions about which models or representations are most appropriate. This refers to illustrations, models, examples and analogies that can be used to represent specific content to students and also knowledge of their respective strengths and weaknesses. Teachers should be aware of diverse representations and also where and when which will be most appropriate. This may also include a teacher's ability to create such representations given a learning situation. Analogies given by teachers can be common examples of representations used in instruction.

2.4. Knowledge of Student Ideas

One common component of these various frameworks is that teacher knowledge includes the ideas and preconceptions that students bring to learning. This type of knowledge of student thinking is found throughout research efforts surrounding PCK. This falls under Shulman's *Pedagogical Content Knowledge*, Magnusson's *Knowledge of Students' Understanding of Science* and Ball's *Knowledge of Content and Students.* Student difficulties and preconceptions have been included as a central part of teacher knowledge in other research efforts as well, such as Grossman (1990) and Hill, Schilling, & Ball (2004). We label this specific type of knowledge as the Knowledge of Student Ideas (KSI). KSI includes knowledge of common student misconceptions, confusions and difficulties.

Effective instruction requires that teachers possess knowledge of student preconceptions and difficulties within a particular subject in order to address, build upon, and reshape these incorrect and partial understandings. Models of student learning and conceptual change, such as the Conceptual Change Model proposed by Posner, suggest that the ideas and preconceptions that students bring to new learning situations are very resistant to change (Posner et al., 1982). For accommodation of a new concept to occur – to modify a student's existing (incorrect) model using new information – there must be a certain amount of cognitive conflict wherein students can see the shortcomings and breakdown of their initial understanding. For instruction to be effective, teachers must recognize and be able to anticipate these common preconceptions held by students in order to efficiently target them.

2.5. Previous Studies Measuring PCK

The question of how to best scaffold the development of PCK among new and pre-service teachers has become both a focus of teacher preparation programs, and the research within these programs. While many aspects of PCK are gained through teaching experience itself, one of the most substantial contributions teacher preparation programs can make to building pre-service teacher's PCK is by exposing them to student ideas that they will later encounter in their practice. Thompson, Christensen, and Wittmann (2011) present a model of instruction for developing pre-service teachers' knowledge of student ideas and also for assessing the acquisition of that knowledge in a graduate-level physics education course. Their instructional cycle included content, examinations of relevant research on the learning of that content, and examination of student ideas within that content. Questions were administered both before and after instruction to the pre-service teachers to assess their levels of content understanding of physics and their understanding of student ideas. To assess KSI, future teachers were given a physics problem and asked to predict what an "ideal incorrect student" might answer to this problem. These incorrect responses were deemed reasonable if they were consistent with incorrect student ideas from research literature. The results of this study suggest that courses designed to engage future teachers in literature on student thinking can have a positive effect on the PCK of future teachers, specifically their KSI.

Another vehicle for enhancing the KSI of pre-service teachers is through authentic teaching experiences, such as teaching assistant and learning assistant programs at both the graduate and undergraduate level. Maries and Singh (2013) reported on a study looking at the ability of first-year physics graduate students to predict student difficulties among introductory physics students. All the graduate students in the study were instructing introductory undergraduate physics labs and recitations at the University of Pittsburgh. As part of their teaching assignments, graduate students were enrolled in a semester-long teaching assistant (TA) training course. This study looked at the connection between graduate students' abilities to predict undergraduate student difficulties related to graphical representations of motion and how these predictions relate to the learning gains of students in the recitation sections that the graduate students instructed. Graduate students were given the Test of Understanding Graphs in Kinematics (TUG-K), a multiple-choice assessment tool (Beichner, 1994), and asked to complete three tasks. First, they were asked to identify the correct answer for each question, then they were asked to select which one of the four remaining incorrect choices would be most commonly chosen by introductory physics students after instruction if the introductory student did not know the correct answer. They then repeated the second step as a group discussion with 2-3 other graduate TAs.

PCK scores for each graduate student were calculated based on their selection of the most common incorrect answer and what fraction of introductory students actually chose that incorrect answer. Maries and Singh's analysis found that working in groups significantly improved the graduate students' PCK scores. They additionally found that graduate students were more successful at predicting moderate student difficulties compared with major difficulties and that their ability to predict these difficulties was very context dependent, meaning that their ability to predict the difficulty varied when the same student difficulty appeared in a different question with different contexts.

Looking at the interaction of teacher knowledge and student learning at the middle school level, Sadler et al. (2013) have used a very similar method to our own to look for correlations between teacher subject matter knowledge (SMK), teacher knowledge of students' misconceptions (KOSM), and student learning. Sadler sent multiple-choice tests to teachers and their students across the U.S. Over 9,500 students and 181 middle school teachers completed the test items, with students taking them pre-instruction, in the middle of the year, and post-instruction. Teachers were also asked to predict the most common incorrect student answer. Sadler et al. differentiated between questions that showed a strong or weak misconception based on student responses. On an item, if a single incorrect multiple-choice option received greater than 50% of student responses, it was labeled as a strong misconception.

Also included in their design were questions to gauge students' effort and ability at taking the test. This included two reading items to measure students' literal and inferential abilities of science texts. Two mathematics items were also included to measure both operational math ability, and the ability to solve a word problem. These additional questions allowed Sadler et al. to differentiate between "low non-science" and "high non-science" students based on their reading and math responses. Their analysis found that low non-science students were more dependent on their teacher's SMK and made no significant gains unless their teacher had high SMK and the question did not include a strong misconception. Questions that showed strong misconceptions were found to have little gain with low non-science students.

For high non-science students, they found a clear relationship between teacher knowledge and student learning. Their analysis found that high non-science students made moderate gains, regardless of their teachers' SMK or KOSM, but those high non-science students who had teachers with higher levels of SMK and KOSM made more significant gains. This was particularly true for questions with a strong misconception. Teachers who had great KOSM saw greater learning gains among their students with greater math and reading abilities than teachers with lower levels of KOSM.

2.6. Difficulties and Preconceptions in Force and Motion

Piaget first detailed young children's abilities in the preoperational stage to understand motion as changes in position, and to judge differences in speed by one object overtaking another or reaching a finish point first. With the development into the concrete operational stage, children can come to understand the relationship between distance traveled and duration. Adding to this earlier work, Mori, Kojima and Deno (1976) found that Japanese students could develop this idea of differential velocity at earlier ages, while still in the preoperational stage. This idea of speed as a ratio of distance per unit of time is fundamental in building the concepts of constant velocity (uniform motion) and acceleration.

Driver, Guesne and Tiberghien (1985) compiled findings from various studies to outline the difficulties students face in learning force and motion concepts. Due to students' own experiences with the motion and behavior of objects in the everyday world around them, students enter the learning of Newtonian force and motion with a wide variety of previously formed explanations for what role forces play in the motion of objects. Driver summarizes these student ideas into five intuitive rules:

1. Forces are to do with living things
2. Constant motion requires a constant force
3. The amount of motion is proportional to the amount of force
4. If a body is not moving there is no force acting on it
5. If a body is moving there is a force acting on it in the direction of motion

Students believe that for an object to move at uniform motion there must be a constant force applied to maintain that motion (rule 2). Numerous studies have shown this idea to be widespread among students of all ages and abilities, even after instruction. Students commonly report that if a force is not continuously applied then the force that was first applied to make the object move is "used up" and the object will slow and stop due to the exhausting of the force. Additionally, students also believe that if an object is not moving there must be no force acting on it (rule 4). In short, students commonly hold the idea that any motion, even uniform motion, directly correlates to an applied force and therefor lack of motion implies lack of force, or forces.

Related to these first ideas is the "impetus theory" were force is thought to be stored in objects and objects remain in motion until the force runs out (rule 3). This idea is often probed by asking students to interpret the forces acting on objects projected upwards into the air, such as a coin or ball. Students often believe that the ball will continue upwards until the force imparted from the throwers hand is used up or runs out, then gravity will take over and return the ball to the earth.

Students also commonly believe that if an object is moving in a direction there must be some force acting on the object in that direction to cause that motion, regardless of the acceleration of the object (rule 5). Again, motion implies a force and that force is in the direction of motion. These ideas come from real life experience and make intuitive sense. They fit the model that we have grown with and interact with everyday and are therefor very resistant to change, even after learning has occurred.

These student difficulties in physics, and specifically in concepts relating to Newtonian force and motion have also been extensively documented at the college level. In a 1982 study, Clement reported how "conceptual primitives" obstruct college students' abilities to gain full understanding of force and motion concepts. These "conceptual primitives," or preconceptions, are the mental constructs that students form and bring to learning before entering the classroom, based on real world observations and experiences. Forming mental models in a world that is constantly constricted by friction leads many students to believe that motion implies an applied force. Clement used various exercises, such as coin toss and pendulum models, to show that even after instruction many students still hold on to the belief that if an object is moving, even at a constant velocity, their must be a force causing the motion. The work of Clement shows how the earlier preconceptions outlined by Driver and Piaget are still present and resistant to change even at the college level.

2.7. Instruments Used for Measuring Understanding of Force and Motion

One facet of this research has been the development of instruments to measure student understanding of force and motion. Many instruments have been developed and validated for this purpose, mostly at the college level. Among many are the Force Concept Inventory (FCI)(Hestenes, Wells, & Swackhamer, 1992), the Test of Understanding Graphs in Kinematics (TUG-K)(Beichner, 1994), and the Force and Motion Conceptual Evaluation (FMCE)(Thorton and Sokoloff, 1998). Of these instruments, the FCI has been the most widely used and adopted (Hake, 1998). The FCI was developed by researchers at Arizona State University to evaluate student understanding of Newtonian force concepts at the college and upper high school levels. The inventory consists of 29 multiple-choice questions.

Each question presents students with a scenario and asks them to choose between 5 options, one displaying the complete Newtonian explanation for the scenario and four distractors based upon common incorrect understandings. In this way, students are forced to choose between Newtonian explanations and alternatives that make intuitive sense based on experiences with force and motion in their everyday lives. The complete FCI probes 28 distinct misconceptions, which can be grouped into six larger categories. These categories include: *kinematics, impetus, active force, action/reaction pairs, concatenation of influence* and *other influences on motion*.

Items in the category *Kinematics* includes the ability to differentiate between position, velocity, and acceleration. This includes representations of motion and being able to distinguish between representations of objects moving with constant motion versus ones that are experiencing acceleration.

The category of *Impetus* includes items that test for the misconception that objects in motion must have some intrinsic force that is keeping them in motion, and without this force the object's motion will cease.

Active force is represented by items that test student understanding of the relationship between force, velocity, acceleration. This probes the misconception that motion must be the result of a force and therefore velocity is a result of a force, rather than acceleration.

Action/Reaction Pairs items test student understanding of forces applied between objects concerning Newton's third law, where students often employ a dominance principle. In this way they often, incorrectly, predict that larger or more massive objects apply greater force on other smaller objects in an interaction. *Concatenation of Influences* relates to the previous category but includes items that probe for student misapplication of Newton's third law, such as on opposing forces acting on one object.

The sixth misconception category, *Other influences of Motion,* includes items dealing with a variety of misconceptions, such as those relating to gravity, air pressure, mass, centrifugal force and the lack of forces attributed to inanimate objects.

Prior to publication, the FCI was field tested by administering it to more than 1500 high-school students, and over 500 university students. Among high school physics students, the mean scores before and after instruction were 27/51 for regular classes, 34/67 among honors classes, and 57/71 among AP classes. These represent absolute gains of 24, 33 and 14 points respectively. The authors note, that although these scores are low, they are at the baseline for developing a complete model of Newtonian force and motion, and these students are still successful physics students who may be scoring well on conventional tests. They also comment that many conventional tests and curricula may be based on more quantitative problem solving skills that avoid these major misconceptions, as teachers see these concepts as too difficult and therefore do not make them the focus of instruction or assessment.

One issue that has been brought to light with the FCI is that the length and complexity of the questions and multiple-choice responses may hinder students with lower reading levels and English language learners. The Simplified Force

Concept Inventory (SFCI) was created from the original FCI as an attempt to modify the instrument for use in high school physics settings by simplifying the language of items and creating more familiar and relevant contexts for high school age students (Jackson, 2007). Language and contexts of the FCI test items were modified to conform to a seventh grade reading level. A study by Popp and Jackson (2009) among high school 11^{th}- and 12^{th}-grade students found that the FCI and SFCI both measure the same concepts and at the same level of difficulty with no significant difference between mean test scores. The study also reports findings indicating that 9^{th}-grade students perform significantly higher on the simplified version than on the original FCI. This result indicates that the simplified language and contexts of the SFCI allows the use of the instrument with younger students while still maintaining the integrity of the inventory.

The American Association for the Advancement of Science (AAAS), as part of a long-term science reform initiative, has compiled an online database of more than 600 test items for measuring student understanding of science in a number of science content areas including life, earth, physical and the nature of science. These multiple-choice items assess students' conceptual understanding and test for common misconceptions. AAAS Project 2061 also makes available student response rates from national field testing of these items, broken down by grade spans, gender, and whether or not English is the primary language of the student. To create the test items, key ideas were identified by a team composed of assessment specialists, scientists and science educators. A review of relevant literature was conducted to identify common student misconceptions within each key idea and then clusters of items were created to closely align to key ideas including these incorrect understandings in the answer options. Items were then pilot tested with feedback from both teachers and students. Revisions were made and then again reviewed by assessment specialists, scientists and science educators before being field tested on a national scale.

CHAPTER 3

METHODS

3.1. The Research Context

This study is embedded within the Maine Physical Sciences Partnership (MainePSP), which is a National Science Foundation-funded collaborative effort between the University of Maine and 19 school districts across central and eastern Maine, as well as the Maine Department of Education and other non-profit partners. The MainePSP looks to strengthen rural middle school science education in Maine by providing common professional development and instructional resources, and building a supportive infrastructure for the educational community. One of the explicit goals of the MainePSP is to strengthen teacher content knowledge and pedagogical content knowledge through professional development.

One method of addressing these goals was to select and pilot common instructional resources as a means to focus teachers around common activities and concepts. As part of this selection process, *Project Based Inquiry Science* (Kolodner et al. 2010) was chosen as the curriculum for 8th grade physical science classes. This 1-year curriculum would include *Diving into Science,* an introductory unit on scientific practices and engineering design principals; *Energy,* a unit addressing energy types and transfers; and *Vehicles in Motion (VIM),* a unit dealing with force and motion concepts. *VIM* centers on students constructing, testing, and modifying wooden coaster cars as a means of introducing them to and allowing them to explore force and motion concepts, scientific practices and the engineering design cycle. These materials were piloted in the first year of implementation with teachers who took part in the instructional materials selection process.

Data collection for this study took place within the second year of implementation of the *VIM* curriculum, which included a new cohort of teachers, many of whom had never seen the materials previously, in addition to most of the original cohort. During this year, teachers were participating in common professional development, monthly cohort meetings, and shared journaling about their teaching experiences with the new curriculum. In an attempt to get a true sense of these curricular materials, teachers were asked to adhere to "fidelity of implementation" and not deviate from the materials during the first pilot years.

3.2 Instrument Design

To evaluate the respective effects of teacher CK and KSI on student learning this study involves three different measures, and three different but related instruments. Instruments were compiled based on previously established survey items and methods and administered to teachers before, and students before and after, they had completed the *VIM* force and motion unit. Participating teachers in the study used the same instructional materials and participated in common professional development.

3.2.1 Student Learning

Student learning gains were measured by comparing responses on multiple-choice survey items both pre and post instruction of the *VIM* unit. Concepts were first identified from the unit, based upon the *VIM* student and teacher texts, and grouped together to create 5 categories. It should be noted these categories do not represent the entire content of the *VIM* unit, but were the concepts chosen to measure by this study. Table 3.1 outlines the five categories and their correlation to the targeted concepts found in the *VIM* unit.

Table 3.1. Targeted Concepts in Vehicles in Motion Curriculum

Category	*VIM* Targeted Concept
Identifying Forces	"An object's motion is the result of the combined effect of all forces acting on the object."
Balanced Forces	"When the forces on an object are balanced (net force = 0), an object at rest will remain at rest and an object in motion will continue in motion at a constant speed in a straight line."
Unbalanced Forces	"When the forces on an object are unbalanced (net force ≠ 0), an object changes its speed, or direction of motion, or both."
Uniform vs. Changing Motion	"Average speed is the total distance traveled divided by the total time elapsed. The speed of an object along the path traveled can vary. "
Newton's Third Law	"For every action there is an equal and opposite reaction."

The student survey consisted of 11 multiple-choice items, which were selected from pre-existing instruments based upon their correlation to concepts appearing in *VIM* and their appropriateness for middle-school-age students. Items were selected from preexisting instruments for two major reasons. One, we wanted to use items from established sources rather than create novel items. Two, student performance in this study can be compared to existing results from these instruments. Attention was given to both complexity and the reading level required of the items, and also the overall amount of time that would be required of students to complete the survey.

Test items for this study were selected from both the SFCI and the AAAS Project 2061 Assessment test bank. Items 1-8 were selected from the Simplified Force Concept Inventory (SFCI)(Jackson, 2007). SFCI items were selected because of the success of the SFCI with 9^{th} grade students, indicating that the reading level may be accessible to 8^{th} grade students. Additionally, the widespread use of its predecessor, the FCI, allows us for some comparison of overall test results among high school students. Items 9, 10 and 11 of the student survey were selected from the AAAS Project 2061 Science Assessment test bank (AAAS, 2012). AAAS assessment items were also selected for this ability to compare our students to national results, and also to offer some variety in the sources of the items for comparison.

Table 3.2 presents the content category and source for each question on the survey. Figure 3.1 gives examples of items from the survey.

Table 3.2. Source Student Learning Survey Items

Survey Item	Category	Source
1	*Identifying Forces*	Simplified Force Concept Inventory (SFCI)
2	*Newton's Third Law*	Simplified Force Concept Inventory (SFCI)
3	*Newton's Third Law*	Simplified Force Concept Inventory (SFCI)
4	*Balanced Forces*	Simplified Force Concept Inventory (SFCI)
5	*Uniform Motion*	Simplified Force Concept Inventory (SFCI)
6	*Uniform Motion*	Simplified Force Concept Inventory (SFCI)
7	*Balanced Forces*	Simplified Force Concept Inventory (SFCI)
8	*Unbalanced Forces*	Simplified Force Concept Inventory (SFCI)
9	*Unbalanced Forces*	AAAS Science Assessment
10	*Unbalanced Forces*	AAAS Science Assessment
11	*Balanced Forces*	AAAS Science Assessment

Figure 3.1. Example of Student Survey Items

Identifying Forces

1. You throw a softball straight up in the air. What are the main forces acting on the ball after it leaves your hand?
   A. A downward force of gravity and an upward force that gets smaller and smaller.
   B. On the way up: an upward force that gets smaller and smaller
   C. On the way up: a force of gravity and an upward force that gets smaller and smaller.
   D. Only a downward force of gravity.
   E. No forces. The ball falls back to the ground because that's its natural action.

Figure 3.1. Example of Student Survey Items (continued)

Balanced Forces

4. While you're slowly lifting a book straight upwards at a constant speed, the upward push of your hand on the book is:

A. greater than the downward pull of gravity on the book.
B. equal to the downward pull of gravity on the book.
C. smaller than the downward pull of gravity on the book.
D. equal to the sum of the book's weight and the pull of gravity on the book.
E. the only push on the book.

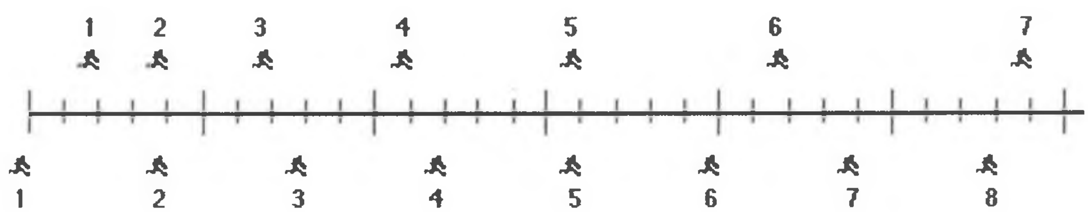
Unbalanced Forces

9. What will happen to an object that is moving forward if the force pushing it backward is greater than the force pushing it forward?

A. The object will move at constant speed for a while and then slow down and stop.
B. The object will slow down for a while and then move at a slower constant speed.
C. The object will slow down, stop, and then begin to move faster and faster in the opposite direction.
D. The object will slow down, stop, and then begin to move at a constant speed in the opposite direction.

Uniform vs. Changing Motion

5. While you and your friend are running, your science teacher takes measurements. Later he makes this drawing. The little stick figures show where both of you are (your positions) at every second of time. You're both running to the right.



Are you and your friend ever running at the same speed?

A. No.
B. Yes, at second 2.
C. Yes, at second 5.
D. Yes, at both second 2 and second 5.
E. Yes, at some time between seconds 3 and 4.

Figure 3.1. Example of Student Survey Items (continued)

Newton's Third Law

A school bus breaks down, and a car pushes it back to the garage.

3. When the car begins to push the school bus, which applies the larger force on the other?
   A. Both apply forces of the same strength on each other.
   B. The bus, because it's heavier.
   C. The car. The bus applies a force, too.
   D. The car. The bus can't apply any force to the car, because its engine isn't running.
   E. Neither applies any force on each other. The bus is pushed forward because it's in the cars way.

By administering the student survey before and after instruction of the VIM unit, both absolute and normalized gains could be measured. Absolute gain is represented by the difference between pretest and post-test responses by student, or class mean on the survey. Absolute gain can be used as a measure of individual questions or as a score for the entire instrument (percentage correct post-test – pretest).

Normalized gain is a measure that represents what percentage students achieve of what was available for them to gain from pre to post assessment (post-test –pretest)/(100 – pre) (Hake, 1998). This measure was originally used in an effort to more accurately describe and compare shifts in student understanding on the FCI. For example, Student A who scores 50% on a pretest has a possible gain of 50% to achieve on a post-test. Student A, who scores 90% on a pretest, only has the ability to gain a maximum of 10% on the post. If both students scored 100% on the post-test Student A would have an absolute gain of 50%, while Student B would have an absolute gain of only 10%. By using normalized gain (post test – pretest)/(100 – pre), Student A has a normalized gain of 1.0 and student B has a normalized gain of 1.0. They both achieved 100% of what was available for them to gain from pre to post.

To calculate the level of statistical significance between pre and post student results a paired samples t-test was run on the data sets. From these results the over-all effect size could be measured. To further compare the significance of teacher on the student results a repeated measures ANOVA was run on the data sets. This test included a single within factor of pre-post and a single between factors variable, teacher. From the ANOVA results it could be determined if student results were significantly different when looking at class results for different teachers.

3.2.2. Teacher Content Knowledge (CK)

Teacher CK was measured by administering to teachers a written survey consisting of 14 test items before they started teaching the *VIM* unit in the fall of 2012. The survey was comprised of a combination of items. Survey items 1-7 are the same as items found in the student survey, coming from both the SFCI and AAAS assessment test bank, while items 8-14 are at a higher complexity and content level. These additional teacher items (8-14) were adapted from two sources: *Tutorials in Introductory Physics* (McDermott and Shaffer, 2002) and *Physics by Inquiry* (PBI)(McDermott, 1996). *Tutorials in Introductory Physics* is a widely used set of research-based instructional resources and assessments designed for introductory calculus based physics majors at the college level. *Physics by Inquiry* is another research-based physics curriculum designed for prospective and practicing K-12 teachers. This pairing of items 1-7 between the student and teacher surveys allows for the comparison of teacher CK with that of their students and intends to measure the direct relationship between teacher CK and student learning gains on those items. Items 8-14 assess teacher CK above the level of the student materials and allows for further differentiation of the level of CK among teachers.

Table 3.3. Source Teacher Content Survey Items

Survey Item	Category	*Source*
1	*Identifying Forces*	SFCI
2	*Newton's Third Law*	SFCI
3	*Balanced Forces*	SFCI
4	*Uniform Motion*	SFCI
5	*Unbalanced Forces*	AAAS
6	*Unbalanced Forces*	AAAS
7	*Balanced Forces*	AAAS
8	*Unbalanced Forces and Change in Velocity*	*Physics By Inquiry**
9	*Balanced Forces*	*Tutorials in Introductory Physics*
10	*Non-uniform motion*	*Physics By Inquiry***
11	*Graphs of position and velocity*	*Physics By Inquiry***
12	*Graphs of position and velocity*	*Physics By Inquiry***
13	*Newton's Second Law and Systems*	*Physics By Inquiry**
14	*Newton's Second Law and Systems*	*Physics By Inquiry**

* adapted from *Physics By Inquiry* Vol. II, Dynamics, 2nd Edition
** adapted from *Physics By Inquiry* Vol. II, Kinematics, 2nd Edition

3.2.3. Teacher Knowledge of Student Ideas (KSI)

KSI was measured by adapting previously established research methods that ask teachers to predict student incorrect reasoning (Maries and Singh, 2013; Thompson, Christensen, and Wittmann, 2011). Before they started teaching the *VIM* unit, teachers were asked to complete an online survey. The survey presented them with four of the items from the student survey (1, 5, 10, 11). These four items were also included on the teacher content survey. For each question they were asked to evaluate the likelihood that a significant portion of their students (>10%) would choose a response option and give the student's reasoning for selecting that option. On the KSI survey, teachers predicted the probability that their students would choose a multiple-choice option (greater than 10% of their students) for a selected survey item and then gave student reasoning for choosing that option. They were asked to do this for 4 of the 11 student items (Student Items 1, 5, 10, 11).

KSI scores for each teacher were calculated using a method previously employed by Maries and Singh (2013). A teacher's score was assigned based upon their predictions and the fraction of students who selected that prediction on the pretest. For example, on KSI item 1 (Student Item 1), overall student responses for A, B, C, D, E are 52.4%, 12.2%, 16.8%, 14.1% and 4.3%, so the scores for each option on item 1 are .52, .12, .17, .14 and .04, respectively. Teachers received the score for a selected option if the student response rate was greater than 10%, and they gave some insight into what a student would be thinking choosing that option. Some teachers said that greater than 10% of their students would chose an option but failed to give insight into students' reasoning for choosing that option. A teacher's total score was calculated by summing their scores over the four items. Teachers were asked to select any options that they felt greater than 10% of their students would choose, so the maximum points available on item 1 was .97. For example, a teacher selecting and giving student reasoning for options A and B on item 1, would receive a score of .64 for that item (.52+.12). A teacher selecting only option E would receive 0 points because the student response rate (4.3%) was lower than the 10% threshold.

Nine teachers completed the online KSI survey. The instructions to teachers did not specify whether teachers should ignore the correct answer option or tell teachers which option was correct, just to select options that greater than 10% of their students would choose. From looking at their responses for students reasoning, and by cross referencing their responses to the corresponding items on the teacher CK survey, many teachers did not recognize the correct answer option and exhibited many of the incorrect understandings as their students.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Student Learning

The student survey was administered to students both before and after instruction of the *VIM* unit in Fall 2012. The survey was made available through an online website, and instructions and the link to the survey were sent via email to participating teachers (See Appendix A, Force and Motion Student Survey). In order to calculate individual learning gains for each student, and to account for attrition and changes in student populations between the administering of the pre- and post-tests, students' post-test entries were matched with those from the pretest. This allowed for the calculating of individual learning gains for each student. Table 4.1 shows the number of participating teachers, students taking the pretest and post-test, and the number of matched student responses.

Table 4.1. Response Counts to Student Learning Survey

Teachers	Students Pre	Students Post	Matched
14	521	530	418

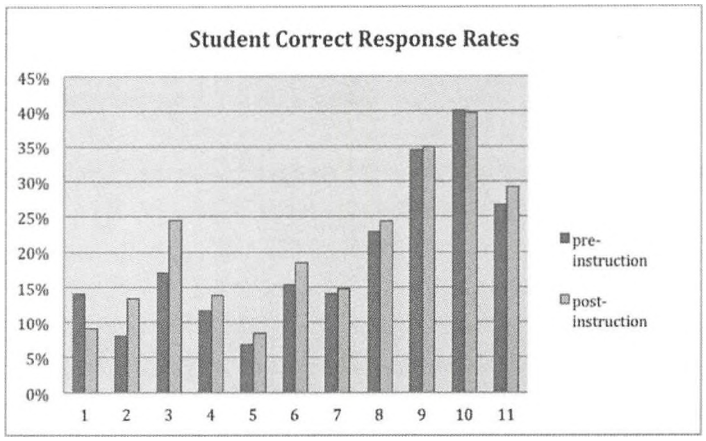
Pretest results show that students had very little conceptual understanding of Newtonian force and motion prior to instruction of the *VIM* unit. The mean student score across all 11 items was 19.01% for the pretest. The mean correct response rate was 19.19% per item.

Post-test results show that students made minimal gains across all test items. The mean student score across all items was 20.7% for the post-test. The greatest gain was found on item 3 with an absolute gain of 7.5% overall (17%–24.5%, pre/post), and the lowest on item 1 with a negative gain of -5.1% (14.1%-9.1% pre/post). Results are shown in Table 4.2.

Table 4.2. Student Correct Response Rates, Pre- and Post-Instruction

Survey Item	Correct response rate pre-instruction	Correct response rate post-instruction
1	14.1%	9.1%
2	8.1%	13.4%
3	17.0%	24.5%
4	11.6%	13.8%
5	6.8%	8.4%
6	15.3%	18.5%
7	14.1%	14.8%
8	22.8%	24.3%
9	34.5%	35.0%
10	40.1%	39.8%
11	26.6%	29.2%
Mean	**19.2%**	**21.0%**

Figure 4.1. Student Correct Response Rates



4.1.1. SFCI v. AAAS Results

Comparisons between SFCI and AAAS items are displayed in Table 4.3. Pretest results show that on items from the SFCI (1-8), the mean correct response rate was 13.7%; this is less than the 20% correct response rate that would be expected from random guessing from the five multiple-choice options. The item with the highest correct response rate of the SFCI items was item 8, with 22.8% of students choosing the correct option. The item with the lowest correct response rate for SFCI items 1-8 was item 5, with only 6.8% of students choosing the correct option.

On items compiled from the AAAS Project 2061 Science Assessment test bank (items 9, 10, 11), correct response rates before instruction were significantly higher than those found on the SFCI items, with a mean correct student response rate of 33.8%. Response rated on 9, 10 and 11 are similar to the national results reported by AAAS Project 2061. The highest response rate was found on item 10, with 40.1%

of students choosing the correct response, and the lowest on item 11 with 26.6% of students choosing the correct response.

Post-test results are similar for both SFCI and AAAS items. For SFCI (items 1-8) the mean absolute gain was 2.1%. Item 3 had the highest gain of 7.5%, and Item 1 had the lowest gain of -5.1%. On items from the AAAS Project 2061 Science Assessment (items 9-11) the mean gain was 0.9%. Item 11 had the highest gain of 2.5% and item 10 had the most negative gain of -0.3%. It should be noted that these gains of 0.9% and 2.1% represent less than a one-question gain on average per set for the SCFI (9 items) and AAAS(3 items), so do not represent a significant shift in responses. Additionally, the higher overall response rates to AAAS questions can be partially attributed to the number of answer options for those questions compared to SFCI question items. The AAAS question items have only four options, whereas SFCI question items have five.

Table 4.3. Student Response Rates, SFCI v. AAAS

Survey Item	Survey Items	Mean correct response rate pre-instruction	Mean correct response rate post-instruction	Mean gain
AAAS	9, 10, 11	33.8%	34.6%	.9%
SFCI	1-8	13.7%	15.9%	2.1%

Table 4.4. AAAS National Reported Data Comparison

Survey Item	Correct response rate on Student Survey	Correct response rate AAAS Data Grades 6-8
9	34.5%	32%
10	40.1%	38%
11	29.2%	26%

4.1.2. Student Responses Compared to National Results

AAAS provides student response rates for their items from national field testing. These data are combined and averaged over different grade spans, and provide a snapshot in time of student thinking rather than pre- and post-test results. Without further differentiation, these data do not allow for a direct comparison, but do provide us with a loose means of comparison. Comparing the response rates of our student population to the national results provided by AAAS Project 2061 shows that our students performed at least on par with, if not slightly better than, the AAAS results. These data are displayed in Table 4.4. This information gives us a means to determine whether our population of students is performing similarly to other student populations on these items. Without further information about when the AAAS data were collected from students, further differentiation by grade level, and whether students had been exposed to any learning materials on force and motion it remains an indirect comparison. But even so, it does show that our students performed similarly compared to other students nationally when given the same test items before instruction on items 9-11.

SFCI data are more limited in availability, but Popp and Jackson (2009) do provide some results for comparison. They report findings from a study of 9th grade students (n=51) who were given the complete SFCI, which is comprised of 30 items, after completing a mechanics curriculum. Their analysis gives mean scores for the assessment, but does not provide results for individual items. Our study did not administer the complete SFCI, but chose 8 items from the 30, so direct comparison is not possible. But, as with the AAAS results, we can still use their results as a rough means of comparison. Popp and Jackson reported a mean score of 14.77 for 9th grade students on the SFCI. For SFCI items on our assessment (1-8), the student mean score was 15.8. Again, this is a coarse comparison, without further delineating the Popp and Jackson data, but does show that our students are performing similarly to those in other studies.

4.1.3. Student Learning by Content Category

Further analysis of student learning data can be reported by content category. Results are displayed in Table 4.5. Students made the most gain in the category of *Newton's Third Law*, gaining 6.4%. This category is represented by items 2 and 3 on the student survey, with gains of 5.3% and 7.3% respectively. *Identifying Forces* was only represented by one survey item, Item 1 and saw the most negative shift of -5%.

Table 4.5. Student Response Rates by Category

Category	Correct response rate pre-instruction	Correct response rate post-instruction	Gain
Identifying Forces	14.1%	9.1%	-5.1%
Balanced Forces	17.4%	19.3%	1.9%
Unbalanced Forces	32.5%	33.0%	.5%
Uniform vs. Changing Motion	11.0%	13.4%	2.4%
Newton's Third Law	12.6%	19.0%	6.4%

4.1.4. Normalized Student Gains

By matching student pretest and post-test responses normalized gains were calculated for each student. By averaging <g> for all students within a class a mean <g> was calculated for each teacher as a measure of the learning of their students. The mean class normalized gain across all teachers was 1.9%.

4.1.5. Statistical Significance of Student Responses

To calculate the level of statistical significance between pre- and post-instruction results, a paired samples t-test was run on the data sets to measure the overall effect size. The results from this test show that there were statistically significant differences between the pre and post-test responses ($\sigma = .044$). Further analysis of the mean scores pre and post show a minimal effect size ($p = .14$). Although the results are significant, the effect size shows that this difference is small to very small in magnitude.

4.2. Teacher Content Knowledge

Teacher Content Surveys were sent via mail to participating teachers before the beginning of the *VIM* unit (See Appendix B Force and Motion Teacher Content Survey). Eleven teachers completed and returned the survey. Teachers displayed a wide level of content understanding on the Teacher Survey. Overall scores for teachers were calculated by dividing their number of correct responses to the 14 multiple-choice questions by the total number of questions (number correct/14).

Of the 11 teachers responding to the survey, the mean score was 60%, the minimum score was 14% and the maximum score was 93%.

On items 1-7, which also appeared on the student survey, the mean score was 62%, with a minimum score of 0 and a maximum score of 100. The highest correct response rates were found on items 1, 5 and 7 (72.7%). The lowest correct response rate was found items 2 and 3 (36.4%). Results for each question are displayed in Table 4.5.

Table 4.6. Teacher Correct Response Rates on Individual Teacher Content Survey Items (SFCI = Simplified Force Concept Inventory, PBI = Physics By Inquiry, TIP = Tutorials in Introductory Physics)

Survey Item	Item Source	Correct Response Rate (%)
1	SFCI	72.7
2	SFCI	36.4
3	SFCI	36.4
4	SFCI	45.5
5	AAAS	72.7
6	AAAS	63.6
7	AAAS	72.7
8	*PBI*	36.4
9	*TIP*	45.5
10	*PBI*	63.6
11	*PBI*	63.6
12	*PBI*	72.7
13	*PBI*	81.8
14	*PBI*	27.3

4.3. Teacher Knowledge of Student Ideas

Teacher KSI scores for all four of the KSI questions are displayed in Table 4.4. KSI scores were also calculated for each teacher for each of the four student items that they were asked to evaluate. The maximum possible KSI score attainable across all 4 items was 3.55. Teacher overall scores ranged from 0.8 to 2.93 with a mean score of 2.1 and median score of 2.37.

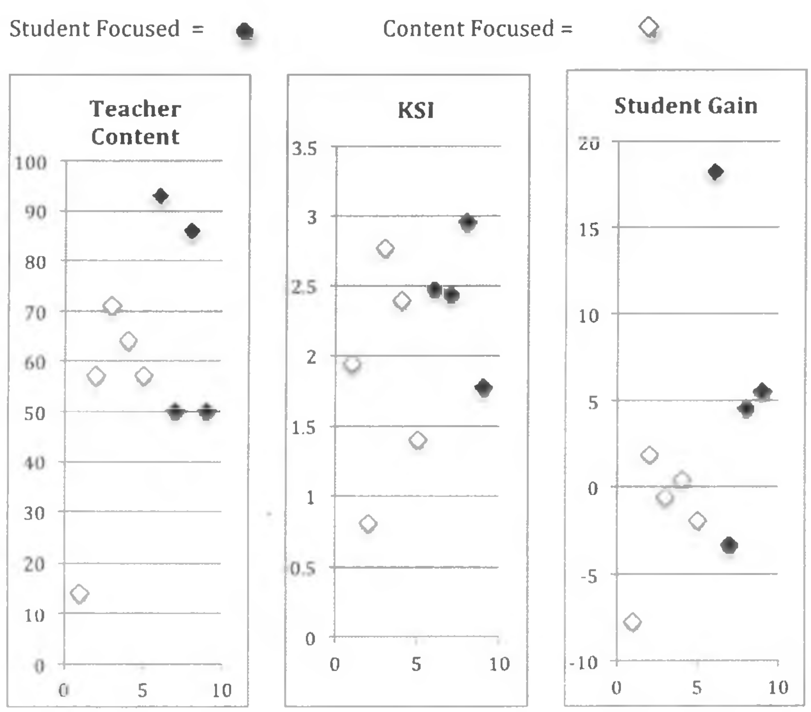
This KSI score includes selections teachers made, even if they did not choose the correct answer themselves for that particular item. An alternative KSI can be calculated based only on KSI items that teachers also answered correctly. This KSI w/CK score is also included in Table 4.7.

Table 4.7. Teacher KSI Scores

Teacher	KSI Score (Overall)	Item 1	Item 2	Item 3	Item 4	KSI w/CK
A	0.8	0.12	0	0.25	0.43	0.37
B	1.38	0.8	0.6	0	0	0.78
C	1.77	0.29	0.6	0.88	0	1.48
D	1.92	0.66	0.6	0.25	0.43	0
E	2.37	0.83	0.79	0.5	0.27	1.08
F	2.41	0.83	0.6	0.5	0.5	1.81
G	2.45	0.54	0.6	0.63	0.7	2.45
H	2.75	0.83	0.79	0.88	0.27	2.75
I	2.93	0.97	0.6	0.88	0.5	2.93

Additional insights into KSI can be gained from examining the way teachers framed the reasoning on the KSI questions. Some teachers are explicit about describing the reasoning as student thinking, with terms such as “they,” “students,” and "kids" included in their responses. Other teachers make more declarative statements about the content, such as "force would make it go up then gravity pulls it down" without including language about students. Teachers were grouped based on whether the majority of their KSI responses included "student-focused" or "content-focused" language. This division places five teachers in the content-focused group, and four in the student-focused group. Examining the mean scores of each group shows that teachers who use student-focused language have higher average CK, KSI and student gains. Plots of teacher CK score, KSI score, and each teacher's students' normalized gain, with a distinction between student-focused and content-focused teachers, are displayed in Figure 4.1.

Figure 4.2. Student-Focused vs. Content-Focused Language by Teacher



Even though mean values for the student-focused teachers are higher than those of the content-focused teachers, the level of overlap among the distributions shown in these plots indicate that this difference is not meaningful. Teachers who use student-focused language may have teaching practices that more frequently draw out student thinking and thus they think about student thinking more explicitly, while the content-focused teachers' practices may be less likely to elicit student thinking in the classroom (Franke, 2001). Additional data on teaching practices could give more insight.

4.4 Correlations between Teacher CK, KSI and Student Learning

What are the relative effects of CK and KSI on student learning? To attempt to address this research question we need to compare how each of these two types of teacher knowledge may correlate to student learning outcomes. A total of 9 teachers who completed the KSI survey also completed the Teacher Content Survey and had their students (n=418 matched responses) complete student surveys as pretests and post-tests, providing a complete data set of all three components (student normalized gain, Teacher CK, KSI). For these teachers, the mean normalized student gain for each teacher's class was calculated and used as the measure of student learning specific to that teacher. Table 4.8 displays scores for each of the three measures by teacher.

In order to determine if the teacher had a significant impact on student learning, a repeated measures ANOVA was run on the data sets. This test included a single within factor of pre-post and a single between factors variable, teacher. From the ANOVA results it could be determined if student results were significantly different when looking at class results for different teachers. This test showed that teacher did have a significant impact on the learning of their students ($p<.001$).

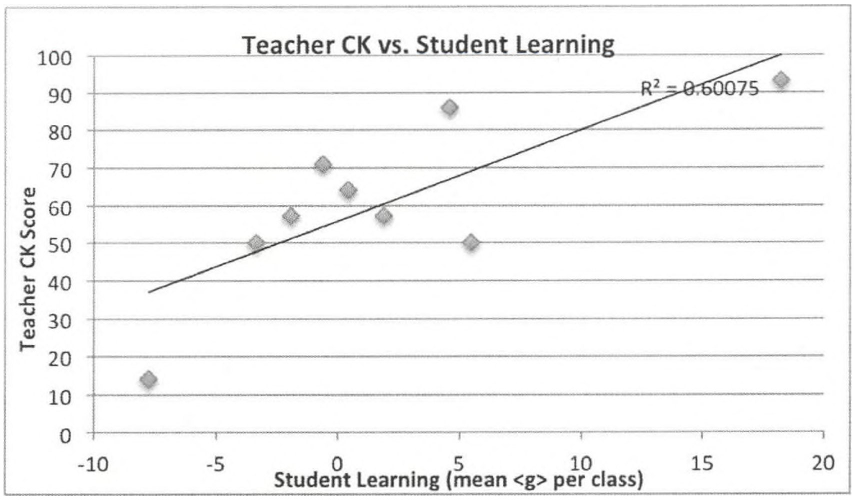
Table 4.8. Student Normalized Gain, CK and KSI by Teacher

Teacher	Mean normalized student gain (%)	Teacher CK (%)	Teacher CK (%): Student Items Only	KSI Score
A	-7.74	14	0	1.94
B	1.89	57	71	0.8
C	-1.94	57	57	1.4
D	5.47	50	71	1.77
E	0.4	64	71	2.39
F	-3.38	50	71	2.43
G	18.24	93	100	2.47
H	-0.6	71	57	2.77
I	4.56	86	86	2.95

4.4.1. Teacher CK and Student Learning

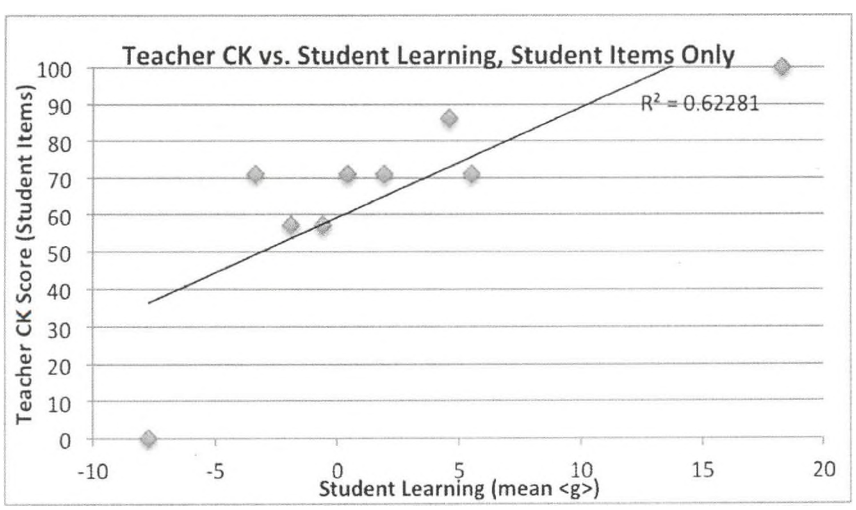
Looking at the mean normalized gain and CK scores for each teacher, we can see that there is a weak overall positive correlation between higher CK and higher student learning gains ($R^2= .60$). This relationship between Teacher CK and Student Learning is shown in Figure 4.2.

Figure 4.3. Teacher Content Knowledge vs. Student Learning



A second CK score was calculated for each teacher based only on their responses to the items that were repeated from the student survey, i.e., items 1-7 on the Teacher Content Survey, which correspond to items 1, 2, 4, 5, 9, 10 and 11 on the Student Survey. Teacher CK scores on only the student items and the mean learning gains of their students are displayed in Table 4.8 and Figure 4.3.

Figure 4.4. Teacher Content Knowledge vs. Student Learning, Student Questions Only



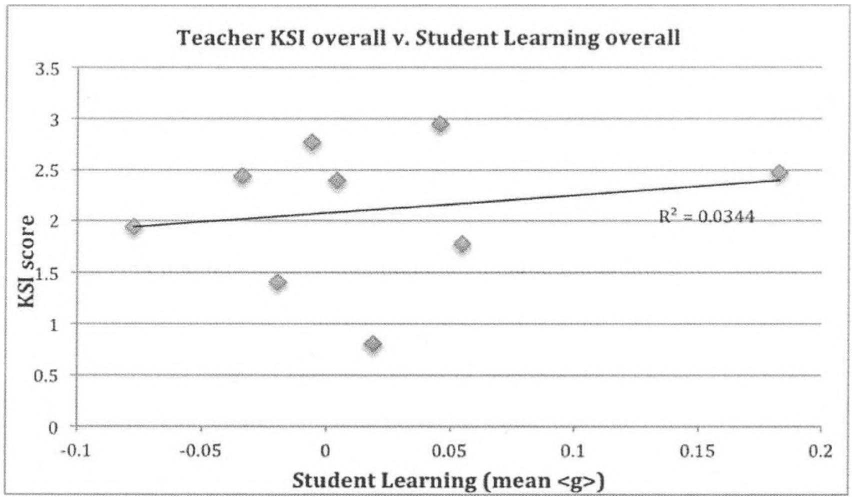
Limiting the CK analysis to only including the student questions in the teacher CK score only marginally strengthens the relationship between teacher CK and student learning (R^2=.62). Again, there appears to be some relationship, with Teacher G having both the highest CK score (100) and student learning gain (18.24), and Teacher A having the lowest CK score (0) and most negative learning gain (-7.74). But other teachers, such as Teacher D (CK = 50, Student gain = 5.47) and Teacher F (CK = 50, Student gain = -3.38), do not fit this pattern, having the same CK score but very different learning gains among their students.

It is noticeable from these two graphs that the mean student normalized gains are centered around 0, with a mean of 1.8 and median value of 0.4. If we remove the two outliers of Teacher G and Teacher A, the level of correlation between the two factors drops considerably (R^2 = .09). Without further measures to differentiate class scores and overall student learning, there is little spread to compare teacher CK scores to.

4.4.2. Teacher KSI and Student Learning

Figure 4.4 displays the relationship between teacher KSI scores for the 4 KSI questions, and the normalized gains of their students on the Student Survey. From the figure we can see that this produces a very weak correlation (R^2= .03) between the two variables.

Figure 4.5. Teacher KSI vs. Student Learning <g>



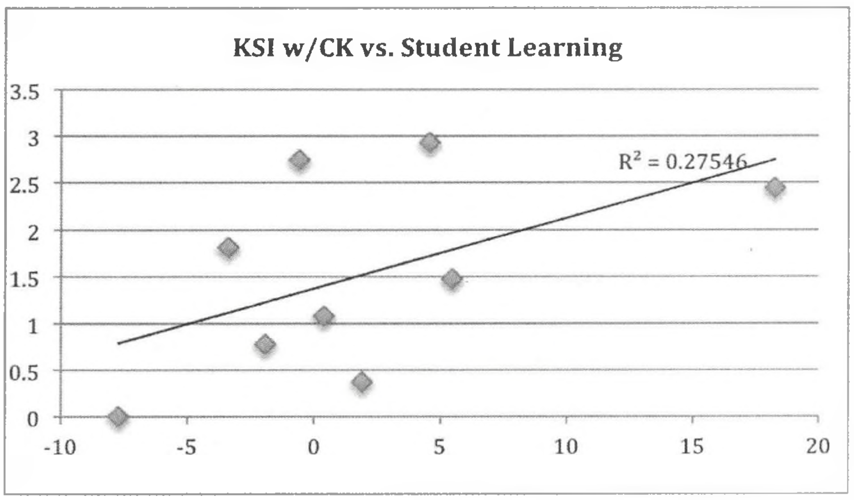
We can further focus our analysis to comparing teacher KSI scores and student learning gains for each of the four KSI questions. This matches a teacher's KSI scores for a particular question with the normalized gain of their students on that particular question. We can see in table 4.10 that this level of analysis does not improve the strength of the correlation between the two variables. These results suggest that our measure for KSI had very little relationship to the learning of students, even less so than teacher CK.

Table 4.9. Levels of Correlation Between KSI and Student Learning

KSI Item	R^2 Value
1	.028
2	.048
3	.04
4	.01

Whether teachers answered the question correctly gives some insight into how they are choosing their KSI answers. Are they basing their KSI prediction on knowledge of students or are they reasoning about the problem as a student would? In an attempt to further differentiate KSI, we can look at the relationship between student learning and KSI when teachers also possess the CK to correctly answer the item. Figure 4.5 compares this KSI w/CK score with student learning.

Figure 4.6. Teacher KSI w/CK vs. Student Learning



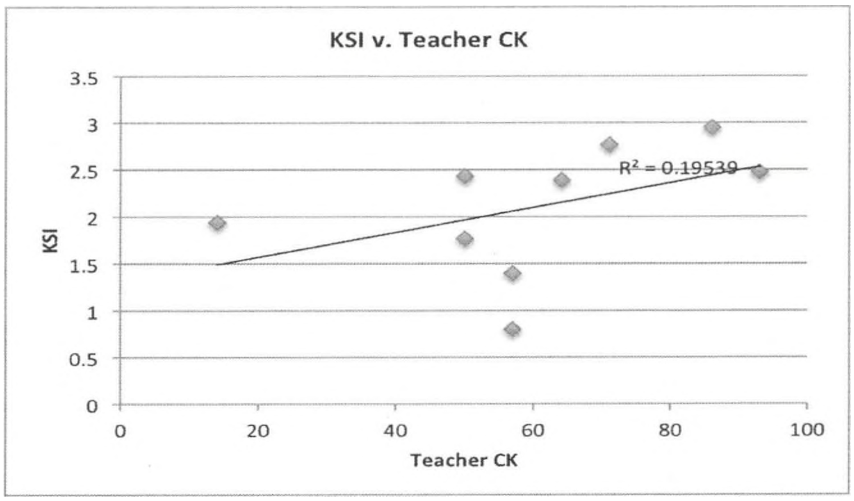
We can see that only basing KSI scores on items that teachers also answered correctly strengthens the relationship between student learning and KSI. Although this is still a weak relationship (R^2=.28), it is significantly stronger than the level of correlation found in Figure 4.3 (R^2=.03).

4.4.3. Teacher KSI and CK

We can also look for the level of correlation between teacher CK and KSI. From Figure 4.6 we can see that this comparison produces a very weak correlation

(R^2=.20). One further level of analysis when looking for connections between teacher CK and KSI is comparing their CK responses to KSI responses on the four KSI questions.

Figure 4.7. Teacher KSI vs. Teacher CK



4.4.4. Discussion and Summary of Correlations

When looking for relationships among CK, KSI, and student learning gains, the survey data do not provide strong correlations. Teachers with higher CK scores did not, in all cases, have students who ultimately achieved higher learning gains after instruction compared to those teachers with lower CK scores. The R^2 value of 0.6 (Fig. 4.2) suggests that there is some relationship, albeit not strong, between the two data sets. Figure 4.2 shows that values for the mean normalized gains per class are centered near 0, with a class gain mean of 1.8 and median of 0.4, showing that very little movement occurred in student understanding, giving a small range of normalized gains to correlate with teacher CK.

For example, Teacher D had a CK score of 50% and still one of the higher learning gains of 5.47%. Teacher F had the same CK score of 50% and a negative student learning gain of -3.38. We can see from these contradicting cases and an overall lack of strong correlation that the content understanding of a teacher is not a strong predictor of student learning gains in the *VIM* unit for teachers in the middle of the CK range.

On the other hand, there may be some information to glean from fact that the two extreme CK scoring teachers also had the extremes of student learning gains. Teacher G had the highest mean student learning gain (18.24) and the highest CK score (93%), while Teacher A had the lowest (most negative) student gain (-7.74%) and also had the lowest CK score (14%, with 0% on the student items). These extreme cases suggest that there are threshold levels of CK that must be achieved in order to achieve any student gains, or in the case of Teacher A, to not experience negative student gains. Comparing Teacher A's CK responses on the student items to those on their students' pretests and post-tests shows that student responses shifted toward Teacher A's incorrect responses after instruction, actually moving away from the correct understanding. This alone exemplifies the importance of a certain threshold of CK that is required for effective instruction. Teachers without content understanding cannot help students achieve that understanding. Other teachers above this low extreme of CK had small to no gains among their students; it is not until the opposite extreme of Teacher G that we see any meaningful shift in student understanding. In this way, teacher CK may be linked to student learning, but not in a completely linear relationship.

Similarly to CK, teachers with high KSI did not in all cases have students that achieved higher learning gains, compared with those teachers with lower KSI. This relationship is illustrated in Figures 4.3 and 4.4. In some cases, teachers predicted student incorrect answers but also held those answers themselves, giving them a higher KSI score even in the absence of the CK to correctly answer the question.

This raises the possibility that teachers are accessing KSI in different ways. Some are relying on actual knowledge of students while some were reasoning about what seems difficult about the problem. In an attempt to further differentiate teacher KSI and the sources of this KSI, a second KSI score was calculated combining CK and KSI across the four KSI items. This score gives teachers KSI points only on items that they also answered correctly. This KSI w/CK score creates a stronger relationship with student learning, albeit still a weak one (Figure. 4.6.)

Another level of analysis, in an attempt to further differentiate KSI, was to look at the nature of teacher's written responses. One clear difference between teacher responses was in the way that they described student difficulties. Teacher written responses could be grouped into two sets, content-focused and student-focused. Student-focused teachers used language describing student thinking while content-focused teachers made statements about the context of the problem. In this way, some teachers were thinking about students, which was evident in their responses, while some of the teachers were reasoning about the features of the problem that they found difficult and then relating that to student thinking. They were using their own CK to assess KSI by looking at what they, being unsure of the correct response, thought students would find reasonable. Comparison of these two groups shows that teachers who used student-focused language in more questions in their KSI written responses had, on average, higher student learning gains, overall KSI and CK scores, although the distributions of the two groups had considerable overlap. This result is tentative, only comparing a total of nine teachers, but is suggestive and could be an avenue for future investigation, which will be discussed in Chapter 5.

4.4.5. Importance of KSI in the Absence of CK

Teacher A had a very low CK score and low class gain but still had a strong overall KSI score. Teacher A had an overall KSI of 1.94, putting this teacher near the middle of the range of KSI scores, which ranged from 0.8 to 2.95, with a mean score of 2.1 and median score of 2.37. In addition to scoring 14% on the CK survey, Teacher A chose incorrect content answers for all 4 of the student KSI questions, showing little content understanding.

Looking at the shifts of Teacher A's students before and after instruction on the 4 KSI questions, we can see different outcomes depending on the teacher's ability to predict the most popular student response. Teacher A did predict the most common student incorrect answer including student reasoning for KSI questions 1 and 2, but did not predict the most common student responses for questions 3 and 4. On questions 3 and 4, where Teacher A could not predict student incorrect answers, the students saw the most negative shifts. On question 3 student responses shifted from 66.7% to 55.6% pre-to-post instruction and 66.7% to 11.1% on question 4. On both KSI questions 3 and 4, where the teacher did not choose the correct response, or predict student incorrect responses, students shifted to the teacher's incorrect answer. On question 3, the correct answer was C while the teacher chose D. Two thirds (66.7%) of Teacher A's students chose C and 18.2% chose D on the pretest. On the post-test 55.6% of students chose C, while the number selecting D had risen to 44.4%. Students had shifted to the incorrect understanding of their teacher.

On question 4, the correct answer was C while the teacher chose B. Again, 66.7% of the teacher's students chose C on the pretest, while 11.1% chose B. On the post-test only 11.1% of students chose the correct answer while 77.7% had shifted to B. In this case, when the teacher did not select the correct answer or select the most common incorrect student answer, student responses shifted towards the incorrect teacher understanding on the post-test results.

Comparing Teacher A to Teacher G, we can see that Teacher G chose the correct answers for each of the KSI questions and predicted student responses on items 1, 2 and 4. Teacher G saw substantial learning gains compared with Teacher A. These results indicate that even in the absence of CK, the ability to recognize the most popular student response can have an impact on student learning outcomes.

Table 4.10. Comparison of Responses of Teacher A vs. Teacher G

	KSI Item	Correct Response	Teacher Response	KSI prediction	Student Pre	Student Post	Student Gain (%)
Teacher A	1	D	B	A, B	A	A	11
	2	E	A	D	D	D	-12.5
	3	C	D	B	C	C	-33
	4	C	B	A	C	B	-56
Teacher G	1	D	D	A	A	A	15
	2	E	E	B, C, D	D	D	0
	3	C	C	A, C	D	C	5
	4	C	C	A, C, D	A	C	50

CHAPTER 5

CONCLUSIONS

The analysis of the data does not show clear connections between teacher knowledge (CK and KSI) and student learning. Student responses suggest that students are not gaining conceptual understanding of foundational concepts of force and motion through the *VIM* curriculum. Results from the student survey pretests and post-tests show that student made minimal learning gains. These results were statistically significant ($p = .044$), but the magnitude of these differences was very small (effect size = .137). The mean normalized gain across all students was 0.73%, meaning that on average they learned less than 1% of what was available for them to learn pre-to-post.

Looking across the five different content categories represented on the survey, some generalizations can be made about students' ideas regarding the content. The results show that students tend to relate net force with velocity, rather than net force with acceleration. They think that if an object is moving in a direction, then there must be a net force moving it in that direction, regardless of whether the object is slowing down, speeding up, or traveling at constant speed. Students relate forces with motion rather than changes in motion, showing that students are lacking connections between balanced forces and uniform motion. Student results further show that they do not have the ability to distinguish between different types of motion. The difficulties exhibited by the students in this study are consistent with results from other published studies, as outlined in Chapter 2 (Clement, 1982; Driver, Guesne and Tiberghien, 1985).

The results from the teacher CK and KSI surveys show that teachers had a wide range of both content understanding and KSI. CK scores ranged from 14% to 93% for teachers, with an average score of 60% on the survey. KSI scores, based on teacher predictions of student answers, ranged from 0.8 to 2.93 out of a possible 3.55, showing that teachers had different ideas about anticipated student answers.

The results from the study do not present clear correlations between teacher CK, KSI, and student learning. We find a weak relationship between teacher CK and student learning (R^2= .60). Most of the teachers, whose CK scores fell in the middle of the CK range, saw small to no gains. However, the teachers at the extremes of the range are also at the same extremes of the student learning gain range, and account for most of the correlation between these values. It may be that there is a certain lower limit of content knowledge that is needed to avoid having students "learn" incorrect ideas that the teacher holds, while a separate, higher content threshold may be needed to lead students to meaningful learning gains.

KSI and student learning do not show a clear relationship when looking at results from across the 4 KSI questions we asked. Further analysis by individual question does not strengthen this relationship.

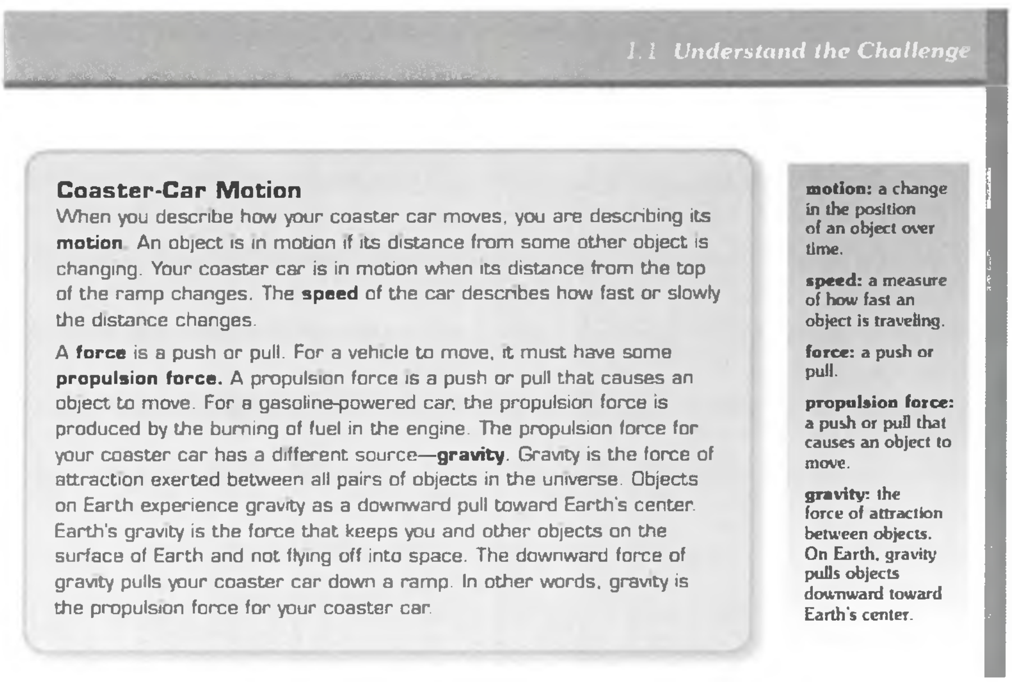
What are some possible explanations for this overall lack of relationship among the three different measures of CK, KSI and student learning gains? There are some distinctive possibilities as to why we see minimal overall correlations.

One explanation may be that student learning gains were so minimal that there was little signal with which to differentiate the teachers. There are a number of factors that could explain the lack of learning gains we encountered. One possibility is that our assessment instrument was too difficult for our student population. This reasoning can be rejected based on the comparison of data from the AAAS and SFCI items. Students in our study performed similarly when compared to results from previous studies and field-testing of the items used on our assessment. Popp and Jackson reported a mean score of 14.77 for 9th grade students on the complete SFCI. For SFCI items on our assessment (1-8), the student mean score was 15.8, showing that our students are performing at a similar level to other students with these questions. Our students also performed very similarly before instruction to the national data presented by AAAS on those items (9, 10, 11). They also made statistically significant, even if small, gains on some items. Therefore, the small learning gains should not be attributed to inappropriate instruments or assessment methods.

When looking at student responses by content category, it is clear that some difficulties persist in student thinking, even after instruction with the *VIM* unit. These difficulties are parallel to those that have been identified in the research base and discussed in the literature review in Chapter 2.

Although these concepts are explicitly stated as targeted concepts in the *VIM* texts (both student and teacher editions), the focus and sequence of the activities does not move student thinking towards a Newtonian model of force and motion. Most of the student engagement with the force and motion concepts is through explanatory text boxes in the student book. Although students are immersed in engineering design throughout the unit (by means of building, testing, and investigating with wooden coaster cars), the focus on the coaster car performance limits some aspects of the experience and does not provide a framework or logical progression with which to build student understanding. Concepts are not sequenced but rather inserted into the curriculum where they seem to match with the engineering design. Figure 5.1. presents an excerpt from the first learning set of the *VIM* student book, page 17 of section 1.1. We can see that the text box simultaneously introduces the concepts of motion, speed, force, propulsion force and gravity through a short reading.

Figure 5.1. Example of Content in VIM. (Kolodner et al., 2010a, p. 17)


1.1 Understand the Challenge

Coaster-Car Motion

When you describe how your coaster car moves, you are describing its **motion**. An object is in motion if its distance from some other object is changing. Your coaster car is in motion when its distance from the top of the ramp changes. The **speed** of the car describes how fast or slowly the distance changes.

A **force** is a push or pull. For a vehicle to move, it must have some **propulsion force.** A propulsion force is a push or pull that causes an object to move. For a gasoline-powered car, the propulsion force is produced by the burning of fuel in the engine. The propulsion force for your coaster car has a different source—**gravity**. Gravity is the force of attraction exerted between all pairs of objects in the universe. Objects on Earth experience gravity as a downward pull toward Earth's center. Earth's gravity is the force that keeps you and other objects on the surface of Earth and not flying off into space. The downward force of gravity pulls your coaster car down a ramp. In other words, gravity is the propulsion force for your coaster car.

motion: a change in the position of an object over time.

speed: a measure of how fast an object is traveling.

force: a push or pull.

propulsion force: a push or pull that causes an object to move.

gravity: the force of attraction between objects. On Earth, gravity pulls objects downward toward Earth's center.

Most recently, efforts have been undertaken to modify the *VIM* curriculum by centering it on a sequence that more explicitly builds conceptual understanding of motion, changes in motion and the forces that cause these changes. It still relies on the coaster car and incorporates the engineering design model, but interjects other activities that allow students direct experiences with uniform motion, acceleration, net force and force interactions. This model centers more on student thinking and the content structure that builds to a complete understanding of Newton's three laws of motion. Further modifications are planned for the future, and data collection is ongoing for both students and teachers.

Another related factor that cannot be overlooked may be the parameters of implementation of the *VIM* curriculum. During the initial years of implementation, there was a strong focus on fidelity of implementation (MainePSP, 2013). For purposes of assessment of the curriculum, teachers were asked to not deviate from the content or sequence of the PBIS materials. This may have prevented activation of certain aspects of PCK from teacher's tool sets, being that they were discouraged from making curricular choices and decisions and to trust in the sequence and presentation of the PBIS materials. This relates to two facets of PCK in the model of Magnusson et al. (1999): *knowledge and beliefs about science curriculum* and *knowledge of instructional strategies* that may explain why we see little relation between student learning and teacher knowledge here: the implementation process may have led the teachers to remove themselves from the curriculum and be facilitators of a set of materials, rather than focusing on the learning of the students.

Another explanation that must be considered from the data is that CK and KSI are not the only strong factors driving teacher performance and subsequent learning gains. Simply because teachers had the necessary content knowledge or even insight into their student's thinking does not necessarily mean they possessed the skills to address those ideas. PCK is more than just student ideas and encompasses many other facets of teacher knowledge, including instructional strategies, sequences, and assessment. It is not just student ideas but what to do with student ideas and how to move students from their incomplete understandings to the more correct knowledge. It may be that the teachers were lacking in some of these categories of PCK, which were not measured in this study.

Even though we did not find strong correlations between our student and teacher measures, there was still differentiation among our teachers and their student's learning. It may be that we needed more sophistication in our assessment methods of KSI, including interviews, classroom observations, and greater reliance on free-response vs. multiple-choice written tasks. Solely investigating the relationship between KSI and student learning may be too narrow of a focus. Multiple facets of PCK may need to be measured to further differentiate teachers and to see how these elements of PCK interact with each other.

5.1. Limitations of the Study

There are many other factors, beyond the scope of this study, not accounted for in our analysis. Our intention for this study was to use methods that could be applied to a large number of teachers and students and efficiently collect a large set of data. We therefore designed our study around instruments and assessment items that lent themselves to this format. Using these methods, there may be things we missed about teacher performance. When looking at teachers, we did not differentiate by factors such as years of teaching experience, college degrees, previous experience teaching physical science, etc.

With student populations we did not attempt to account for differences between classes or schools. Sadler et al. (2013) accounted for differences in student ability by including assessment items to differentiate students' mathematical and problem-solving abilities into "low non-science" and "high non-science" groups. They found that teacher's knowledge of students had a greater impact on high non-science student's gains than those of low non-science students. An example of these unaccounted for student influences can be seen with Teachers G and I. Both at the top of the CK range, Teachers G and I only differ in CK by one question (93/86) on the CK assessment. They both also have similarly high KSI scores of 2.47 and 2.95, respectively. Although they seem equally matched in both CK and KSI, the learning gains of their students were very different, with Teacher G's students having a mean class gain of 18.2% and Teacher I's students much lower at a 4.6% normalized gain. Further analysis shows that these teachers both instruct at the same middle school. What accounts for the differences in student outcomes then? When asked what they thought could be any factors contributing to the different learning outcomes of their students, Teacher I immediately responded that students were grouped by mathematical ability for their math classes. They maintain this grouping for science classes and Teacher I had the "lower-ability" math groups, while Teacher G had the "higher-ability" math groups. Teacher I strongly believed that this was the deciding factor in the difference in student gains between the two groups. Further grouping of the students was not possible through the data we collected, but could be achieved with access to student grades, standardized testing scores, and other means of assessment. In education, there really are endless possibilities when it comes to factors that can affect the performance of both teachers and their students, and it is possible that CK and KSI are two of several competing factors that would all need to be isolated in order to get meaningful results.

5.2. Implications for Future Work

Compare teachers' written responses with a larger data set. Looking at teacher's written explanations for student reasoning shows different ways that teachers approached the KSI prompts. Some teachers included language about students in their answers while others made content-focused statements about the problems themselves. Grouping teachers by the nature of the focus of their written responses shows some distinct differences in their KSI and CK scores, and their student learning gains. Teachers who included language focusing on student thinking in their responses had, on average as a group, higher student learning gains, and higher overall KSI and CK scores. This grouping of the teachers shows some tentative correlations, but is based on a small number of teachers (n=9). The idea of looking at the nature of teacher responses is in need of further study with a larger group of teachers and may be a venue for further research within this project, or similar studies.

Design instruments and methods to provide greater insight into teacher KSI.

One issue to more closely investigate in order to differentiate KSI levels among teachers is the source of their KSI responses. Are teachers drawing on knowledge of students or are they reasoning about the features of the problem that they themselves find difficult? In this study, some teachers failed to select the correct option on the CK survey, but still received KSI points for selecting incorrect student answers and giving reasoning for why a student may choose that option. Methods that can further differentiate KSI from CK are needed to provide greater insight into what teachers think students know. One method to greater assess their KSI is through the nature of their written responses.

Data collection within the PBIS *VIM* curriculum is ongoing. Future efforts should look for greater sophistication in efforts to assess teacher KSI. If multiple-choice assessments are wanted for large data collection, there are ways to further refine the data collected. Items specifically designed for measuring student understanding may not be the most effective at measuring teacher KSI, so it may be beneficial to use separate items for measuring these two factors. Recommendations are to choose items that include distractors with only one strong misconception answer option for teachers to choose from, or to differentiate between strong and weak misconceptions among their answer options (Sadler, 2013). Items that are designed to measure understanding of force and motion, such as those from the SCFI and AAAS, include the correct answer option and then a number of distractors based on common misconceptions. In some cases, the same misconception is presented in a number of different options, spreading out student responses. Having teachers analyze one student option at a time rather than having them choose from 4 or 5 competing options may give clearer insight into their ability to recognize student misconceptions. Another option could be to have teachers rank student responses by which they thought were more likely to be selected by students.

The type of KSI emphasized in this study primarily focused on student difficulties and misconceptions; additional work could highlight the productive aspects of student thinking upon which teachers could build (Frank & Speer, 201X; Carpenter et al. 1996).

5.3. Final thoughts

This, and other similar studies, must continue in attempts to quantify the relative impacts of various types of teacher knowledge on students learning. These studies and the results they generate are of great importance in shaping teacher training and curriculum development. Multiple-choice assessment methods, such as the one in this investigation, are needed for large-scale studies, and the validation of the PCK construct. It is not enough to theorize or postulate about the importance of KSI; we must provide direct evidence of this relationship.

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APPENDIX A

FORCE AND MOTION STUDENT SURVEY

1. You throw a softball straight up in the air. What is the main force(s) acting on the ball after it leaves your hand?

A. A downward force of gravity and an upward force that gets smaller and smaller.

B. On the way up: an upward force that gets smaller and smaller.
On the way down: a force of gravity.

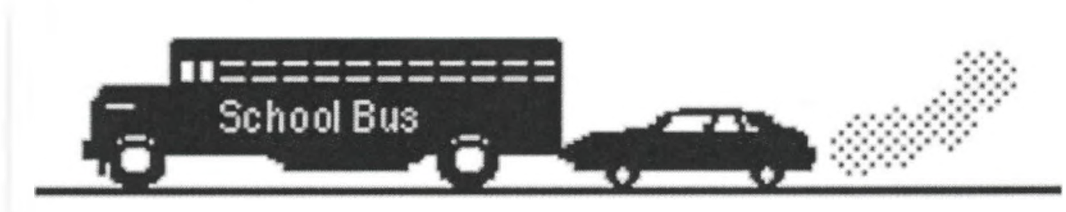
C. On the way up: a force of gravity and an upward force that gets smaller and smaller. On the way down: a force of gravity.

D. Only a downward force of gravity.

E. No forces. The ball falls back to the ground because that's its natural action.

Use the statement and figure below to answer the next two questions (2 and 3).

A school bus breaks down, and a car pushes it back to the garage.



2. When the car begins to push the school bus, which applies the larger force on the other?

A. Both apply forces of the same strength on each other.

B. The bus, because it's heavier.

C. The car. The bus applies a force too.

D. The car. The bus can't apply any force to the car, because it's engine isn't running.

E. Neither applies any force on each other. The bus is pushed forward because it's in the car's way.

3. After the car reaches a safe, constant speed for pushing the bus, which applies the larger force on the other?

A. Both apply forces of the same strength on each other.

B. The bus, because it's heavier.

C. The car. The bus applies a force too.

D. The car. The bus can't apply any force to the car, because it's engine isn't running.

E. Neither applies any force on each other. The bus is pushed forward because it's in the car's way.

4. While you're slowly lifting a book straight upwards at a constant speed, the upward push of your hand on the book is:

A. greater than the downward pull of gravity on the book.

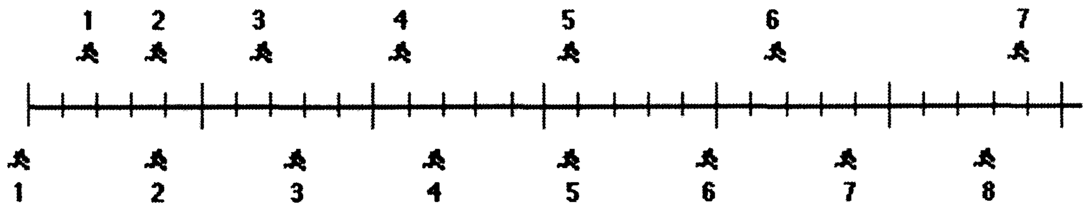
B. equal to the downward pull of gravity on the book.

C. smaller than the downward pull of gravity on the book.

D. equal to the sum of the book's weight *and* the pull of gravity on the book.

E. the *only* push or pull on the book.

5. While you and your friend are running, your science teacher takes measurements. Later he makes this drawing. The little stick figures show where both of you are (your positions) at every second of time. You're both running to the right.



Are you and your friend ever running at the same speed?

A. No.

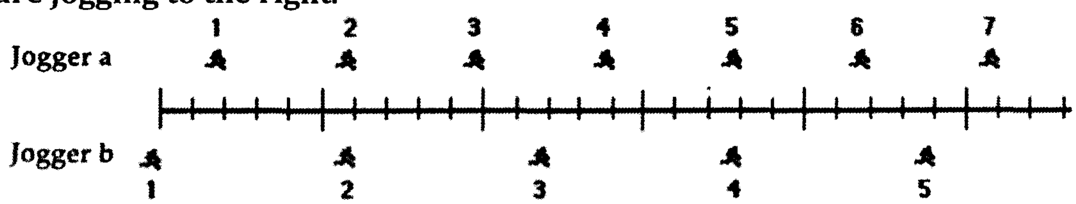
B. Yes, at second 2.

C. Yes, at second 5.

D. Yes, at both second 2 and second 5.

E. Yes, at somewhere between seconds 3 and 4.

6. The position of two joggers at each second of time are shown below. They are jogging to the right.



Which jogger is speeding up more quickly? That is, which jogger is accelerating more?

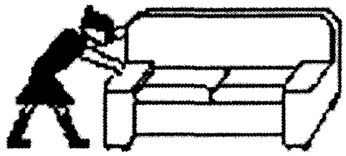
A. Jogger A.

B. Neither. Both are speeding up, and in the same way.

C. Jogger B.

D. Neither is speeding up; their speeds aren't changing.

E. Not enough information to answer this question.



7. Your friend pushes a sofa with a constant horizontal force, so that it moves down your school hallway at a constant speed. The force that she applies is:

A. the same as the weight of the sofa.

B. greater than the weight of the sofa.

C. the same as the total friction forces that resist the sofa's motion.

D. greater than the total friction forces that resist the sofa's motion.

E. the only horizontal force on the sofa. The friction forces aren't "real."

8. If your friend suddenly stops touching the sofa, it will:

A. stop immediately.

B. keep moving at the same speed for a little while, and then slow to a stop.

C. immediately begin slowing to a stop.

D. continue moving at the same speed.

E. speed up, and then slow to a stop.

9. What will happen to an object that is moving forward if a force pushing it backward is greater than the force pushing it forward?

A. The object will move at constant speed for a while and then slow down and stop.

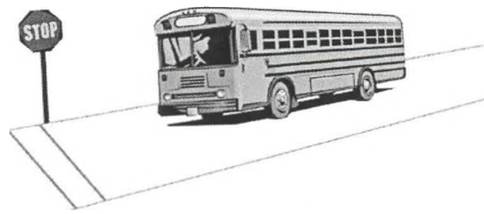
B. The object will slow down for a while and then move at a slower constant speed.

C. The object will slow down, stop, and then begin to move faster and faster in the opposite direction.

D. The object will slow down, stop, and then begin to move at a constant speed in the opposite direction.

10. A school bus is slowing down as it comes to a stop sign.

Which of the following statements is TRUE about the forces acting on the school bus while it is slowing down but still moving forward?



A. As long as the school bus is still moving forward, the forward force of the school bus has not run out.

B. As long as the school bus is still moving forward, any forces moving it forward would have to be stronger than any forces slowing it down.

C. If the school bus is slowing down, any forces moving it forward would have to be weaker than any forces slowing it down.

D. If the school bus is slowing down, any forces moving it forward would have to be the same strength as any forces slowing it down.

11. Is it possible for an object to move at constant speed without a force pulling or pushing it?

A. No, a constant force is needed to keep an object moving at constant speed.

B. No, a force is needed to keep an object moving at constant speed, but it doesn't have to be a constant force.

C. Yes, an object will move at constant speed unless a force acts to change its motion.

D. Yes, an object will move at constant speed as long as the force inside the object doesn't run out.

APPENDIX B

FORCE AND MOTION TEACHER CONTENT SURVEY

1. You throw a softball straight up in the air. What is the main force(s) acting on the ball after it leaves your hand?

A. A downward force of gravity and an upward force that gets smaller and smaller.
B. On the way up: an upward force that gets smaller and smaller.
   On the way down: a force of gravity.
C. On the way up: a force of gravity and an upward force that gets smaller and smaller.
   On the way down: a force of gravity.
D. Only a downward force of gravity.
E. No forces. The ball falls back to the ground because that's its natural action.

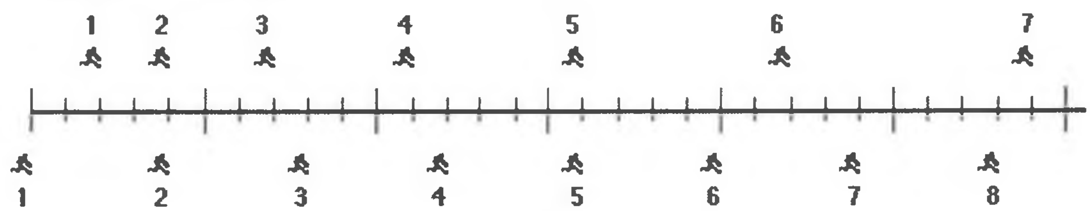
2. A school bus breaks down, and a car pushes it back to the garage.
When the car begins to push the school bus, which applies the **larger** force on the other?

A. Both apply forces of the same strength on each other.
B. The bus, because it's heavier.
C. The car. The bus applies a force, too.
D. The car. The bus can't apply any force to the car, because its engine isn't running.
E. Neither applies any force on each other. The bus is pushed forward because it's in the car's way.

3. While you're slowly lifting a book straight upwards at a constant speed, the upward push of your hand on the book is:

A. greater than the downward pull of gravity on the book.
B. equal to the downward pull of gravity on the book.
C. smaller than the downward pull of gravity on the book.
D. equal to the sum of the book's weight *and* the pull of gravity on the book.
E. the *only* push or pull on the book.

4. While you and your friend are running, your science teacher takes measurements. Later he makes this drawing. The little stick figures show where both of you are (your positions) at every second of time. You're both running to the right.



Are you and your friend ever running at the same speed?

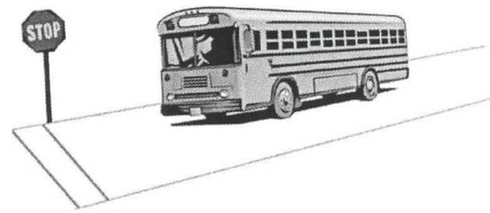
A. No.
B. Yes, at second 2.
C. Yes, at second 5.
D. Yes, at both second 2 and second 5.
E. Yes, at somewhere between seconds 3 and 4.

5. What will happen to an object that is moving forward if a force pushing it backward is greater than the force pushing it forward?

A. The object will move at constant speed for a while and then slow down and stop.
B. The object will slow down for a while and then move at a slower constant speed.
C. The object will slow down, stop, and then begin to move faster and faster in the opposite direction.
D. The object will slow down, stop, and then begin to move at a constant speed in the opposite direction.

6. A school bus is slowing down as it comes to a stop sign.

Which of the following statements is TRUE about the forces acting on the school bus while it is slowing down but still moving forward?

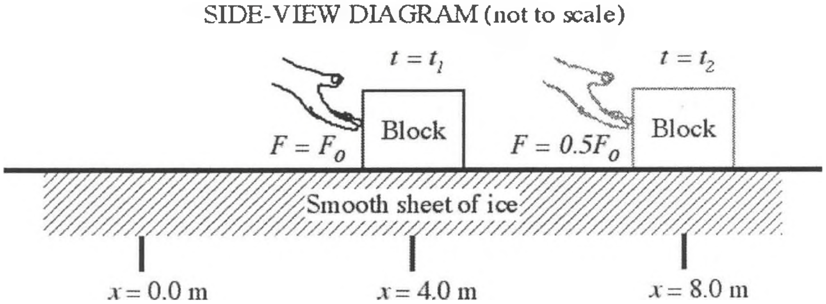


A. As long as the school bus is still moving forward, the forward force of the school bus has not run out.
B. As long as the school bus is still moving forward, any forces moving it forward would have to be stronger than any forces slowing it down.
C. If the school bus is slowing down, any forces moving it forward would have to be weaker than any forces slowing it down.
D. If the school bus is slowing down, any forces moving it forward would have to be the same strength as any forces slowing it down.

7. Is it possible for an object to move at constant speed without a force pulling or pushing it?

A. No, a constant force is needed to keep an object moving at constant speed.
B. No, a force is needed to keep an object moving at constant speed, but it doesn't have to be a constant force.
C. Yes, an object will move at constant speed unless a force acts to change its motion.
D. Yes, an object will move at constant speed as long as the force inside the object doesn't run out.

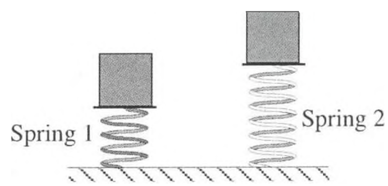
8. A student pushes a wooden block, initially at rest at x = 0.0 m, a distance of 8.0 m across a smooth, level ice surface as shown. Assume that friction is negligible. As the block covers the first 4.0 m, the student exerts a constant horizontal force of magnitude F_0. Then, as the block moves *between the 4.0 m and 8.0 m marks,* the student continuously *decreases* the magnitude of the horizontal force from F_0 to 0.5 F_0.



Describe the motion of the block between the 4.0 m mark and the 8.0 m mark.

A. The block moves with constant speed.
B. The block speeds up.
C. The block speeds up until it reaches a constant speed.
D. The block slows down.

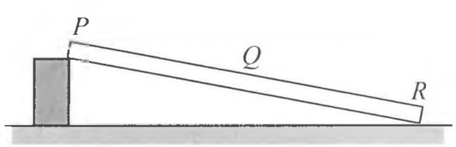
9. Two blocks are at rest on springs as shown below. The *blocks* are identical but the *springs* are different.



The magnitude of the force on the left block by spring 1 is:

A. Greater than that on the right block by spring 2.
B Less than that on the right block by spring 2.
C. Equal to that on the right block by spring 2.
D. There is not enough information provided to answer.

10. A student releases a ball from rest at point *P*, and observes the subsequent motion of the ball as it travels along a straight, inclined aluminum track. Point *Q* is located halfway between points *P* and *R*.

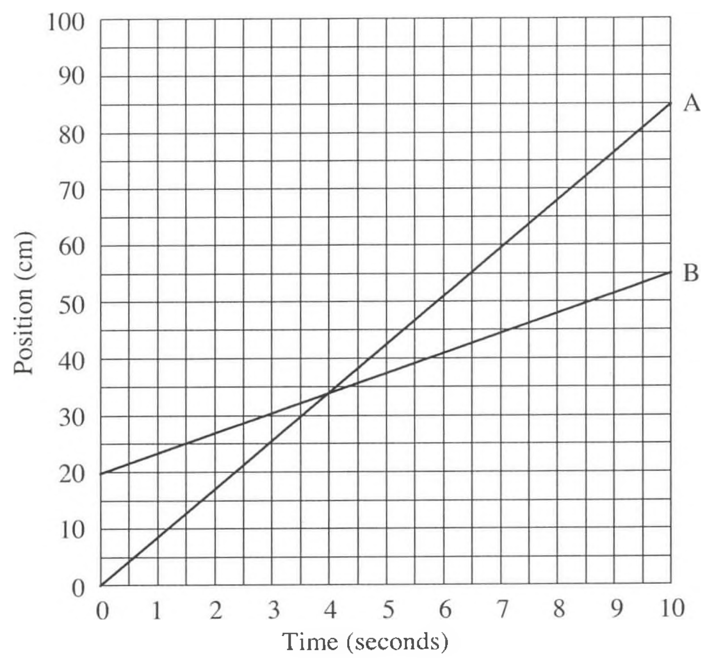


Suppose the ball is released from *P* at time $t = 0$ s and reaches *R* at $t = t_o$. At time $t = t_o/2$, the ball is located:

A. Somewhere between P and *Q*.
B. At Q.

C. Somewhere between Q and R.
D. There is not enough information provided to answer.

The following is a position versus time graph for the motions of two objects, A and B, that are moving along the same meter stick.



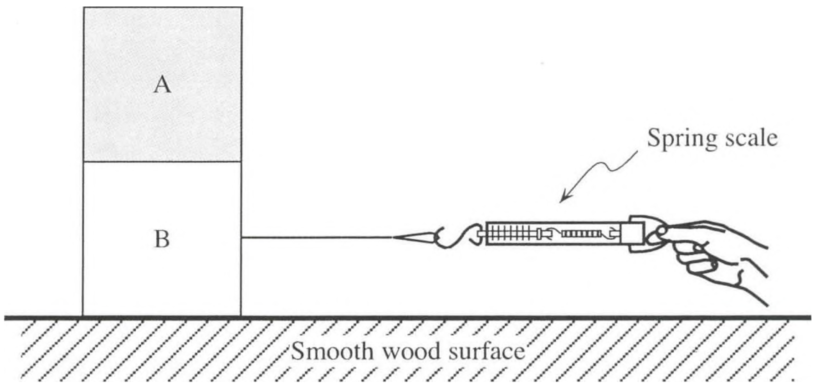
11. At the instant t = 2 seconds, the speed of object A is:

A. Greater than that of object B.
B Less than that of object B.
C. Equal to that of object B.
D. There is not enough information provided to answer.

12. Do objects A and B ever have the same speed?

A. Both objects have the same speed once, which is at t = 4 seconds.
B Both objects have the same speed twice.
C. Both objects have the same speed three times.
D. The two objects never have the same speed.

Block A is placed on block B, which is initially at rest on a smooth wood surface. The mass of block A is twice that of block B.



A spring scale is then used to exert a constant force on block B, and block B is observed to speed up. Block A does *not* slip on block B.

13. The magnitude of the acceleration of block A is:

A. greater than that of block B.
B equal to that of block B.
C. less than that of block B but not zero.
D. zero.

14. The magnitude of the net force on block A is:

A. greater than that of block B.
B equal to that of block B.
C. less than that of block B but not zero.
D. zero.

APPENDIX C

FORCE AND MOTION TEACHER KSI SURVEY

Name: ____

School: ____

Grade(s) you teach: _______

Years of teaching experience: _______

Years of teaching experience in physical science: _______

Academic background: college major and degree(s)

____

____

This survey contains four different student questions. For each of the four student questions, please review the multiple-choice responses presented (A, B, C, D, E) and indicate whether or not a significant percentage of your students would choose that option (regardless of the correctness of the option). If you think a significant percentage of your students would choose the option, please indicate why they might choose this option and describe <u>their thinking</u> in the space provided.

Please give as much detail about your students' thinking as possible.

Student Question 1:

1. You throw a softball straight up in the air. What is the main force(s) acting on the ball after it leaves your hand?

   A. A downward force of gravity and an upward force that gets smaller and smaller.
   B. On the way up: an upward force that gets smaller and smaller. On the way down: a force of gravity.
   C. On the way up: a force of gravity and an upward force that gets smaller and smaller. On the way down: a force of gravity.
   D. Only a downward force of gravity.
   E. No forces. The ball falls back to the ground because that's its natural action.

A. A downward force of gravity and an upward force that gets smaller and smaller.

Would a significant percentage of students (>10%) in a given class choose this answer?

Yes No

A student who chose this response might be thinking:

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____

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**B. On the way up: an upward force that gets smaller and smaller.
On the way down: a force of gravity.**

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

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**C. On the way up: a force of gravity and an upward force that gets smaller and smaller.
On the way down: a force of gravity.**

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

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D. Only a downward force of gravity.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

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E. No forces. The ball falls back to the ground because that's its natural action.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

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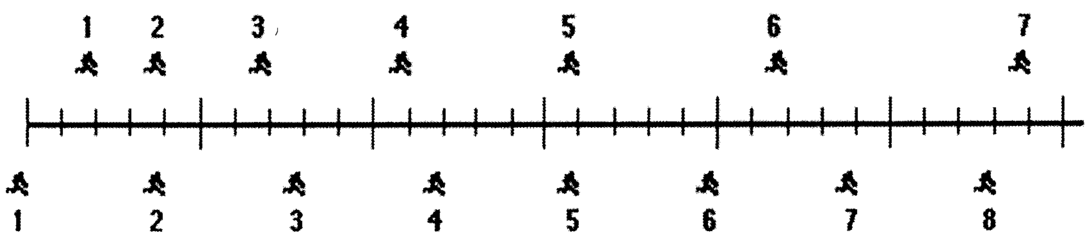
Student Question 2:

2. While you and your friend are running, your science teacher takes measurements. Later he makes this drawing. The little stick figures show where both of you are (your positions) at every second of time. You're both running to the right.



Are you and your friend ever running at the same speed?

A. No.
B. Yes, at second 2.
C. Yes, at second 5.
D. Yes, at both second 2 and second 5.
E. Yes, at somewhere between seconds 3 and 4.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

B. Yes, at second 2.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

C. Yes, at second 5.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

D. Yes, at both second 2 and second 5.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

E. Yes, at somewhere between seconds 3 and 4.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

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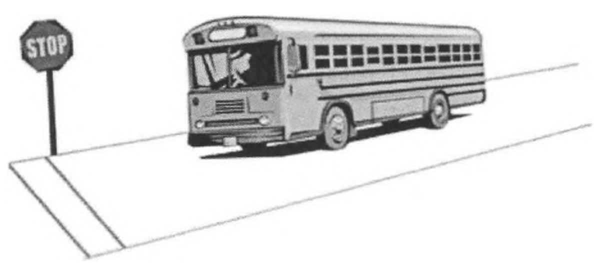
Student Question 3:

11. A school bus is slowing down as it comes to a stop sign.



Which of the following statements is TRUE about the forces acting on the school bus while it is slowing down but still moving forward?

A. As long as the school bus is still moving forward, the forward force of the school bus has not run out.

B. As long as the school bus is still moving forward, any forces moving it forward would have to be stronger than any forces slowing it down.

C. If the school bus is slowing down, any forces moving it forward would have to be weaker than any forces slowing it down.

D. If the school bus is slowing down, any forces moving it forward would have to be the same strength as any forces slowing it down.

A. As long as the school bus is still moving forward, the forward force of the school bus has not run out.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

B. As long as the school bus is still moving forward, any forces moving it forward would have to be stronger than any forces slowing it down.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

C. If the school bus is slowing down, any forces moving it forward would have to be weaker than any forces slowing it down.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

D. If the school bus is slowing down, any forces moving it forward would have to be the same strength as any forces slowing it down.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

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E. The object will slow down, stop, and then begin to move at a constant speed in the opposite direction.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

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Student Question 4

10. What will happen to an object that is moving forward if a force pushing it backward
is greater than the force pushing it forward?

A. The object will move at constant speed for a while and then slow down and stop.
B. The object will slow down for a while and then move at a slower constant speed.
C. The object will slow down, stop, and then begin to move faster and faster in the opposite direction.
D. The object will slow down, stop, and then begin to move at a constant speed in the opposite direction.

A. The object will move at constant speed for a while and then slow down and stop.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

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B. The object will slow down for a while and then move at a slower constant speed.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

____

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C. The object will slow down, stop, and then begin to move faster and faster in the opposite direction.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

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D. The object will slow down, stop, and then begin to move at a constant speed in the opposite direction.

Would a significant percentage of students in a given class (>10%) choose this answer?

Yes No

A student who chose this response might be thinking:

BIOGRAPHY OF THE AUTHOR

Daniel Laverty was born in Millinocket, Maine in 1982. He grew up in the small town of Medford, Maine and graduated from Penquis Valley High School in 2000. Daniel then enrolled and attended the University of Maine, graduating in 2005 with a Bachelors of Science degree in Ecology and Environmental Science. He returned to the University of Maine in 2011 to complete a Masters of Science in Teaching degree. In the fall of 2012 he started teaching math and science at Mattanawcook Junior High School in Lincoln, Maine, where he currently teaches 7th grade life science. Daniel is a candidate for the Master of Science in Teaching degree from the University of Maine in December 2015.