A COMPARATIVE STUDY OF THE EMPIRICAL RELATIONSHIP IN STUDENT PERFORMANCE BETWEEN PHYSICS AND OTHER STEM SUBJECTS

by

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Abstract

The Next Generation Science Standards (NGSS) advocated by the National Research Council emphasize the connections among Science, Technology, Engineering, and Mathematics (STEM) disciplines. By design, NGSS is expected to replace the previous science education standards to enhance the quality of STEM education across the nation. To support this initiative, this investigation was conducted to fill a void in the research literature by developing an empirical indicator for the relationship of student performance across STEM subjects using a large-scale database from the Trends in Mathematics and Science Study (TIMSS). In particular, an innovative approach has been taken in this study to support the canonical correlation analysis of student plausible scores between physics and other STEM subjects at different grade levels and in a cross-country context. Results from this doctoral research revealed the need to strengthen the alignment between the intended, implemented, and attained curricula to support the integration of STEM disciplines in the United States.

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TABLE OF CONTENTS

Page

LIST OF TABLES ... ix

LIST OF FIGURES ... x

CHAPTER 1: INTRODUCTION ... 1

Background ... 1

Mathematics and Science Assessments ... 3

Problem Statement ... 6

Significance of Study ... 9

Theoretical Framework for Study ... 9

Overview of Learning Theories ... 10

Constructivist Learning Theory ... 11

Developmental Stage Theory ... 13

Multiple Intelligences Theory ... 14

Curriculum Evaluation Model ... 15

Research Questions and Hypotheses ... 16

Assumptions ... 17

Limitations ... 17

Delimitations ... 18

Key Terms ... 18

Summary ... 19

Organization of Remaining Chapters ... 19

CHAPTER 2: REVIEW OF THE LITERATURE ... 20

Curriculum Integration ... 20

Debate on Curriculum Integration ... 21

Integration of Mathematics and Science 23
Cross-Subject Integration with Physics 25
Physics and Mathematics Integration 25
Physics and Science Integration 27
Student Achievement across Grades and Countries 29
Cognitive Development between the Fourth and Eighth Grade 29
Curriculum Differences across Countries 33
TIMSS Dataset and Student Achievement 35
Development of TIMSS Dataset 35
Summary 37
CHAPTER 3: METHODOLOGY 39
Features of the Study 39
TIMSS Theoretical Framework 39
TIMSS Dataset 41
Sampling Procedures 45
Data Analysis 47
Participants and Variables 47
Statistical Method 49
Summary 51
CHAPTER 4: RESULTS 52
Descriptive Findings 52
Fourth Grade 52
Eighth Grade 55
Correlation of Student Performance Between Physics and STEM Subjects 58
Fourth Grade Comparison 58

Eighth Grade Comparison 61
Correlation of Student Performance between Physics and
Cognitive Domains 63
Fourth Grade Comparison 63
Eighth Grade Comparison 68
Summary 72
CHAPTER 5: CONCLUSION 73
Overview of Findings 73
Correlation of Student Performance between Physics and
STEM Subjects 74
Correlation of Student Performance between Physics and Cognitive
Domains 77
Median Correlation of Student Performance between Physics and
Cognitive Domains 82
Practical Implications 85
Limitations 87
Suggestions for Future Research 87
Conclusion 88
REFERENCES 90
APPENDIX: COPYRIGHT PERMISSION LETTER 117

LIST OF TABLES

Page

Table 1 *Mathematics Assessment Framework* 42

Table 2 *Science Assessment Framework*.. 43

Table 3 *Cognitive Processes and Content Knowledge for Mathematics* 48

Table 4 *Cognitive Processes and Content Knowledge for Science*....................... 48

Table 5 *Mathematics and Science Achievement of 4th Grade Participating Countries*.. 54

Table 6 *Mathematics and Science Achievement of 8th Grade Participating Countries*.. 57

Table 7 *Correlation between Physics and Other STEM subjects for 4th Grade Participating Countries* 60

Table 8 *Correlation between Physics and Other STEM subjects for 8th Grade Participating Countries* 62

Table 9 *Correlation between Physics and Cognitive Domains in Mathematics for 4th Grade Participating Countries* 65

Table 10 *Correlation between Physics and Cognitive Domains in Science for 4th Grade Participating Countries*... 67

Table 11 *Correlation between Physics and Cognitive Domains in Mathematics for 8th Grade Participating Countries* 69

Table 12 *Correlation between Physics and Cognitive Domains in Science for 8th Grade Participating Countries*... 71

Table 13 *Physics and Cognitive Domains in Mathematics at the Fourth Grade* . 83

Table 14 *Physics and Cognitive Domains in Science at the Fourth Grade*.......... 83

Table 15 *Physics and Cognitive Domains in Mathematics at the Eighth Grade*.. 84

Table 16 *Physics and Cognitive Domains in Science at the Eighth Grade* 84

LIST OF FIGURES

Page

Figure 1. Different types of learning in a Modified Illustration of Bloom's Taxonomy. 31

Figure 2. Components within the Curriculum Evaluation Model. 40

Figure 3. Fourth grade assessment item illustrating the integration of mathematics and physics. 75

Figure 4. Eighth grade assessment item illustrating the integration of chemistry and physics. 76

Figure 5. Fourth grade assessment item illustrating the integration of physics and other STEM subjects within the reasoning domain. 78

Figure 6. Additional fourth grade assessment item illustrating the integration of physics and other STEM subjects within the reasoning domain. 79

Figure 7. Eighth grade assessment item illustrating the integration of physics and other STEM subjects within the reasoning domain. 80

Figure 8. Eighth grade assessment item illustrating the integration of biology and mathematics. 81

CHAPTER 1: INTRODUCTION

Data from the Trends in International Mathematics and Science Study (TIMSS) were employed in this dissertation to examine the correlation of student achievement between physics and other Science, Technology, Engineering, and Mathematics (STEM) subjects. The analysis encompassed a comparison of empirical relationships across grade levels and countries. To assess the impact of cross-subject integration, this study focused on indicators of student achievement from a large-scale empirical investigation. Altogether this study was designed to assess the impact of cross-subject correlation on STEM learning outcomes using an international dataset.

Background

Educators who wish to learn about education systems have benefited greatly from international assessments (Eckert, 2008; Frank & Mackett-Frank, 1978). Mislevy (1995) pointed out that the main purpose of international assessments is to compare education systems across nations, assess the effect of educational policies, and examine country's priorities in relation to student achievement. As a result, international assessments have become the impetus for educational reform and policies in the United States (Beaton, Martin, & Mullis, 1997; Turgut, 2013). The focus on curricula helps educators identify strengths and weaknesses within their education system to improve student achievement (Gustafsson, 2008; Plisko, 2013; Plomp, 1990).

Although international assessments have a significant effect on education reform, some researchers question their validity because test scores are affected by several factors (Tienken, 2010). Critics of international assessments suggest that external evaluators cannot possibly develop a full understanding of factors affecting the achievement of students (Frank & Mackett-Frank, 1978). In part, this is because of the lack of in-depth understanding of the education systems and the population that they serve. Failure to take these factors into consideration can lead to ineffective reforms as a result of different "objectives, values, and organization" within countries (Hurn, 1983, p. 7). On the other hand, proponents of international assessments stress the benefits of borrowing ideas to advance the educational achievement of students (Frank & Mackett-Frank, 1978). Comparative information can serve as a common indicator; however, educators need to be cautious when interpreting scores because international assessments might not represent a complete picture of an educational system (Cavanagh, 2012; Rutkowski & Prusinski, 2011). Curriculum designs for several subjects such as those in the STEM field vary across countries even though they are universally taught as core subjects in schools. Therefore, international assessments merely instigate the adoption of effective education reforms that have the potential to spur global competiveness.

International assessments have now become an important resource for secondary analysis in science education (Miller, 1982). These assessments offer researchers an opportunity to access quality, comprehensive, and inexpensive large-scale datasets collected by experts in the field, which cannot easily be replicated (Greenhoot & Dowsett, 2012; Miller, 1982). Researchers can essentially use the datasets to identify new patterns that were not available to primary researchers in a small scope investigation (Chow & Kennedy, 2014; Smith, 2008). Nevertheless, those using existing datasets need to acknowledge potential pitfalls. Considering that the data are usually collected for a different purpose, researchers may find that the variables and population do not exactly apply to their research study (Greenhoot & Dowsett, 2012). Researchers that do find applicable data may still struggle with the interpretation of findings because they are not familiar with the process used to collect the data (Cheng & Phillips, 2014). In short, “the combination of decreasing federal support for science education research and increasing data collection costs” stress the importance of secondary analysis in the research community (Miller, 1982, p. 724). In the past, organizations such as the National Science Foundation have provided funding for secondary data analyses that led to improvement of curriculum and instruction in science teaching (National Science Foundation, n.d.).

Mathematics and Science Assessments

International assessments in mathematics and science have garnered a significant amount of attention for more than half a century. The significance of international assessments in mathematics and science was greatly affected by the climate that resulted from the Sputnik launch in 1957, which initiated a competition among nations in the science and technology field (Husen, 1979; Turgut, 2013). This competition supported the research projects of the International Association for the Evaluation of Educational Achievement (IEA) because nations were becoming interested in their international ranking (Baker, 2007).

In history, the launch of the Sputnik satellite was taken as a sign of inferiority in the United States to result in implementation of the National Defense Education Act (NDEA) of 1958, which was aimed at improving student performance in core subjects by infusing funding into the education system (Kay, 2013). The introduction of this act became known as the federal government’s first attempt to reform the education system (Steeves, Bernhardt, Burns, & Lombard, 2009), an area that used to be delegated to local and state governments in the past (Kay, 2013). The NDEA was strongly supported by Americans who believed that the demise of the United States in science, technology, and engineering was the result of a flawed education system (Steeves et al., 2009; Turgut, 2013).

Student performance was once again highlighted in a report titled *A Nation at Risk* in 1983 (Koretz, 2009). This report focused on the poor performance of students on international assessments and outlined potential solutions to improve the quality of education, which was intended to initiate discussions similar to those spurred by the Sputnik launch in 1957 (Strickland, 1985). The argument for an education reform was reflected in the following statement:

> The educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a Nation and a people. What was unimaginable a generation ago has begun to occur--others are matching and surpassing our educational attainments. (National Commission on Excellence in Education, 1983, p. 13)

This statement insinuated that the United States was at risk of losing its superior status in a knowledge-based economy, which could only be addressed by producing educated individuals capable of meeting workforce demands (Allen, 2008).

A Nation at Risk eventually contributed to the standards-based education reform movement in the United States (Johanningmeier, 2010). Issues outlined in the report made it difficult to ignore the need for standards; as a result, President George H. Bush held a summit on education in 1989 with the nation's governors to develop national standards and assessments to improve the quality of education (Viteritti, 2004). This summit resulted in an agreement to develop national standards and assessments known as "America 2000"; however, this initiative never materialized (Schwartz, Robinson, Kirst, & Kirp, 2000).

The proposal for academic standards was eventually carried into the Clinton Administration; however, the administration did not focus on national standards to avoid unnecessary controversy on the federal government's role in education (Turgut, 2013). That administration managed to get approval for state standards and assessments known as "Goals 2000" (Viteritti, 2004). Although "Goals 2000" was yet to be attained, it served as a foundation for other legislation aimed at improving the quality of education (Moores, 2004), such as the No Child Left Behind (NCLB) Act of 2001. NCLB was a federal attempt to reform the education system, under the George W. Bush Administration, through standardized testing aimed at holding states accountable for student achievement (Dee & Jacob, 2011; Rush & Scherff, 2012). The ultimate goal of NCLB was to narrow the achievement gap by improving the academic performance of all students (Ellis, 2007). Standardized testing only created an education system focused on preparing students in a limited number of subjects; consequently, teachers often disregarded other subjects that could enhance student achievement (Guifoyle, 2006).

Issues created by the NCLB are now being addressed by the Common Core State Standards (CCSS) from the Council of Chief State School Officers and the National Governor's Association (Liebtag, 2013). The goal of this movement is to create common standards for academic skills and knowledge across the nation (Porter, McMaken, Hwang, & Yang, 2011). This movement is strongly supported by various groups with an interest in the education sector including the Obama Administration. A press release issued in 2009 indicated that 49 states had already adopted CCSS (Tienken, 2010). State governors now need to ensure that CCSS is implemented equitably across all schools, including those that are disadvantaged, by reducing the variability in "teacher training, materials used, and experiences offered to students" (Liebtag, 2013, p. 60).

Problem Statement

Success in the STEM field is correlated with student performance in mathematics and science (President's Council of Advisors on Science and Technology, 2010); unfortunately, the United States is currently falling behind several nations in these two subjects (Tienken, 2013). The inferior performance of the United States is reflected in the most recent results from international and national assessments. Results from TIMSS 2011 for fourth and eighth grade students indicated that the United States performed above average in science and mathematics when compared to other countries; however, the United States is still trailing behind several countries (Provasnik et al., 2012). These results are even more concerning considering that the performance of students typically declines from the fourth to the eighth grade, which stresses the need to address curriculum issues (Valverde & Schmidt, 1997-98). The poor performance of students is further reflected in results from the most recent Program for International Student Assessment (PISA) for 15-year olds, which indicates that the United States has a large percentage of students performing below the international average scores in mathematics, science, and reading (Kelly et al., 2013). Within the United States, the result does not fare any better in the National Assessment of Education Progress (NAEP). Historical data from NAEP show that even though the United States has improved student performance since the 1970s, only a small number of students have fallen under the proficient or above proficient category (National Science Foundation, Division of Science Resources Statistics, 2002).

Trends from international and national assessments seem to suggest that there are flaws in the curriculum, which is contributing to a lack of scientific degrees (U.S. Congress Joint Economic Committee, 2012). As a result, the United States is expected to have a STEM workforce shortage in the near future, which can threaten the nation’s economic stability (Duncan, 2012; Lehman, 2013). Researchers have indicated that the STEM field is experiencing significant job growth with 15 out of the 20 fastest growing occupations requiring a background in mathematics and science (Froschauer, 2006). However, scientific degrees awarded to individuals 18-24 year olds have decreased in the last 30 years (Griep, 2012); in fact, the United States is ranked 32 among 90 countries in the production of STEM degrees (Froschauer, 2006). Several countries including Japan and China are now surpassing the number of STEM degrees awarded in the United States, at a time in which technology plays a significant role in the economy (Costello, 2010).

Educators, policy makers, and business professionals must now address the lack of interest and academic preparation of students in the STEM field (ACT, 2006). A focal point of this issue is the retention of STEM majors. Less than half of the students who enroll in a STEM program earn a degree (President’s Council of Advisors on Science and Technology, 2012). The retention of students is particularly important for students pursuing a career in engineering, a field that is projected to encounter a significant shortage compared to other STEM fields (Finn & Baker, 1993; Rockland et al., 2010). This projection is strongly supported by a 20% decrease in engineering degrees since 1985 (Robinson & Ochs, 2008). Addressing this shortage requires preparing students in essential subjects such as physics, chemistry, and calculus (Sonmez, 2012; White & Cottle, 2011). Students with a strong background in physics are more likely to pursue a STEM degree (Bottia, Stearns, Mickelson, Moller, & Parker, 2015); in fact, students with a background in physics represent the “nation’s future science teachers, doctors, scientists, and engineers” (Sadler, & Tai, 2001, p.111).

Consequently, initiatives such as the Next Generation Science Standards (NGSS) have been introduced to improve student achievement in the STEM field. These standards place more emphasis on the integration between one or more STEM subjects (Kurson, 2014). This initiative primarily stresses the importance of subject matter competency to ensure understanding of the relationship between STEM content. Nevertheless, researchers have not been able to provide empirical evidence for STEM integration (Rochrig, Wang, Moore, & Park, 2012) despite growing calls to emphasize the connections among subjects. It was noted that "currently, however, there is little research on how to best integrate STEM disciplines" (Board of Regents of the University of Wisconsin System, 2014, para. 6). Cross-subject integration between physics and other STEM subjects is particularly important because physics is an integral component to support STEM achievement in higher education (Meltzer & Otero, 2014; Yager & Krajcik, 1989). To broaden the research horizon, the effectiveness of interdisciplinary integration demands an articulation of student achievement across grade levels and countries. Cognitive development is believed to have an influence on the reasoning skills of science students (Lawson, 1980; Lawson, Karplus, & Adi, 1978), whereas results from comparative studies in mathematics and science are expected to improve student achievement (Pratt, 2005).

While the NAEP produces report cards to assess learning outcomes in core STEM subjects, such as mathematics and science (Jacob & Ludwig, 2009), no student is given mathematics and science tests concurrently in NAEP assessments. Thus, no national indicators have been developed to correlate mathematics and science achievement (E. Johnson, 1998). Similarly, PISA is another project widely cited in the literature. However, no correlation analysis can be conducted between subjects because of its rotation of assessments in mathematics, science, and reading every three years. In contrast, TIMSS is the only large-scale study that includes both mathematics and science assessments in its data gathering; however, no one has taken this opportunity to examine the correlation of student achievement between physics and other STEM subjects.

Significance of Study

Results from this study will inform education policy makers, researchers, and practitioners who are interested in STEM integration because there is a lack of literature on cross-subject integration and student performance using large-scale datasets. These stakeholders could essentially benefit from the construction of an empirical indicator that will enable them to monitor student learning across grade levels and countries. Results from a cross-country analysis in particular would give the United States an opportunity to learn from different educational approaches. Overall, this study will enrich the understanding of the United States' education system in a global context.

Theoretical Framework for Study

This study was viewed through the lens of the Constructivist Learning Theory, the Theory of Cognitive Development, and Zone of Proximal Development. Constructivist Learning Theory served as the foundation for this study as it enriched an understanding of curriculum integration across subjects. This theory was supplemented by the Developmental Stage Theory and Multiple Intelligences Theory aimed at addressing differences in the performance of fourth and eighth grade students. Differences in student achievement across countries were interpreted to support the identification of a Curriculum Evaluation Model. Together these theories provided the underlying premise for this research.

Overview of Learning Theories

More than one theory has an influence on the study of student learning (Hean, Craddock, & O'Halloran, 2009). Three primary theories in the field of education are behaviorism, cognitivism, and constructivism (Ertmer & Newby, 1993). Bigge and Shermis (1992) noted that Skinner, a leading theorist in behavioral learning, believed that "all human behavior is a product of either biological natural selection or psychological operant reinforcement" (p. 96). Behaviorists primarily focus on the link between a stimulus and response through consistent reinforcement for the acquisition of knowledge (Cooper, 1993). This paradigm is essentially perceived as a strategy to manage learning and behavior in an educational setting (Driscoll, 2000). The sole responsibility of an educator is to ensure that students internalize critical knowledge; however, viewing students as passive recipients neglects their ability to discover knowledge in the STEM field.

In contrast, cognitivists focus on mental processes instead of observed learning behavior (Carey, 1986). Driscoll (2000) noted that Atkinson and Shiffrin, leading theorists in cognitive learning, stressed that learning is an active process in which individuals categorize and organize incoming knowledge. The attainment of knowledge is ultimately correlated with distinct intellectual stages (Kirby & Biggs, 1980), which influence how "information is received, organized, stored, and retrieved" (Ertmer & Newby, 1993, p. 51). Even though the cognitive perspective expands the role of students in the learning process, it does not support inquiry-based learning in STEM education. Students are simply expected to absorb and recall information presented by educators.

The shortcomings of behaviorism and cognitivism have prompted educators to advocate for constructivism. Cognitive theorists, such as Jean Piaget, eventually focused on the construction of knowledge through one's experiences (Fosnot, 1996; Keyes & Bryan, 2001). Renner, Abraham, and Birnie (1986) indicated that Piaget's adaptation and organization model, focused on the interpretation of experiences, was evident in the construction of knowledge among high school students in physics. Students in this case were characterized as active learners responsible for the creation of knowledge through inquiry with the guidance of teachers and assistance of peers (Mvududu, 2005; Renner et al., 1986). As a result, the constructivist theory serves as the foundation for reform initiatives in mathematics and science education (Lunenberg, 1998).

Constructivist Learning Theory

Constructivist theorists believe that "students learn through connections formed between prior knowledge and new experiences and as connections arise among existing ideas" (Bosse, Lee, Swinson, & Faulconer, 2010, p.262). Physics in particular requires the use of proportional reasoning (Akatugba & Wallace, 1999a) to understand density and speed concepts; hence, theorists illustrate that student learning is improved when ideas are interconnected (Czerniak, Weber, Sandmann, & Ahern, 1999), which leads to a deep understanding of concepts and coherent knowledge (Mason, 1996). This perspective requires that students take an active role in the learning process and recreation of knowledge (Khan, 2013). Constructivists advocate the following practices: "(1) elicit students' prior conceptions on the topic being taught and (2) create a cognitive conflict in students' minds that confronts their prior conceptions with new phenomenon, with the conceptions of other children, or with new knowledge" (Bachtold, 2013, p. 2478). These practices prompt students to acknowledge different perspectives of an issue, assess contradicting evidence, support claims with evidence, and make inferences (Willingham, 2007). Numerous examples are embedded in STEM education to support student cognitive development.

The skills advocated by constructivists represent higher order thinking skills, which are required in different contexts including school and the workplace. Higher order thinking is characterized as the construction of knowledge, whereas lower order thinking is characterized as simply recalling information introduced in the classroom (Barak, Ben-Chaim, & Zoller, 2007). The latter perspective offers students a simplistic educational experience in which “knowledge acquired through rote learning is soon lost, and even forgotten, this knowledge cannot be used effectively in problem solving” (Novak, 1977, p. 453). Cakir (2008) stressed that bombarding students with concepts and activities does not improve student learning. Students need experiences that prompt them to reconstruct knowledge through conceptual learning (Lamanauskas, 2010) in physics and other STEM subjects. The need for higher order thinking skills can be reflected in student learning outcomes across STEM subjects; nevertheless, ensuring that students do well in one discipline does not guarantee that they will be able to transfer knowledge into other disciplines (Edmondson, 1999). Overall, the constructivist theory exemplifies the importance of cross-subject integration.

Zone of Proximal Development. The cognitive ability of students could be enhanced with scaffolding strategies supported by Vygotzky’s Zone of Proximal Development with an emphasis on those who have not reached the appropriate cognitive development stage for STEM learning. Lawson and Renner (1975) have indicated that a large proportion of students in high school biology, chemistry, and physics courses exhibit cognitive abilities manifested among younger students. The Zone of Proximal Development Theory “is the gap between what a learner has already mastered, his actual development, and what he can achieve when provided with educational support, called potential development” (Rezaee &

Azizi, 2012, p. 51). This theory suggests that scaffolding is necessary for tasks that children are not able to complete on their own, which can help them reach their potential development (Armstrong, 2015; Benko, 2012; Van Compernolle & Williams, 2012). The abilities that children develop in assisted tasks eventually become part of their actual cognitive development (Mestad & Kolsto, 2014). Because the mastery of knowledge concurrently occurs across different subjects in a school setting, there is a need to examine relationships of student performance between physics and other STEM subjects. Overall, the Zone of Proximal Development illustrates the relationship between assisted learning and cognitive development (Fernandez, Wegerif, Mercer, & Rojas-Drummond, 2015; Rezaee & Azizi, 2012).

Developmental Stage Theory

Student achievement, in all academic fields, could be influenced by cognitive development. Piaget's Developmental Stage Theory encompasses four stages that exemplify the development of an individual's mental processes from early childhood to adulthood (Cartwright, 2001). The stages introduced by Piaget include the following: sensorimotor stage, preoperational stage, concrete operations stage, and formal operations stage. Each stage corresponds to a specific age range, which can be linked to a grade level within an education system. In particular, TIMSS data were gathered from the fourth to eighth grade. Hence, characteristics of concrete and formal operations are relevant to this investigation:

Concrete operations stage (7-11 years old). The concrete operations stage is characterized by a child's ability to think logically about concrete objects, activities, or events (Cartwright, 2001). Children in this stage are able to address problems that are tangible or observable (Ault, 1983; Brainerd, 1978; Wadsworth, 1971). Problems that are presented to children usually deal with seriation, classification, causality, and time and speed (Piaget, 1970).

Formal operations stage (11 years old and older). The formal operations stage states that children have the ability to think rationally and logically about abstract ideas or concepts (Cartwright, 2001). Children are no longer limited to the understanding of concrete events or objects, which facilitates the identification of solutions for complex problems (Piaget, 1970; Wadsworth, 1971). Solutions for problems are derived through careful reasoning and reflection (Brainerd, 1978), which exemplifies higher order thinking (Ault, 1983).

The stages identified above exemplify the cognitive abilities of students. Due to their generic role in student learning, these stages can support the interpretation of student achievement across STEM subjects at the fourth and eighth grade.

Multiple Intelligences Theory

Differences in student achievement could be attributed to Gardner’s Multiple Intelligences Theory. This theory advocates that there is more than one capacity for learning (Gardner, 1993); hence, a cookie cutter approach to learning is not the ideal solution for a diverse student population (Ellison, 1992). Heckman (2011) indicated that “at birth, each child inherits different capabilities and different resources” that should be acknowledged (p. 32). The Multiple Intelligence Theory outlined eight intelligences that can help describe the learning capacity of individuals (Adcock, 2014):

- Linguistic: The ability to communicate with words in writing and/or orally.

- Mathematical/Logical: The ability to use critical thinking skills to problem solve.
- Naturalistic: The ability to understand topics related to nature.
- Spatial: The ability to visualize and create mental images.
- Bodily/Kinesthetic: The ability to interact with the environment.
- Musical: The ability to identify patterns and/or rhythms.
- Interpersonal: The ability to interact with different individuals.
- Intrapersonal: The ability to identify personal strengths and weaknesses.

Individuals in this case may exhibit one or more of these intelligences, which may facilitate learning (Karamustafaoglu, 2010).

The intelligences identified above ultimately pose universal implications for student learning. Based on the Multiple Intelligence Theory, student performance across STEM subjects is built on the mutual support of learning processes.

Curriculum Evaluation Model

The correlation between cross-subject integration and student achievement could be interpreted using the Curriculum Evaluation Model, which is applied to more than one comparative study administered by the IEA on a wide range of topics (International Association for the Evaluation of Educational Achievement, 2011). This theoretical framework encompasses three components: intended curriculum, implemented curriculum, and attained curriculum. Education initiatives, such as the Next Generation Science Standards, have made curriculum integration a desired component of the intended curriculum in STEM education. Curriculum integration is reflected in the implemented curriculum as a result of the Common Core movement. Following the three-tier framework, progress in the intended and implemented curriculum forms a sharp contrast against the lack of research indicators for student achievement at the achieved curriculum level. As a result, this research study is deeply grounded in the theoretical framework from TIMSS; thus, the construction of an inter-subject indicator is naturally supported by TIMSS measures of student performance.

Research Questions and Hypotheses

This research study investigated the following hypothesis for each of the research questions:

1. What is the correlation of student performance between physics and other STEM subjects?
   a. H_0: There is no significant correlation of student performance between physics and other STEM subject.
2. What is the correlation of student performance between the fourth and eighth grade?
   a. H_0: There is no variation in the correlation of student performance between the fourth and eighth grade.
3. What is the correlation of student performance across countries?
   a. H_0: There is no variation in the correlation of student performance across countries.

In general, curriculum differences across countries were expected to impact correlation of student performance in STEM subjects. This assertion was supported by a statement from TIMSS, which stresses that findings from comparative studies must acknowledge factors that influence student's opportunity to learn (Beaton et al., 1996). In fact, Martin, Mullis, Gonzalez, and Chrostowski (2004) indicated that when "comparing achievement across countries, it is important to consider differences in students' curricular experiences" (p. 177). These experiences are primarily affected by curricular alignments such as differences in the scope of subjects and sequences between subjects (Mullis, Martin, & Foy, 2005).

Assumptions

Given the nature of a secondary data analysis four assumptions were made to support this investigation:

- Scores from TIMSS are a valid representation of student performance in mathematics and science.
- Students who participated in the TIMSS assessment did their best on the test.
- TIMSS assessment outcomes are unbiased across gender and other demographic dimensions.
- STEM subject definitions are generally applicable to both developed and developing countries.

Limitations

Without involvement of primary data collection, four limitations were acknowledged for this comparative study:

- TIMSS 2011 was not a cross-sectional study in 2011. Thus, no student tracking occurred in the data collection to assess achievement gains at the student level from the fourth to eighth grade.
- A few countries did not strictly follow the IEA sample design, which could cause incomprehensive coverage of the target population for international comparison.
- Missing data are irrecoverable because the information was gathered in 2011.

- Countries like the U.S. do not have a national curriculum; thus, the variation in implemented curricula may demand special attention to the interpretation of student performance across STEM subjects.

Delimitations

Specific boundaries were applied to clarify the scope of this research on two fronts:

- This study was delimited to data from TIMSS 2011; hence, the findings were confined within participating countries, 52 countries at the fourth grade and 45 countries at the eighth grade.
- This research study focused on the correlation of student performance between physics and other STEM subjects at the fourth and eighth grade level; however, no attempt was made to construct correlation indicators across all STEM subjects such as chemistry.

Key Terms

Terms used in the research study were defined to help the reader develop an understanding of the context. There are a total of four terms that were defined in this section.

1. International assessments/studies: The assessment and comparison of student achievement/performance across countries (Medrich & Griffith, 1992).
2. Empirical research: Research studies in which data is obtained through direct observation or experimentation (Gleeson Library, n.d.). Evidence from a research study may be used as primary data by researchers who own the dataset or secondary data by researchers who have access to the existing dataset (Cheng & Phillips, 2014).

3. STEM education: Interdisciplinary learning and teaching approaches at K-12 level for the following four disciplines: science, technology, engineering, and mathematics (Gonzalez & Kuenzi, 2012).
4. Cross-subject integration: The integration of "knowledge and skills" from one or more academic subject in an educational setting (James, 2011, p. 4).

Summary

The academic achievement of students across STEM subjects is critical in a global market competition. As students engage in STEM learning, correlations of student achievement could support the transfer of knowledge and skills across disciplines in a school setting; in addition, examining the correlations of student achievement across grades could highlight differences in student learning. This was particularly important for physics because it lays the foundation for other STEM subjects. The TIMSS dataset also provides an opportunity to assess the correlation of student achievement between physics and other STEM subjects across grades in each country.

Organization of Remaining Chapters

Chapter 2 will establish the context of this study by providing an overview of literature relevant to cross-subject integration. Chapter 3 will provide an overview of the methodology for this study including the selection of variables and statistical analysis. Chapter 4 will report the research findings in relation to each research question. Chapter 5 will include a summary of findings, discussion and implications, and directions for future research.

CHAPTER 2: REVIEW OF THE LITERATURE

This chapter surveys literature and empirical research related to student achievement across STEM subjects. The chapter begins with a review of past research on student achievement relations between physics and other STEM subjects at grades 4 and 8. Next, it explores past research on student achievement across grade levels and countries. That section is then followed by an overview of TIMSS with a particular emphasis on its development and relevance to cross-subject integration. Overall, the literature identified in this chapter justifies the need to advance ongoing inquiries beyond the existing knowledge base using a large-scale dataset.

Curriculum Integration

More than one form of curriculum integration is cited in the literature. Some strategies integrate content within mathematics and science, whereas others integrate disciplines between mathematics and science (Davison, Miller, & Metheny, 1995). As a result, not all researchers agree on a global definition of curriculum integration (I. Jones, Lake, & Dagli, 2005; Schleigh, Bosse, Lee, & University, 2011), which makes it difficult to interpret relationships of student achievements across STEM subjects (Pang & Good, 2000). Nonetheless, educators still contemplate pre-requisites that are necessary for an integrated curriculum. These pre-requisites include content and discipline choice, teacher preparation, administrative support, and an assessment of student learning (Lonning & Defranco, 1997; Mason, 1996). A successfully integrated curriculum is believed to “stimulate motivation; incorporate higher level problem solving; and connect learning with real world issues” (Mason, 1996, p. 268).

Debate on Curriculum Integration

Since the late 1980s, educators have advocated the integration of mathematics and science in the K-12 system (Basista & Matthews, 2002; Berlin & Lee, 2005; Lehman & McDonald, 1988; Lonning & Defranco, 1997; Meyer, Stinson, & Harkness, 2010). Meanwhile, the integration of mathematics and science has not gained the necessary momentum in schools, which is evident in schools that continue to offer discipline-specific courses (Isaacs, Wagreich, & Gartzman, 1997). As a result, the research community is still debating whether curriculum integration should be supported.

Proponents. The interest in curriculum integration is attributed to notions about knowledge acquisition and application (Beane, 1996). Proponents of curriculum integration state that the historical relationship between mathematics and science is negated by the separation of these subjects (Furner & Kaumer, 2007; Orime & Ambusaidi, 2011). Segregating these subjects offers students an incoherent learning environment because mathematics could be an integral part of a science curriculum (Basista & Matthews, 2002; Hodgson, Keck, Patterson, & Maki, 2005). In fact, Galileo stressed that mathematics and science are written in a common language (as cited in Orton & Roper, 2000). Science is viewed as inquiry whereas mathematics is viewed as problem solving (Pang & Good, 2000), which exemplifies the interdependence between these subjects.

Fortunately, educators are acknowledging the problems with discipline-specific curriculums in regard to student's knowledge and skills (Furner & Kumar, 2007). Students who lack a holistic understanding of problems are unable to link concepts between mathematics and science or view concepts as part of a bigger picture (Basista & Mathews, 2002; Francis & Underhill, 1996; Furner & Kumar, 2007; Honey, Pearson, & Schweingruber, 2014). The transfer of knowledge and skills into different contexts is essentially the foundation of an integrated curriculum (Honey et al., 2014). The importance of mathematics and science integration was evident in the rise of pertinent articles during 1990-2001 (Berlin & Lee, 2005); nevertheless, only a few empirical research studies focused on student achievement (Westbrook, 1998).

Advocates further argue that curriculum integration has the potential of making STEM subjects meaningful for students and teachers (Honey et al., 2014). The advocacy for curriculum integration prompted the National Academy of Engineering and National Research Council Committee to conduct a literature review of integrated curricula (Honey et al., 2014). Although the committee identified critical elements for curriculum integration, advocates acknowledged that current assessment practices prevent educators from adopting an integrated curriculum (Honey et al., 2014). This issue is intensified by the voluntary adoption of education standards advocated by the National Academy of Engineering and National Research Council of the National Academies, which support and promote curriculum integration. Meanwhile, the push for accountability tests has forced educators to focus on discipline-specific courses in mathematics and science instead of focusing on education standards that push for integration (Meyer et al., 2010).

Opponents. Arguments against an integrated curriculum focus on the lack of empirical research (Czerniak et al., 1999; Meier, Nicole, & Cobbs, 1998; Pang & Good, 2000). The available research primarily focuses on the perception of teachers with the exception of a few research studies that highlight the relationship between curriculum integration and student achievement. This argument is further enhanced by four issues pertaining to an integrated curriculum (Isaacs et al., 1997):

- Mathematics and science knowledge is organized differently, making it difficult to integrate subjects.
- An attempt to identify topics that balance mathematics and science may force educators to sacrifice content coherence.
- Real world problems could challenge students intellectually or distract students from curricular goals.
- Testing mandates on mathematics and science make it difficult to align assessments with an integrated curriculum.

These issues highlight difficulties that could arise when implementing an integrated curriculum.

In summary, a lack of empirical research contributes to the debate on curriculum integration despite the call for mathematics and science integration (Schleigh et al., 2011). This alone warrants the need for empirical research in the field of curriculum integration with an emphasis on student achievement. Without an empirical indicator for curriculum integration it is difficult to monitor the achievement of students exposed to an integrated curriculum, which is an important component of the outcome-based accountability movement in the United States.

Integration of Mathematics and Science

Regardless of debates on the value of curriculum integration, available research suggests that the integration between mathematics and science improves student achievement. Judson and Sawada (2000) conducted a research study to evaluate a traditional and an integrated curriculum at the middle school level. Results indicated that the integration between mathematics and science concepts improved student grades (Judson & Sawada, 2000). Similarly, Orime and Ambusaidi (2011) conducted a research study to compare the achievement of fourth grade students exposed to an integrated curriculum and those exposed to a traditional curriculum. The analysis of pre and post tests indicated that an integrated curriculum improved the problem solving skills of students (Orime & Ambusaidi, 2011). In short, case studies seem to suggest that the alignment between mathematics and science improves student achievement.

A longitudinal study conducted by L. Ma and Ma (2005) on the growth between mathematics and science indicated that middle school and high school students experienced issues with both subjects. L. Ma and Ma (2005) stated that "if students do not learn mathematics well, they are unable to apply mathematics to problem solving in science" (p. 90). Wang (2005) conducted a similar research study focused on the relationship between mathematics and science achievement among eighth grade students at an international level. Results from a correlation analysis indicated that a moderate relationship existed between mathematics and science achievement. This relationship is further exemplified by a research study on the relationship between course patterns in mathematics and science using student transcripts at the high school level (X. Ma, 2009). Results showed that a relationship existed between course patterns in mathematics and science. In fact, X. Ma (2009) indicated that students who took advanced courses in mathematics were more likely to take advanced courses in science. This pattern was attributed to the interdependence between mathematics and science.

Altogether these studies suggest that the relationship between mathematics and science has a positive effect on student achievement. Because research on the relationship between curriculum integration and student achievement is limited, more investigations are needed to construct an empirical indicator capable of assessing student achievement.

Cross-Subject Integration with Physics

Besides the focus on mathematics and science, it is important to broaden the relationship across STEM disciplines; therefore, this dissertation is designed to examine the link between physics and other STEM subjects. As a core subject of science, physics not only includes mathematics as an important tool, but also incorporates lab components like other science subjects. This section is devoted to an examination of the first research question in the literature base.

Physics and Mathematics Integration

Physics depends on numerous analytic tools from mathematics, such as vector analysis, advanced calculus, Riemannian geometry, and partial differential equations. The integration between mathematics and physics is evident in the work of Isaac Newton and Albert Einstein. They treated mathematics as a tool to develop classic and modern physics, respectively (Berlinski, 2000; Broglie, Armand, & Simon, 1979). As an example, when Newton studied mechanics, he contributed to the development of calculus methods (Berlinski, 2000).

The relationship between physics and mathematics is further supported by a study focused on the role of mathematics in physics. Findings indicated that students viewed mathematics as an integral part of physics, whereas physicists viewed mathematics as a tool for problem solving in physics (Wilson, 2014). In particular, some theoretical physicists use mathematics at an advanced level, making it difficult to differentiate them from mathematicians (Quale, 2011; Uhden, Karam, Pietrocola, & Pospiech, 2012).

The interdisciplinary relationship between physics and mathematics has an influence on student achievement (Akatugba & Wallace, 1999b; Quale, 2011; Tuminaro & Redish, 2004). Westbrook (1998) conducted an evaluation of an integrated physical science and algebra curriculum at the ninth grade to assess student achievement in the United States. Results from the evaluation indicated that students exposed to an integrated curriculum were far more capable of linking mathematics and science concepts (Westbrook, 1998). Students in the integrated course ultimately developed an understanding of concepts, instead of simply following procedures to solve problems like those in a traditional course (Westbrook, 1998). The better achievement of students is also reflected in "physics first" curricula. An evaluation of a "physics first" curriculum in New Jersey indicated that students were more likely to take and pass an advanced placement exam in physics (Goodman & Etkina, 2008). These results were attributed to the alignment between physics and mathematics.

Researchers indicate that the mathematical skills of students is a predictor of their achievement in college level physics (Ayene, Damtie, & Kriek, 2010; Orton & Roper, 2000). This finding is supported by a research study intended to assess the influence of academic and personality variables on physics achievement. Results showed that academic variables in high school such as exposure to physics, grades in physics courses, and course patterns in mathematics predicted the achievement of physics students (Norvilitis, Reid, & Norvalitis, 2002; Hudson & Rottman, 1981). Buick (2007) found that mathematical knowledge has a positive effect on the learning gains of physics students. Hence, a strong background in mathematics is necessary to succeed in physics.

D. Jones and Roseman (2012) found that students use mathematics as a tool to solve physics problems. This finding is supported by a research study conducted by Akatugba and Wallace (1999b) to assess the steps that high school students in Nigeria use to solve proportional reasoning problems in physics. Results showed that students without a strong background in mathematics were unable to offer a coherent explanation for their solution, translate physics problems into mathematics, and identify proportional variables (Akatugba & Wallace, 1999b). Similarly, Tuminaro and Redish (2003) conducted a research study at the University of Maryland to identify two reasons that hinder the achievement of physics students with a focus on problem solving tasks. Researchers found that student achievement is deterred by a poor background in mathematics and inability to apply mathematical concepts to physics problems (Tuminaro & Redish, 2003). Nonetheless, the most significant reason for poor student achievement was the inability to apply mathematical skills and knowledge in a physics course.

Physics and Science Integration

Science integration is evident at all levels of education, which is a reflection of state and national science education standards (Everett & Spear, 2008). Educators indicate "that science integration, if presented in meaningful contexts and coupled with appropriate pedagogical support, will lead students to a better understanding of the world and help them learn effective problem-solving skills" (Richmond & Striley, 1994, p. 42). Subjects such as physics, chemistry, and biology are often integrated to offer students meaningful learning opportunities (Purvis-Roberts et al., 2009).

Eggebrecht et al. (1996) assessed the effectiveness of an integrated science program connecting multiple science subjects at the Mathematics and Science Academy in Illinois. Findings indicated that students in an integrated science program performed better than students in a traditional course (Eggebrecht et al., 1996). Nevertheless, the adoption of an integrated science curriculum may not be the only key to improving science achievement. Assessment results from TIMSS show that countries such as the Czech Republic are one of the top performers in Europe despite the use of a compartmentalized science curriculum (Nezvalova, 2007).

Regardless of differing viewpoints on an integrated science curriculum, physics is often linked with more than one science subject; courses in biology and chemistry tend to rely on physics concepts (Wilt, 2005). In contrast, physics rarely relies on concepts from other sciences. Instead it is viewed as the base for science subjects such as biology and chemistry (Ewald, Hickman, Hickman, & Myers, 2005; Marx, 1980). As an example, biology uses physics concepts to describe the laws of nature (Neulieb & Neulieb, 1975); whereas, chemistry uses physics to examine the substance and structure of atoms (Isayev, 1993).

The advantage of integrating physics with other sciences is evident at the high school level. G. Johnson (1972) found that a 2-year integrated physics-chemistry course at a Minnesota high school improved the achievement of students compared to those who took compartmentalized courses in science. Results indicated that students in the integrated course retained more concepts and had a better understanding of interrelated concepts (G. Johnson, 1972). The positive effect of science integration also has an impact on curriculum designs in higher education. For example, researchers indicate that even though biology and physics are distinct disciplines they depend on observations and measurements to explain different aspects of the world (Hoskinson, Couch, Zwicki, Hinko, & Caballero, 2014). The integration between biology and physics is ideal for topics such as cell structure and processes that are heavily influenced by physics (Woodin, Vasaly, McBride, & White, 2013). This example demonstrates the need to transfer concepts to other disciplines, which ultimately improves a student's level of understanding (Clay, Fox, Gaunbaum, & Jumars, 2008; Mashood & Singh, 2013).

In summary, research on the integration between physics and other STEM subjects is limited, and its impact on student achievement demands more investigation. The available research primarily focuses on the achievement of high school and college students, which creates a gap in the literature for further studies at the elementary and middle school level. This gap is particularly important because educational initiatives are stressing the importance of curriculum integration for K-12 students in the United States. Thus, this dissertation is designed to fill this void and advance the existing knowledge through an empirical study on the relationship of student achievement at the fourth and eighth grade in an international context.

Student Achievement across Grades and Countries

The examination of student achievement across grade levels and countries is necessary to compare the impact of different curriculum settings on student learning. While the last section provided literature support to examine the first research question, this section is devoted to the justification of the last two research questions on student achievement across grades in a cross-country context.

Cognitive Development between the Fourth and Eighth Grade

In addition to curriculum considerations, cognitive development is a profound factor of adolescent learning that has been investigated by psychologists for many years. The learning ability of students is a reflection of their reasoning skills, which is heavily influenced by cognitive development. Overton, Ward, Noveck, Black, and O'Brien (1987) conducted an investigation of student's reasoning ability in the fourth through 12^{th} grade at a Philadelphia school. Findings indicated that preadolescent students did not exhibit the logical reasoning skills that were evident in adolescent students (Overton et al., 1987). This finding was grounded on the difficulties that preadolescent students encountered with abstract problems when compared to adolescent students. Developmental differences among students are further supported by a research study conducted by Topiak, West, and Stanovich (2014), which showed that a relationship existed between the cognitive ability and reasoning skills of K-9 students. The performance of students ultimately improved with age; therefore, assessing the performance of students in adjacent grades is necessary (Schmidt & McKnight, 1998).

Cognitive differences among fourth and eighth grade students could be explained using Bloom's Taxonomy, which describes cognition levels in a hierarchical sequence (Eber & Parker, 2007). A modified version of Bloom's Taxonomy is illustrated in Figure 1. This hierarchy begins with the simplest processes of remembering to the most complex processes of creation. These processes could be used to assess student performance at the fourth and eighth grade. In particular, physics concepts at the fourth grade are often taught as a set of scientific facts for students to remember and understand. At the eighth grade, students are equipped with certain algebra tools to apply proportional reasoning and digest basic concepts such as density and speed (Elert, 2015).

The academic achievement of students could be negatively affected by a discrepancy between cognitive development and grade level. Yazgan and Kincal (2009) found that the cognitive abilities of Turkish students in the seventh and

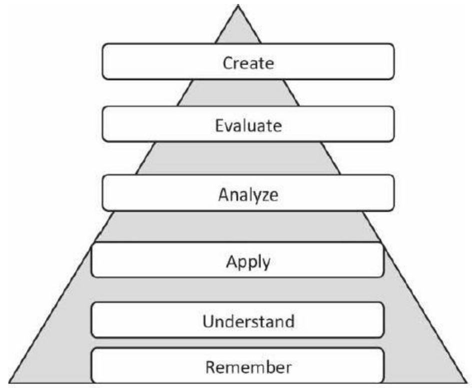

Figure 1. Different types of learning in a Modified Illustration of Bloom's Taxonomy.
Adapted from A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives, by L.W. Anderson (Ed.), D.R. Krathwohl (Ed.), P.W. Airasian, K.A. Cruikshank, R.E. Mayer, P.R. Pintrich, J. Raths, M.C. Wittrock, 2001, New York, NY: Longman, p. 67-68. Copyright 2001 by Addison Wesley Longman, Inc.

eighth grade varied based on multiple factors such as culture, socio-economic status, schooling experience, and academic achievement. Although students in the seventh and eighth grade were expected to fall under the formal operational stage, a significant number of students remained at the concrete operational stage (Yazgan & Kincal, 2009), which makes it difficult to comprehend abstract concepts. This finding is further supported by Lawson's (1973) research aimed at assessing the cognitive development of high school students in science disciplines. Results from his study indicated that the majority of students in biology, chemistry, and physics courses fell under the concrete operational stage instead of the formal operational stage, which demanded special attention in STEM education (Lawson, 1973). Formal operational reasoning was essentially a pre-requisite for the mastery of physics tasks at an application level (Liberman & Hudson, 1979).

In addition, Moore and Rubbo (2012) conducted a study to assess the cognitive development of non-STEM and STEM majors taking physics and astronomy courses at the college level. Results indicated that non-STEM majors were more likely to fall under the concrete operational stage, which made it difficult to complete deductive reasoning tasks in physics (Moore & Rubbo, 2012). The inability to complete these tasks has a negative effect on the achievement of engineering students. Vazquez and de Anglat (2009) conducted research on the cognitive development of first-year engineering students taking courses in science and mathematics including physics. Researchers found that just over a quarter of students fell under the concrete operational stage, suggesting that students were in need of remedial education to improve their academic achievement (Vazquez & de Anglat, 2009). Although these studies were conducted beyond K-12 levels, it seems safe to postulate that an even larger proportion of fourth and eighth grade students might remain at the concrete operational stage.

Researchers concluded that formal operational students are better able to understand abstract concepts introduced in the science field (Cantu & Herron, 1978; Renner, Abraham, Grzybowski, & Marek, 1990). Renner and Grant (1978) argued that "students who are not capable of formal reasoning cannot understand formal concepts" (p. 30). In essence, students who fail to reach the appropriate cognitive development stage perform poorly in science (Sayre & Ball, 1975). Hiebert (1981) concurred that "children who have not yet developed these cognitive abilities presumably are unable to benefit from instruction on certain topics" (p. 197).

Consequently, the misalignment between instruction and cognitive development has a negative effect on the achievement of students across grade levels. For instance, Murat (2013) conducted a longitudinal study to assess the performance of Turkish students in the fourth and eighth grade. Results from this study indicated that the performance of students in science and technology decreased from the fourth to eighth grade, which could be attributed to the introduction of abstract concepts at upper grade levels (Murat, 2013). These results implied that many students in the eighth grade did not develop the cognitive abilities necessary to understand abstract concepts (Bliss & Morrison, 1990). The understanding of abstract concepts is further complicated by individual differences that have an effect on the cognitive development of four to 12 year old students (Weinert & Helmke, 1998). As a result, cognitive development is a strong predictor of student achievement.

The cognitive development of students can be enhanced with the use of scaffolding in the classroom. According to Burkhalter (1995), educators in elementary schools could use “a dynamic approach to learning that triggers children’s potential through adult assistance rather than a more rigid one that bases curriculum design on what they are or not capable of doing” (p. 198). This statement suggests that the developmental stage of students should not dictate what they are capable of mastering in elementary school. Moreover, Greenes (1995) indicated that scaffolding approaches such as modeling help students reach their cognitive potential. The benefits of scaffolding are evident in a research study conducted by Rubin and Norman (1992), which assessed the effect of teacher modeling on the cognitive ability of adolescent students in the sixth through ninth grade. Results from this study indicated that concrete operational students had the ability to develop integrated science process skills that are evident in formal operational students (Rubin & Norman, 1992).

Curriculum Differences across Countries

In addition to the influence of cognitive development, student achievement varies internationally as a result of differences in the adopted curriculum. According to O’Connor (2014), education systems with a national curriculum are becoming more common around the world. High achieving countries such as China implemented a national curriculum more than three decades ago (Zhang & Yin, 2014). China and other Eastern Asian countries have also introduced an integrated curriculum (Lam, Alviar-Martin, Adler, & Sim, 2013; Wei, 2009). Slight differences in the adopted curriculum ultimately have an effect on student achievement.

The structure of an education system is heavily influenced by culture. Nah (2011) indicated that educational differences among the Western and Eastern countries could be attributed to beliefs and values ingrained within the culture. These cultural factors eventually make their way into the curriculum with an emphasis on pedagogical approaches to teaching and learning (Nah, 2011), which form part of the intended and implemented curriculum (Lui & Leung, 2013).

Based on classroom observations in Japan, China, and the United States, Stigler and Perry (1988) indicated that culture had a significant effect on the mathematics achievement of students because of its influence on the "curriculum, in the organization and functioning of the classroom, and beliefs and attitudes about learning mathematics that prevail among parents and teachers" (p. 28). A study on the mathematics achievement of elementary students in Japan, Taiwan, and the United States further emphasized the significance of cultural differences (Stigler, Lee, Lucker, & Stevenson, 1982). This study in particular found that the United States designated less time to mathematics instruction and homework compared to Japan and Taiwan (Stigler et al., 1982). Findings such as these are believed to contribute to achievement differences between the United States and other parts of the world such as Japan and Taiwan. The significance of cultural differences is also supported by a study on the mathematics achievement of elementary and middle school students in Korea and United States (Song &

Ginsburg, 1987). Results from that study indicated that the superior performance of Korean students, in comparison to American students, was attributed to environmental and cultural influences (Song & Ginsburg, 1987). Therefore, cultural factors need to be taken into consideration when interpreting results from comparative education studies (Gustafsson & Undheim, 1996). For example, “In the United States, if we looked at the students who attend schools where child poverty rates are under 10%, we would rank as the number one country in the world, outscoring countries like Finland, Japan, and Korea” (Berliner & Glass, 2014, p.15).

In summary, comparative education studies suggests that student achievement varies across grade levels and countries. This stresses the need for expanding an empirical indicator on the relationship of STEM achievement across grade levels and countries. This dissertation is designed to fill this gap in the literature, which is currently neglected by researchers.

TIMSS Dataset and Student Achievement

The structure of the TIMSS dataset lends itself to an analysis of student achievement across STEM subjects. This analysis can be further extended to encompass student achievement across grade levels and countries. The current structure of the TIMSS dataset is attributed to its evolution over several decades.

Development of TIMSS Dataset

The TIMSS assessment is an outcome of large-scale surveys conducted by the IEA. In history, the IEA conducted the first large-scale survey in the late 1950’s (Husen, 1979; Plomp, 1990). The overall goal of the IEA, since its inception, was to attain data on factors that have an effect on the educational achievement “between countries, between schools within countries, and between students within countries" (Platt, 1975, p. 33) while contributing to the expansion of international studies (Eckert, 2008; Frank, & Mackett-Frank, 1978). IEA founders believed that these studies offered "a natural laboratory for examining the inputs and outcomes of schooling to inform educational improvement" (Plisko, 2013, p. 327).

A survey of national education systems was first introduced in 1958 by social researchers and testing experts at the United Nations Educational, Scientific and Cultural Organization (UNESCO) Institute for Education in Germany (Husen, 1979) because international studies on student achievement was an area that researchers had not addressed at that time (Bybee, 2007; Plisko, 2013; Purves, 1987). This issue was eventually put on the agenda as a result of public discussions about the quality of education around the world (Husen, 1979), including the United States and Europe (Petterson, 2014). Common concerns among nations paved the way for an international assessment of student achievement, which was facilitated by a feasibility study to determine whether student performance in different educational systems could be assessed using a standardized test (Husen, 1974).

Results from the feasibility study highlighted important limitations and findings, but most importantly, stressed the need for a large-scale survey (Postlethwaite, 1975). This eventually prompted social science researchers and testing experts to conduct a pilot survey focused on mathematics (Husen, 1974; Postlethwaite, 1974), which was believed to improve the performance of students in science (Postlethwaite, 1975). The pilot survey became known as the First International Mathematics Study, which was carried out in the early 1960s with 12 countries (Drent, Meelissen, & Van Der Kleij, 2013; Purves & Travers, 1982). The administration of the single-subject survey was soon followed by a six-subject survey covering “science literature, reading comprehension, English and French as a foreign language, and civic education” (Husen, 1974, p.407).

Even though the IEA focused on different subjects, mathematics and science became significant subjects for countries around the world as a result of the growing knowledge-based economy (Cromley, 2009). Studies conducted by the IEA included the First International Mathematics Study (FIMS), First International Science Study (FISS), Second International Science Study (SISS), Second International Mathematics Study (SIMS), and Third International Mathematics and Science Study (TIMSS) (Medrich & Griffith, 1992). The TIMSS acronym was eventually altered to represent Trends in Mathematics and Science Study, which encompassed repeated IEA studies every four years since 1995. The introduction of TIMSS in 1995 marked the beginning of a recurring trend study in comparative STEM education (Gonzalez & Smith, 1997). The overall goal of TIMSS was to assess the skills and knowledge of fourth and eighth grade students in mathematics and science in an international context (Reddy, 2005).

In summary, TIMSS is considered to be one of the most grand and complex undertakings by the IEA (Tamir, 2009) on the concurrent analysis of mathematics and science achievement. The IEA first introduced a comparative study focused on the recurring assessment of mathematics and science achievement in 1995, which resulted in the ideal dataset for an analysis of cross-subject integration across STEM subjects.

Summary

This literature review focused on several topics relevant to cross-subject integration and student achievement. The available research on this topic suggested that there is a limited amount of empirical research, despite the availability of data, to link student performance between physics and other STEM subjects. However, researchers indicated that cross-subject integration improves student achievement at the high school and college level. Research studies revealed the potential link of student achievement between physics and other STEM subjects. The curriculum coherence between STEM subjects ultimately improves student learning under different contexts, which warrants the need for research at the elementary and middle school level. Filling this void will add empirical evidence to inform NGSS on “identifying cross-cutting concepts, scientific and engineering, and disciplinary core ideas” between mathematics and science (Metz, 2014, p. 6). Through TIMSS data analysis, the purpose of this dissertation was to construct an empirical indicator of student performance that encompasses all three dimensions: (1) STEM subjects, (2) grade levels, and (3) countries.

CHAPTER 3: METHODOLOGY

This chapter will provide a description of the research methodology supporting the secondary analyses of TIMSS data in this investigation. In addition to grounding the inquiry approaches from the literature review in Chapter 2, the methodology chosen for this investigation was guided by the research questions introduced in Chapter 1. Special features of the TIMSS data received additional considerations in the methodology description.

Features of the Study

The goal of this study was to investigate the correlation of student achievement between physics and other STEM subjects. In addition, this investigation focused on assessing student achievement across grade levels and countries using data from the fifth administration of TIMSS. Although TIMSS included extensive background information from students, teachers, and educational administrators, science and mathematics achievement data were primarily utilized for this investigation. The three questions introduced for this investigation hinged on a postulation that students learn STEM subjects concurrently in a school setting, which is linked to student learning. Built on an assumption that the whole could be larger than the sum of its parts, this investigation broadened the horizon by examining similarities and/or differences of correlational findings between fourth and eighth grade students in an international context.

TIMSS Theoretical Framework

TIMSS is founded on a curriculum evaluation model developed for IEA more than a decade ago (Bennett, 2003). This model is comprised of three components: intended curriculum, implemented curriculum, and achieved curriculum. Figure 2 provides a visual representation of the curriculum evaluation model with all of its components outlined in chronological order.

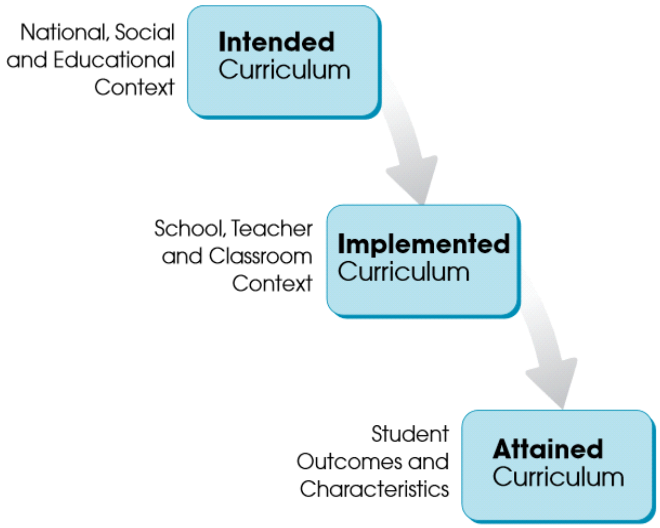

Figure 2. Components within the Curriculum Evaluation Model.
Adapted from TIMSS 2011 Assessment Frameworks, by I.V.S Mullis, M.O. Martin, G.J. Ruddock, C.Y. O'Sullivan, and C. Preuschoff, 2009, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.10. Copyright 2009 by the International Association for the Evaluation of Educational Achievement (IEA), Amsterdam, the Netherlands.

The intended curriculum includes goals of an educational system, which serve as a guide for curriculum developers (McKnight & Schmidt, 1998). These goals are reflected in lesson plans and instructional materials necessary to implement a curriculum (Plomp, 1990). The implemented curriculum is the actual instruction provided to students in the classroom including the activities and materials (Bennett, 2003; McKnight & Schmidt, 1998). Curricula are often interpreted differently by teachers resulting in variations from the intended curriculum (Suter, 2000). The misalignment between an intended and implemented curriculum essentially stresses the need for an assessment to identify issues in student learning (Plomp, 1990). The attained curriculum represents the learning gains of students in the classroom. This component essentially assesses whether students acquire the skills and knowledge that they were intended to attain in the classroom (Bennett, 2003).

TIMSS Dataset

In TIMSS assessment of student performance, items for content domains focused on topic areas for students in the fourth and eighth grade. The content domain is aligned with the mathematics and science curriculum at each grade level. Content domains and topic areas for the mathematics and science assessment are outlined in Tables 1-2, respectively. The assessment framework exemplifies the knowledge that students should attain at each grade level. Topic areas introduced in the eighth grade are far more complex than those introduced in the fourth grade.

The depth of learning in content domains for mathematics and science is measured to assess the cognitive skills of students at each grade level. The assessment framework specifically focuses on cognitive domains for knowing, applying, and reasoning. Items for knowing require students to recall relevant knowledge, items for applying require students to apply relevant knowledge, and lastly, items for reasoning require students to use their critical thinking skills to solve complex problems (Mullis, Martin, Ruddock, O'Sullivan, & Preuschoff, 2009).

Items for mathematics and science were far more numerous than time permits students to answer during the testing session; hence, a matrix sampling approach was used to spread the items across several booklets for content representation purposes. Matrix sampling is commonly used for large-scale assessments to ensure that a curriculum is thoroughly covered. This method ultimately collects sufficient data for result generalization (E.G. Johnson, 1992).

Table 1

Mathematics Assessment Framework

Grade Level	Content Domains	Topic Areas
4th Grade	Number	Whole numbers Fractions and decimals Number sentences with whole numbers Patterns and relationships
	Geometric shapes and numbers	Point, lines, and angles Two- and three- dimensional shapes
	Data display	Reading and interpreting Organizing and representing
8th Grade	Number	Whole numbers Fractions and decimals Integers Ratio, proportion, and percent
	Algebra	Patterns Algebraic expressions Equation/formulas and functions
	Geometry	Geometric shapes Geometric numbers Location and movement
	Data chance	Data organization and representation Data interpretation Chance

Note. Adapted from *TIMSS 2011 Assessment Frameworks*, by I.V.S Mullis, M.O. Martin, G.J. Ruddock, C.Y. O'Sullivan, and C. Preuschoff, 2009, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p. 22-38. Copyright 2009 International Association for the Evaluation of Educational Achievement (IEA).

Table 2

Science Assessment Framework

Grade Level	Content Domains	Topic Areas
4th Grade	Life Science	Characteristics and life processes of living things Life cycles, reproduction, and heredity Interaction with the environment Ecosystems Human health
	Physical science	Classification and properties of matter Sources and effects of energy Forces and motion
	Earth science	Earth's structure, physical characteristics, and resources Earth's processes, cycles, and history Earth in the solar system
8th Grade	Biology	Characteristics, classification, and life processes of organisms Cells and their functions Life cycles, reproduction, and heredity Diversity, adaptation, and natural selection Ecosystems Human health
	Chemistry	Classification and composition of matter Properties of matter Chemical change
	Physics	Physical states and changes in matter Properties of matter Chemical change
	Earth science	Earth's structure and physical features Earth's processes, cycles, and history Earth's resources, their use and conversation Earth in the solar system and the universe

Note. Adapted from *TIMSS 2011 Assessment Frameworks,* by I.V.S Mullis, M.O. Martin, G.J. Ruddock, C.Y. O'Sullivan, and C. Preuschoff, 2009, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p. 52-79. Copyright 2009 International Association for the Evaluation of Educational Achievement (IEA).

As a consequence, students who participated in the assessment are required to complete one booklet with mathematics and science items. These booklets are created using a combination of item blocks that include a limited number of items in mathematics and science, which result in a total of 28 blocks including 14 blocks for mathematics and 14 blocks for science (Mullis et al., 2009). Blocks for the fourth grade include 10-14 items with a time limit of 72 minutes, whereas blocks for the eighth grade include 12-18 items with a time limit of 90 minutes (Mullis et al., 2009). Item blocks are primarily used to expand the range of content covered by the assessment.

The item response theory (IRT) was used to scale student performance (National Center for Education Statistics, 2009). Three IRT models were created for multiple-choice and constructed-response items focused on determining the odds of students choosing a particular answer (Martin & Mullis, 2012). These models ultimately provided “a common scale on which the performance of students receiving different blocks of items can be placed” (National Center for Education Statistics, 2009, para. 1).

In addition to the mathematics and science assessment, the testing booklets included a short student questionnaire. The questionnaire included demographic, home, student learning, and mathematics and science perception questions. Surveys for the fourth and eighth grade were almost identical with the exception of a few questions that were tailored to each grade level (Mullis et al., 2009). Results from this survey were supplemented by teacher, school, and curriculum questionnaires that provided an overview of students’ educational environment.

Individual scores from the assessment were translated into plausible scores, which make use of assessment and background data to estimate student ability distributions. Plausible scores are essential for large scale assessments that administer subsets of assessment items when non-biased population estimates cannot be obtained from individual test scores (Mislevy, Beaton, Kaplan, & Sheehan, 1992). Assessing the achievement of students based on a subset of items essentially lowers the accuracy of individual test scores (National Center for Education Statistics, 2008; Von-Davier, Gonzalez, & Mislevy, 2009). As a result, this method led to the creation of a dataset with plausible scores to evaluate the variability of data imputation.

Sampling Procedures

The sampling process was conducted by each country's national research coordinator using manuals developed by the TIMSS and Progress in International Reading Literacy Study International Study Center with support from the IEA Data Processing and Research Center (DPC) and Statistics Canada. National research coordinators also received assistance from Statistics Canada to facilitate the sampling process considering that they are the entity responsible for all documentation related to national sampling plans. Finally, national sampling plans were approved by the TIMSS and PIRLS International Study Center.

The target population was selected by identifying grade levels with the largest student population in certain age groups; in this case, the identified grade levels were the fourth and eighth grade (E.G. Johnson, 1992). The selection of students was facilitated by UNESCO's International Standard Classification of Education (ISCED), which is a "classification scheme for describing levels of schooling across countries" (Joncas & Foy, 2012, p.3). Students in the fourth grade must have 4 years of schooling and be at least 10 years old, whereas students in the eighth grade must have 8 years of schooling and be at least 14 years old (Keeves, 1992). Nevertheless, complete coverage of eligible students across countries was impossible as a result of various factors at the school and student level. Particular schools were excluded on the basis of their geographic location, size, grade or curriculum structure, or student characteristics, whereas some students were excluded on the basis of their functional ability, intellectual ability, and native language (Joncas & Foy, 2012).

TIMSS also used a rigorous two-stage cluster sample design to obtain a representative sample from each country. The first stage involves sampling schools with eligible students using the probability proportional to size (PPS) method to ensure that larger schools have a higher probability of being chosen and the second stage involves taking a sample of intact classes at the fourth and eighth grade level from each participating school to ensure that there are equal probabilities within schools (Joncas & Foy, 2012). Sampling weights for students are then created for participating countries to account for selection probabilities. The overall sampling weight for students is calculated using the following three components: “school, class (within school), and student (within class)” (Joncas & Foy, 2012, p. 13). School weights take into account the schools probability of being selected among eligible schools in a country, classroom weights take into account the probability of being selected among eligible classrooms in a school, and lastly, student weights take into account the probability of students being selected in a classroom.

Because selection probabilities are negatively affected by the non-participation of sampled schools, classes, and students within participating countries, the sampling weight is adjusted for schools that do not participate, classes with fewer than 50% of students participating, and students who fail to take the assessment as expected (Joncas & Foy, 2012). These adjustments are then incorporated into the sampling weight for schools, classes, and students, which make up the student sampling weight used to report data from the TIMSS assessment.

Data Analysis

These data were downloaded from the TIMSS and PIRLS website, which contains a database for mathematics and science achievement data for students in the fourth and eighth grade in addition to questionnaire data for students, teachers, schools, and the curriculum. Data can be accessed using statistical software such as the Statistical Package for the Social Sciences (SPSS) and Statistical Analysis System (SAS). This study in particular used SAS to extract data following the user guide for the TIMSS 2011 database, which provided valuable information on its content and organization. Results of published TIMSS reports were reconfirmed to ensure proper data access.

Participants and Variables

The literature review on student achievement across STEM subjects guided the selection of variables for this study. This study included all of TIMSS's participants at the fourth and eighth grade level. More than 600,000 students participated in TIMSS of which approximately 300,000 were from the fourth grade and 300,000 were from the eighth grade (Mullis, Martin, Foy, & Arora, 2012a). The countries sampled for the fourth grade included 53 countries, whereas the countries sampled for the eighth grade included 45 countries.

The variables used for this study encompassed cognitive processes and cognitive knowledge for students at each grade level. The plausible scores for STEM achievement in the fourth and eighth grade were used as the outcome variables. The variables for mathematics and science achievement from the TIMSS 2011 assessment are outlined in Tables 3 and 4.

Table 3

Cognitive Processes and Content Knowledge for Mathematics

Grade Level	Variable	Label
4th Grade	ASMAPP	PV Math applying
	ASMDAT	PV Data display
	ASMGEO	PV Geometry
	ASMIBM	Intern. math bench reached with PV
	ASMKNO	PV Math knowing
	ASMMAT	PV Mathematics
	ASMNUM	PV Number
	ASMREA	PV Math reasoning
8th Grade	BSMALG	PV Algebra
	BSMAPP	PV Math applying
	BSMDAT	PV Data and change
	BSMGEO	PV Geometry
	BSMIBM	Intern. math bench reached with PV
	BSMKNO	PV Math knowing
	BSMMAT	PV Mathematics
	BSMNUM	PV Number
	BSMREA	PV Math Reasoning

Note. Adapted from *TIMSS 2011 International Database*, by P. Foy, A. Arora, and G.M. Stanco, 2013, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College. Copyright 2013 International Association for the Evaluation of Educational Achievement (IEA).

Table 4

Cognitive Processes and Content Knowledge for Science

Grade Level	Variable	Label
4th Grade	ASSAPP	PV Science applying
	ASSEAR	PV Earth science
	ASSIBM	Intern. science bench reached with PV
	ASSKNO	PV Science knowing
	ASSLIF	PV Life science
	ASSPHY	PV Physics
	ASSREA	PV Science reasoning
	ASSSCI	PV Science
8th Grade	BSSAPP	PV Science applying
	BSSBIO	PV Biology
	BSSCHE	PV Chemistry
	BSSEAR	PV Earth science
	BSSIBM	Intern. Science bench reach with PV
	BSSKNO	PV Science knowing
	BSSPHY	PV Physics
	BSSREA	PV Science reasoning
	BSSSCI	PV Science

Note. Adapted from *TIMSS 2011 International Database*, by P. Foy, A. Arora, and G.M. Stanco, 2013, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College. Copyright 2013 International Association for the Evaluation of Educational Achievement (IEA).

Statistical Method

Descriptive statistics were computed to confirm the science and mathematics results in TIMSS reports. A canonical correlation analysis was also conducted, using the Statistical Analysis System (SAS), to assess the correlation of student achievement between physics and other STEM subjects. Because TIMSS reports include the average plausible scores for an international comparison (e.g. Mullis et al., 2012a), it seems tempting to run a correlation analysis of the average plausible scores between physics and other STEM subjects. However, this approach inadvertently ignores the variability among plausible scores in each subject. Borga (2001) further indicated that “even if there is a strong linear relationship between two multidimensional signals, this relationship may not be visible with an ordinary correlation analysis” (p.3).

Alternatively, TIMSS researchers developed the JACKREGP program to use “achievement plausible values as the dependent variable” for regression analyses (Foy, Arora, & Stanco, 2013, p. 40). Statistics Canada (2003) also recommended “an SPSS macro called JACKREGPV.SPS that computes the average multiple correlation [R^2] between the specified plausible values and independent variables” (p. 162). The R^2 result could support the configuration of the correlation coefficient (r) between independent and dependent variables [i.e., r=sqrt(R^2)]. In using the SPSS macro, Brese, Jung, Mirazchiyski, Schulz, and Zuehlke (2011) noted that “it effectively performs five regression analyses – one for each plausible value – and aggregates the results” (p. 86). While five plausible scores from one subject can be entered in the SPSS macro as the dependent variables, the other set of plausible scores must be entered as an independent variable one at a time. Otherwise, a colinearity issue will occur when the independent variables are highly correlated on the same measurement construct.

To avoid this issue, correlation coefficients (*r*) can be produced from the SPSS macro for each entry of the independent variable. However, the five correlation coefficients inflate type I error and cannot be directly added or averaged for reporting. StatSoft (2000) cautioned, “because the value of the correlation coefficient is not a linear function of the magnitude of the relation between the variables, correlation coefficients cannot simply be averaged” (p. 10). Due to the non-additive nature of correlation coefficients, a new method was explored to support this investigation.

Through an extensive review of research literature, the following method was chosen for this study:

> Canonical correlation is an additional procedure for assessing the relationship between variables. Specifically, this analysis allows us to investigate the relationship between two sets of variables. For example, an educational researcher may want to compute the (simultaneous) relationship between three measures of scholastic ability with five measures of success in school. (StatSoft, 2015, p. 1)

French and Chess (2015) further elaborated the canonical correlation procedure in the following formula: $R = R_{yy}^{-1} R_{yx} R_{xx}^{-1} R_{xy}$. Where R_{yy} is the correlation matrix vector q’. R_{yx} is a correlation matrix between q’ and p’. R_{xx} is the correlation matrix vector p’. R_{xy} is the other correlation matrix between q’ and p’.

Although plausible scores computing and canonical correlation analyses were available for many years, few researchers have considered a link between them to support the construction of an indicator for physics achievement and other STEM subjects. The characteristics of this research study bridged the method and substance domains. In the past, Kish’s (1965) design effect was employed to examine the impact of stratified sampling on correlation analyses. Because r values depend on a ratio of the variance and covariance components, Wang and

Ma (2006) found that the design effect was washed out. Hence, a canonical correlation analysis was robust against the influence of complex sampling.

Summary

In this study, five plausible scores in physics served as one set of variables and five plausible scores in other STEM subjects served as another set of variables. Canonical correlation coefficients were computed to examine the relationship between two sets of variables (Question 1). In addition, the results were sorted to examine variations of inter-subject correlation between the fourth and eighth grade (Question 2). This study also examined variations of inter-subject correlation across countries (Question 3). A useful website from UCLA (n.d), "SAS Annotated Output: Canonical Correlation Analysis" was referred to support interpretation of SAS printout.

CHAPTER 4: RESULTS

This chapter primarily focuses on the results from the data analysis. The chapter will begin with descriptive findings. Next, patterns of mathematics and science performance will be identified to support the correlational study in a cross national context. Results from canonical correlation analyses correspond to each research question. This chapter concludes with a summary of the results.

Descriptive Findings

At the initial step of the data analysis, the sample size, as well as mathematics and science achievements, was confirmed with the statistical results from TIMSS reports (Mullis et al., 2012a; Mullis et al., 2012b). The verification of results was intended to assure correct access of TIMSS data for this secondary data analysis.

The sample size in TIMSS 2011 report indicated the number of students assessed within each participating country and mean scores in mathematics and science achievement for international comparisons. The results were summarized at both fourth and eighth grades to provide a description of student performance in each subject.

Fourth Grade

Mean scores in mathematics and science achievement for the fourth grade are presented in Table 5 along with the sample size for each country. Among the 53 participating countries, the sample size ranged from 3,121 to 14,720. Although the target student population was designated at the fourth grade, Botswana, Honduras, and Yemen sampled students at the sixth grade. Curricular differences within education systems resulted in the modification of the target population (Mullis et al., 2012a; Mullis et al., 2012b). As a result, the mean score in mathematics ranged from

248 to 606 and science ranged from 209 to 587. The variation of student achievement demonstrated the differences of learning outcomes among education systems.

The top five mean scores in mathematics achievement ranged between 585 and 606. Education systems in the top five included Chinese Taipei, Hong Kong, Japan, Korea, and Singapore. Those with the bottom five mean scores in mathematics achievement ranged between 248 and 359. The education systems in the bottom five were Kuwait, Morocco, Tunisia, Yemen (fourth grade sample), and Yemen (sixth grade sample). In contrast, the top five mean scores in science achievement varied between 552 and 587. Chinese Taipei, Finland, Korea, Japan, and Singapore ranked in the top five. The bottom five mean scores in science achievement varied between 209 and 347. Kuwait, Morocco, Tunisia, Yemen (fourth grade sample), and Yemen (sixth grade sample) ranked in the bottom five. Among education systems with the top five mean scores in mathematics and science achievement, most of them maintained top-level scores for each subject. Hong Kong and Finland were the exceptions with mean scores entering the top five in one subject. In general, rankings of student performance were parallel between mathematics and science achievement.

In addition, the top five education systems for mathematics achievement had sample sizes ranging from 3,957 to 6,368 whereas education systems in the bottom five had sample sizes between 4,142 and 8,058. Education systems in the top five for science achievement had sample sizes from 4,284 to 4,334 whereas those in the bottom had sample sizes ranging from 4,142 to 8,058. Since education systems in the top five did not have the largest sample sizes, the results suggest that the country ranking did not depend on extensive data gathering.

Table 5

Mathematics and Science Achievement of 4th Grade Participating Countries

		Mathematics Achievement		Science Achievement	
Country	N	Mean Score	Rank	Mean Score	Rank
Armenia	5146	452	39	416	45
Australia	6146	516	18	516	23
Austria	4668	508	23	532	12
Azerbaijan	4882	463	36	438	41
Bahrain	4083	436	41	449	39
Belgium	4849	549	7	509	27
Botswana*	4198	419	44	367	48
Chile	5585	462	37	480	34
Chinese Taipei	4284	591	4	552	5
Croatia	4584	490	30	516	25
Czech Republic	4578	511	22	536	8
Denmark	3987	537	13	528	16
England	3397	542	9	529	15
Finland	4638	545	8	570	3
Georgia	4799	450	40	455	37
Germany	3995	528	16	528	17
Honduras*	3919	396	47	432	42
Hong Kong SAR	3957	602	3	535	9
Hungary	5204	515	20	534	10
Iran, Islamic Rep. of	5760	431	43	453	38
Ireland	4560	527	17	516	22
Italy	4200	508	24	524	18
Japan	4411	585	5	559	4
Kazakhstan	4382	501	27	495	32
Korea, Rep. of	4334	605	2	587	1
Kuwait	4142	342	51	347	49
Lithuania	4688	534	14	515	26
Malta	3607	496	28	446	40
Morocco	7841	335	52	264	52
Netherlands	3229	540	12	531	14
New Zealand	5572	486	31	497	31
Northern Ireland	3571	562	6	517	21
Norway	3121	495	29	494	33
Oman	10411	385	48	377	47
Poland	5027	481	34	505	30
Portugal	4042	532	15	522	19
Qatar	4117	413	45	394	46
Romania	4673	482	32	505	28
Russian Federation	4467	542	10	552	6
Saudi Arabia	4515	410	46	429	43
Serbia	4379	516	19	516	24
Singapore	6368	606	1	583	2
Slovak Republic	5616	507	25	532	13
Slovenia	4492	513	21	520	20
Spain	4183	482	33	505	29
Sweden	4663	504	26	533	11
Thailand	4448	458	38	472	35
Tunisia	4912	359	49	346	50
Turkey	7479	469	35	463	36
United Arab Emirates	14720	434	42	428	44
United States	12569	541	11	544	7
Yemen	8058	348	50	345	51
Yemen*	4929	248	53	209	53

Notes. Sample size data were adapted from *TIMSS 2011 International Database,* by P. Foy, A. Arora, and G.M. Stanco, 2013, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College. Copyright 2013 International Association for the Evaluation of Educational Achievement (IEA).
Mean scores for mathematics were adapted from *TIMSS 2011 International Results in Mathematics* by I.V.S. Mullis, M.O. Martin, P. Foy, and A. Arora, 2012a, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.40-41. Copyright 2012 International Association for the Evaluation of Educational Achievement (IEA).
Mean scores for science were adapted from *TIMSS 2011 International Results in science,* by I.V.S. Mullis, M.O. Martin, P. Foy, and A. Arora, 2012b, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.38-39. Copyright 2012 International Association for the Evaluation of Educational Achievement (IEA).
*Students were sampled from the 6th grade

In comparison to the top and bottom five education systems, the United States had mean scores just below the top five in mathematics and science achievement. The ranking for science achievement in particular was two countries below the top five, while mathematics achievement ranked in 11th place. It appears that students performed relatively better in science. The United States also had one of the largest sample sizes compared to all participating countries including those ranking in the top and bottom five. Thus, an adequate amount of data was gathered to support the international comparison.

Eighth Grade

At the eighth grade, a total of 45 countries participated in the TIMSS 2011 assessment at the eighth grade. Like the results at the fourth grade, exceptions were made in the selection of the target population. In particular, Botswana, Honduras, and South Africa sampled students in the ninth grade. This digression reflects an alignment gap between the curriculum and assessment (Mullis et al., 2012a; Mullis et al., 2012b). Table 6 presents the sample sizes and mean scores for mathematics and science achievements. Sample sizes ranged from 3,378 to 14,089, which was similar to the pattern at the fourth grade. Mean scores in mathematics achievement ranged from 331 to 613 and science achievement ranged from 306 to 590. The range of mean scores demonstrated the diversity of student achievement.

Education systems ranking in the top five for mathematics achievement had mean scores varying from 570 to 613. Those in the top five included Chinese Taipei, Hong Kong, Japan, Korea, and Singapore. The bottom five education systems for mathematics achievement included Ghana, Honduras, Morocco, Oman, and South Africa. Mean scores for these education systems ranged from 331 to 371. Meanwhile, education systems ranking in the top five for science achievement had mean scores from 552 to 590. Chinese Taipei, Finland, Japan, Korea, and Singapore received rankings in the top five. Education systems in the bottom five for science achievement had mean scores from 306 to 404. The bottom five included Botswana, Ghana, Honduras, Morocco, and South Africa. The education systems in the top- and bottom-five lists were nearly identical for mathematics and science subjects. A similar group of education systems also appeared in the top five lists across the fourth and eighth grades, which indicates that there was stability in the international findings.

Additionally, education systems ranking in the top five for mathematics achievement had sample sizes ranging from 4,015 to 5,927 and education systems ranking in the bottom five had sample sizes ranging from 4,418 to 11,969. Those in the top five for science achievement had sample sizes ranging from 4,015 to 4,927 whereas the bottom five had sample sizes ranging from 4,418 to 11,969. The top performing education systems, similar to the fourth grade, did not have the largest sample sizes, indicating that the ranking of countries was not dependent on the amount of data collected in either mathematics and science.

Although the United States had one of the largest sample sizes in TIMSS, the mean scores for mathematics and science achievement ranked below the top five. Mathematics achievement ranked in ninth place whereas science achievement ranked in 10th place. In comparison to the fourth grade results, students did not rank as high as their peers in science achievement. In mathematics, the United States ranked slightly higher at the eighth grade than the fourth grade.

In summary, the international comparison of mean scores in mathematics and science resulted in the identification of two patterns:

1. Similar education systems scored in the top five for mathematics and science achievement at both the fourth and eighth grades;

Table 6

Mathematics and Science Achievement of 8th Grade Participating Countries

		Mathematics Achievement		Science Achievement	
Country	N	Mean Score	Rank	Mean Score	Rank
Armenia	5846	467	21	437	30
Australia	7556	505	11	519	12
Bahrain	4640	409	34	452	26
Botswana*	5400	397	37	404	41
Chile	5835	416	31	461	25
Chinese Taipei	5042	609	3	564	2
England	3842	507	10	533	9
Finland	4266	514	8	552	5
Georgia	4563	431	27	420	34
Ghana	7323	331	45	306	45
Honduras*	4418	338	44	369	43
Hong Kong SAR	4015	586	4	535	8
Hungary	5178	505	12	522	11
Indonesia	5795	386	39	406	40
Iran, Islamic Rep. of	6029	415	32	474	22
Israel	4699	516	7	516	13
Italy	3979	498	15	501	17
Japan	4414	570	5	558	4
Jordan	7694	406	35	449	28
Kazakhstan	4390	487	17	490	20
Korea, Rep. of	5166	613	1	560	3
Lebanon	3974	449	25	406	39
Lithuania	4747	502	14	514	14
Macedonia, Rep. of	4062	426	29	407	38
Malaysia	5733	440	26	426	32
Morocco	8686	371	41	376	42
New Zealand	5336	488	16	512	15
Norway	3862	475	20	494	19
Oman	9542	366	42	420	36
Palestinian, Nat'l Auth	7812	404	36	420	35
Qatar	4422	410	33	419	37
Romania	5523	458	22	465	23
Russian Federation	4893	539	6	542	7
Saudi Arabia	4344	394	38	436	31
Singapore	5927	611	2	590	1
Slovenia	4415	505	13	543	6
South Africa*	11969	352	43	332	44
Sweden	5573	484	18	509	16
Syrian Arab Republic	4413	380	40	426	33
Thailand	6124	427	28	451	27
Tunisia	5128	425	30	439	29
Turkey	6928	452	24	483	21
Ukraine	3378	479	19	501	18
United Arab Emirates	14089	456	23	465	24
United States	10477	509	9	525	10

Notes. Sample size data were adapted from *TIMSS 2011 International Database,* by P. Foy, A. Arora, and G.M. Stanco, 2013, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College.
Mean scores for mathematics were adapted from *TIMSS 2011 International Results in Mathematics,* by I.V.S. Mullis, M.O. Martin, P. Foy, and A. Arora, 2012a, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.42-43. Copyright 2012 International Association for the Evaluation of Educational Achievement (IEA).
Mean scores for science were adapted from *TIMSS 2011 International Results in science,* by I.V.S. Mullis, M.O. Martin, P. Foy, and A. Arora, 2012b, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.40-41. Copyright 2012 International Association for the Evaluation of Educational Achievement (IEA).
*Students were sampled from the 9th grade

2. The United States retained a similar position in the international comparison for mathematics and science performance at both the fourth and eighth grades.

The similarity among rankings suggests the need for an examination of the correlation between mathematics and science performance in a cross-national context.

Correlation of Student Performance Between Physics and STEM Subjects

In K-12 education, STEM subjects are typically confined in mathematics and science when in reality subjects such as physics, part of the physical sciences, have extensive links to mathematics. Given the different curriculum structure across TIMSS-participating countries, there is a need to examine the relationship of student performance in an international context. Hence, the results in this section will focus on an international comparison of the correlation of student performance between physics and these STEM subjects at the fourth and eighth grade. This analysis was intended to address the hypotheses linked to each research question presented in Chapter 1.

Fourth Grade Comparison

Correlation coefficients between physics achievement and mathematics achievement ranged from .657379 to .861390 at α=.001 and correlation coefficients of student performance between physics and science ranged from .847809 to .949941 α=.001 (see Table 7). It was indicated by the results that there was a positive correlation between physics and other STEM subjects. Nevertheless, the correlation between physics achievement and mathematics achievement was around .789011, while the correlation between physics and science was around .917899.

Hence, the correlation between physics and science tends to be larger than the corresponding correlation between physics and mathematics in an international comparison.

The variability in the correlation of student performance was particularly evident in the ranking of education systems with the top and bottom correlation coefficients. Education systems with the top five correlations between physics and mathematics achievements were Botswana, Hungary, Iran, Turkey, and United Arab Emirates and the bottom five included Armenia, Korea, Norway, Saudi Arabia, and Yemen (sixth grade sample). Correlation coefficients for the top five varied from .849528 to .861380 and the bottom five varied from .732229 to .809608. In contrast, the list of the top five correlations between physics and science achievements included Kazakhstan, Romania, Singapore, Thailand, and United Arab Emirates and the bottom five included Belgium, Morocco, Netherlands, Norway, and Yemen (fourth grade sample). The top five had correlation coefficients varying from .941456 to .949941 and the bottom five had correlation coefficients varying from .847809 to .886282. Hence, education systems in the top- and bottom-five lists varied across subjects. The range of correlation coefficients also suggests that the bottom five education systems show more variability in the linkage of student performance.

The United States, in comparison to the top and bottom five, exhibited a difference in the rank of correlation coefficients for each subject with mathematics achievement ranking in 15^{th} place and science achievement ranking in sixth place. These rankings indicate that the correlation of student performance was inconsistent from an international perspective, which resulted in a higher ranking for science achievement.

Table 7

Correlation between Physics and Other STEM subjects for 4th Grade Participating Countries

	Physics-Mathematics		Physics-Science	
Country	*r*	Rank	*R*	Rank
Armenia	0.657379**	53	0.901659**	44
Australia	0.831819**	8	0.926390**	21
Austria	0.811370**	20	0.920154**	30
Azerbaijan	0.744398**	46	0.928261**	18
Bahrain	0.837142**	7	0.932196**	14
Belgium	0.734036**	48	0.886282**	49
Botswana*	0.854734**	3	0.931111**	16
Chile	0.842880**	6	0.938351**	9
Chinese Taipei	0.786126**	29	0.925221**	25
Croatia	0.778490**	32	0.894115**	47
Czech Republic	0.785627**	30	0.915136**	35
Denmark	0.744717**	45	0.923122**	28
England	0.807764**	23	0.925398**	24
Finland	0.765287**	40	0.899325**	45
Georgia	0.812650**	17	0.915238**	34
Germany	0.779330**	31	0.920084**	31
Honduras*	0.774713**	36	0.904083**	41
Hong Kong SAR	0.790252**	27	0.919994**	32
Hungary	0.861380**	1	0.937758**	10
Iran, Islamic Rep. of	0.853678**	4	0.939937**	7
Ireland	0.810225**	21	0.925726**	23
Italy	0.774186**	37	0.922392**	29
Japan	0.775569**	35	0.891156**	48
Kazakhstan	0.797023**	25	0.943243**	3
Korea, Rep. of	0.731532**	50	0.902516**	43
Kuwait	0.811464**	19	0.909954**	39
Lithuania	0.813412**	16	0.898211**	46
Malta	0.761178**	41	0.924158**	26
Morocco	0.751056**	42	0.847809**	53
Netherlands	0.742544**	47	0.879145**	50
New Zealand	0.820536**	12	0.931321**	15
Northern Ireland	0.768018**	39	0.902706**	42
Norway	0.718479**	51	0.877951**	51
Oman	0.824593**	11	0.918896**	33
Poland	0.818890**	13	0.925886**	22
Portugal	0.805770**	24	0.910607**	38
Qatar	0.830076**	9	0.933788**	13
Romania	0.791527**	26	0.949941**	1
Russian Federation	0.750797**	43	0.927434**	19
Saudi Arabia	0.685999**	52	0.934724**	11
Serbia	0.773425**	38	0.924053**	27
Singapore	0.812126**	18	0.949108**	2
Slovak Republic	0.789097**	28	0.934320**	12
Slovenia	0.747003**	44	0.911280**	37
Spain	0.775790**	34	0.913993**	36
Sweden	0.776305**	33	0.929805**	17
Thailand	0.826933**	10	0.941456**	5
Tunisia	0.817467**	14	0.926917**	20
Turkey	0.858004**	2	0.938486**	8
United Arab Emirates	0.849528**	5	0.941609**	4
United States	0.813444**	15	0.940036**	6
Yemen	0.732229**	49	0.849003**	52
Yemen*	0.809608**	22	0.907192**	40

*Students were sampled from the sixth grade
** $p < .001$

Eighth Grade Comparison

Similar to the fourth grade comparison, results indicated that there was a positive correlation of student performance between physics and other STEM subjects. Physics achievement and mathematics achievement varied from .699932 and .885455 at α=.001 and student performance between physics and science varied from .839504 to .969784 at α=.001 (see Table 8). Some growth was also evidenced in the range of correlation coefficients from the fourth to eighth grade. However, the correlation between physics achievement and mathematics achievement was around .815969, whereas the correlation between physics and science was around .927879. Thus, the correlation between physics and mathematics is normally smaller than the correlation between physics and science in a cross-national context.

The inconsistency in the linkage of student performance was further evident in the ranking of the top and bottom five education systems. The list of education systems with the top five correlations between physics and mathematics achievements included Bahrain, Norway, Singapore, South Africa, and Turkey and the list of the bottom five included Armenia, Honduras, Indonesia, Kazakhstan, and Syrian Arab Republic. Correlation coefficients for the top five ranged from .865407 to .885455 and the bottom five ranged from .699932 to .758531.

Conversely, the top five correlations between physics and science achievements were Australia, Singapore, Turkey, United Arab Emirates, and United States and the bottom five were Georgia, Ghana, Honduras, Indonesia, and Morocco. Education systems ranking in the top five had correlation coefficients ranging from .951066 to .969784 and the bottom five had correlation coefficients ranging from .839504 to .896698. The lists of the top and bottom five education

Table 8

Correlation between Physics and Other STEM subjects for 8th Grade Participating Countries

	Physics-Mathematics		Physics-Science	
Country	*R*	Rank	*R*	Rank
Armenia	0.699932**	45	0.904892**	38
Australia	0.851607**	12	0.951066**	5
Bahrain	0.865407**	5	0.943655**	12
Botswana*	0.841672**	16	0.937329**	18
Chile	0.856491**	9	0.930198**	25
Chinese Taipei	0.845823**	13	0.943961**	11
England	0.852626**	11	0.950626**	6
Finland	0.813237**	25	0.915030**	35
Georgia	0.771521**	39	0.890069**	42
Ghana	0.783401**	36	0.896698**	41
Honduras*	0.758531**	41	0.839504**	45
Hong Kong SAR	0.803028**	30	0.933357**	22
Hungary	0.837116**	17	0.936910**	20
Indonesia	0.722922**	44	0.890031**	43
Iran, Islamic Rep. of	0.853269**	10	0.947388**	10
Israel	0.833531**	19	0.947557**	9
Italy	0.793843**	33	0.923874**	33
Japan	0.809627**	28	0.933260**	23
Jordan	0.859636**	7	0.943624**	13
Kazakhstan	0.723663**	43	0.914861**	36
Korea, Rep. of	0.826287**	21	0.938288**	17
Lebanon	0.782218**	37	0.927546**	29
Lithuania	0.843793**	15	0.927490**	30
Macedonia, Rep. of	0.811821**	26	0.924250**	32
Malaysia	0.805290**	29	0.949989**	7
Morocco	0.765744**	40	0.879717**	44
New Zealand	0.832826**	20	0.942682**	14
Norway	0.791287**	34	0.915681**	34
Oman	0.867203**	4	0.948697**	8
Palestinian Nat'l Auth	0.857940**	8	0.937138**	19
Qatar	0.845415**	14	0.939201**	16
Romania	0.825250**	22	0.928526**	28
Russia Federation	0.788540**	35	0.928679**	27
Saudi Arabia	0.800840**	31	0.905136**	37
Singapore	0.885455**	1	0.969784**	1
Slovenia	0.835717**	18	0.932704**	24
South Africa*	0.868762**	3	0.939394**	15
Sweden	0.795230**	32	0.925854**	31
Syrian Arab Republic	0.738075**	42	0.897181**	40
Thailand	0.823371**	23	0.934603**	21
Tunisia	0.782121**	38	0.898366**	39
Turkey	0.871457**	2	0.953593**	3
Ukraine	0.810854**	27	0.929936**	26
United Arab Emirates	0.863176**	6	0.954143**	2
United States	0.823028**	24	0.952072**	4

*Students were sampled from the ninth grade

** $p < .001$

systems differed in Table 8 between *physics-mathematics* and *physics-science*. The range of correlation coefficients also revealed that the top five exhibited less variability in the correlation of student performance than the bottom five. This pattern seems to suggest the presence of a ceiling effect because of the lack of "meaningful variability" between correlation coefficients (Keeley, English, Irons, & Henslee, 2013, p. 442).

Compared to other education systems, the ranking of correlation coefficients from the United States varied across subjects with mathematics ranking in 24^{th} place and science ranking in fourth place. Science received a much higher ranking than mathematics for the correlation of student performance. The discrepancy across subjects resembled the pattern among the top and bottom five education systems at the fourth and eighth grade.

Correlation of Student Performance between Physics and Cognitive Domains

According to researchers, higher order critical thinking skills are necessary for the comprehension of abstract concepts in physics (Lawson & Renner, 1975); hence, relationships between physics achievement and student performance in cognitive domains needs to be examined. While the level of abstraction in STEM education might vary between fourth and eighth grades, the between-grade comparison is also examined in this section. The cognitive domains are classified into *Knowing*, *Applying*, and *Reasoning* categories in mathematics and science according to the original TIMSS design.

Fourth Grade Comparison

Correlation results between physics and cognitive domains in mathematics. At the fourth grade, the results showed little variability in the value of correlation coefficients between physics achievement and cognitive domains in mathematics (see Table 9). Education systems that entered the top five of correlation between physics and *Knowing* were Romania, Serbia, Singapore, Slovenia, and Slovak Republic. In addition, education systems that entered the top five on the correlation between physics and *Applying* were Botswana, Hungary, Singapore, Slovak Republic, and Turkey. Education systems that entered the top five on the correlation between physics and *Reasoning* were Romania, Serbia, Singapore, Slovak Republic, and Slovenia. Although Singapore and Slovak Republic retained the strongest correlations of student performance between physics and cognitive domains in mathematics, countries like Botswana, Hungary, Romania, Serbia, Slovenia, and Turkey did not show the strongest correlation across the board. Hence, this analysis did not reveal the same group of countries with the strongest correlation of student performance between physics and cognitive domains in mathematics. Similar patterns can be identified for countries with the lowest correlation coefficients in Table 9.

The variation of correlation results was also reflected in the ranking of the United States. In Table 9, the correlation between physics and cognitive domains (i.e., *Knowing*, *Applying*, and *Reasoning)* ranked in the 21st, 18th, and 14th places, respectively. As a result, the *Reasoning* part received a much higher rank than the *Knowing* and *Applying* parts. The performance of U.S. students in physics seemed to have a stronger link to the development of mathematical reasoning skills.

Correlation results between physics and cognitive domains in science. Like the results for mathematics, there were minor differences in the value of correlation coefficients between physics and cognitive domains in science (see Table 10). The education systems ranking in the top five on the correlation

Table 9

Correlation between Physics and Cognitive Domains in Mathematics for 4th Grade Participating Countries

	Physics-Knowing		Physics-Applying		Physics-Reasoning	
Country	*R*	Rank	*R*	Rank	*R*	Rank
Armenia	0.601154**	53	0.607128**	53	0.574200**	52
Australia	0.757412**	23	0.755879**	17	0.757994**	12
Austria	0.739053**	28	0.742119**	26	0.716619**	25
Azerbaijan	0.707627**	37	0.703334**	38	0.667824**	42
Bahrain	0.765579**	18	0.758319**	15	0.730174**	21
Belgium	0.656153**	51	0.690924**	43	0.647343**	47
Botswana*	0.789395**	12	0.804589**	5	0.746376**	16
Chile	0.801265**	10	0.785307**	8	0.766307**	11
Chinese Taipei	0.712209**	35	0.711315**	33	0.698955**	29
Croatia	0.699630**	42	0.692920**	42	0.676830**	38
Czech Republic	0.707490**	38	0.724269**	29	0.683064**	37
Denmark	0.672128**	47	0.663863**	48	0.648817**	46
England	0.741247**	27	0.759281**	13	0.736037**	19
Finland	0.686206**	45	0.688266**	47	0.668646**	40
Georgia	0.765145**	19	0.746503**	24	0.703638**	27
Germany	0.721544**	31	0.697926**	41	0.669342**	39
Honduras*	0.723909**	30	0.698936**	40	0.687614**	34
Hong Kong SAR	0.704888**	40	0.720895**	30	0.690329**	32
Hungary	0.818574**	6	0.813489**	2	0.785330**	7
Iran, Islamic Rep. of	0.806839**	9	0.780476**	9	0.766866**	10
Ireland	0.762647**	20	0.745834**	25	0.727404**	22
Italy	0.713629**	34	0.706890**	37	0.684192**	35
Japan	0.704636**	41	0.706903**	36	0.695757**	31
Kazakhstan	0.766632**	17	0.753633**	19	0.731427**	20
Korea, Rep. of	0.662407**	50	0.659234**	50	0.632366**	50
Kuwait	0.714622**	33	0.707739**	35	0.653590**	45
Lithuania	0.746894**	26	0.751987**	21	0.743488**	17
Malta	0.691957**	44	0.690810**	44	0.667847**	41
Morocco	0.675656**	46	0.701013**	39	0.643582**	48
Netherlands	0.669404**	48	0.657596**	51	0.634378**	49
New Zealand	0.752002**	24	0.759036**	14	0.738338**	18
Northern Ireland	0.708470**	36	0.709241**	34	0.665524**	43
Norway	0.638915**	52	0.646168**	52	0.623060**	51
Oman	0.748558**	25	0.748505**	23	0.717292**	24
Poland	0.759800**	22	0.738774**	28	0.725514**	23
Portugal	0.727297**	29	0.741002**	27	0.701946**	28
Qatar	0.777384**	15	0.762406**	12	0.753100**	13
Romania	0.845341**	3	0.794890**	6	0.812434**	5
Russian Federation	0.815249**	8	0.756840**	16	0.803263**	6
Saudi Arabia	0.787212**	13	0.714439**	32	0.708455**	26
Serbia	0.838825**	4	0.778987**	10	0.814639**	4
Singapore	0.865758**	1	0.822227**	1	0.838071**	1
Slovak Republic	0.862390**	2	0.806079**	4	0.836139**	2
Slovenia	0.836374**	5	0.753565**	20	0.820078**	3
Spain	0.707198**	39	0.689577**	45	0.687941**	33
Sweden	0.695701**	43	0.689465**	46	0.683884**	36
Thailand	0.777730**	14	0.766948**	11	0.747318**	15
Tunisia	0.772070**	16	0.749706**	22	0.698380**	30
Turkey	0.816631**	7	0.806388**	3	0.780793**	8
United Arab Emirates	0.799080**	11	0.789181**	7	0.777887**	9
United States	0.761254**	21	0.754868**	18	0.748984**	14
Yemen*	0.714848**	32	0.719860**	31	0.656296**	44
Yemen	0.667498**	49	0.660854**	49	0.573861**	53

*Students were sampled from the sixth grade
** $p < .001$

between physics and *Knowing* were Iran, New Zealand, Romania, United Arab Emirates, and United States. Education systems among the top five on the correlation between physics and *Applying* were Hungary, Romania, Singapore, United Arab Emirates, and United States. Those in the top five on the correlation between physics and *Reasoning* were Romania, Russia, Serbia, Singapore, and Slovak Republic. No country retained their position(s) across the top-five lists except Romania. In general, an inconsistent pattern was observed across countries suggesting that correlations vary between physics and cognitive domains in science (see Table 10).

While *Knowing* as a cognitive domain in both mathematics and science referred to a student's ability to recall, recognize, and describe facts, concepts, and procedures, *Applying* in science includes generating explanations and *Applying* in mathematics had a focus on knowledge and conceptual understanding (Mullis et al., 2009). Likewise, science had an emphasis on using evidence in the *Reasoning* domain and mathematics stressed problem solving beyond routine questions (Mullis et al., 2009). More importantly, differences in the facts, concepts, and procedures between mathematics and science could have resulted in variation of correlation coefficients between these subjects and physics. As a result, no countries demonstrated the top-five correlation in the *Knowing* column of Tables 9 and 10 except Romania. In the *Applying* domain, two education systems (Hungary and Singapore) surfaced among the top five correlations (see Tables 9 & 10). Similarly, three countries (Romania, Serbia, Singapore, and Slovak Republic) had the top five correlation in the *Reasoning* column of Tables 9 and 10. Singapore, as a high performing country in both mathematics and science, seemed to have placed more emphases on the inter-subject connection of the *Applying* and *Reasoning* domains. Apparently, the international comparison suggested the

Table 10

Correlation between Physics and Cognitive Domains in Science for 4th Grade Participating Countries

	Physics-Knowing		Physics-Applying		Physics-Reasoning	
Country	*R*	Rank	*R*	Rank	*R*	Rank
Armenia	0.892182**	43	0.890051**	47	0.862785**	48
Australia	0.931825**	8	0.938349**	11	0.920470**	16
Austria	0.917384**	26	0.917336**	36	0.902341**	29
Azerbaijan	0.916653**	27	0.922758**	30	0.895189**	34
Bahrain	0.922466**	22	0.937304**	13	0.909410**	23
Belgium	0.872552**	49	0.882813**	50	0.860572**	49
Botswana	0.926833**	18	0.930994**	21	0.914429**	19
Chile	0.935227**	6	0.939639**	9	0.927144**	15
Chinese Taipei	0.916259**	29	0.927764**	25	0.910181**	22
Croatia	0.886348**	47	0.898208**	44	0.877273**	43
Czech Republic	0.914925**	32	0.912734**	38	0.896097**	33
Denmark	0.921193**	24	0.919414**	34	0.900975**	30
England	0.926657**	19	0.932701**	19	0.911113**	20
Finland	0.899941**	38	0.906076**	43	0.891903**	37
Georgia	0.912536**	34	0.910379**	41	0.894901**	35
Germany	0.916224**	30	0.923598**	29	0.893585**	36
Honduras	0.890627**	45	0.889313**	48	0.865401**	46
Hong Kong SAR	0.907842**	36	0.918140**	35	0.916050**	18
Hungary	0.932099**	7	0.947230**	4	0.939403**	8
Iran, Islamic Rep. of	0.937801**	4	0.941156**	7	0.930657**	14
Ireland	0.929833**	13	0.929974**	22	0.902592**	28
Italy	0.915337**	31	0.926619**	26	0.907405**	26
Japan	0.884083**	48	0.897800**	46	0.873323**	45
Kazakhstan	0.928472**	15	0.936221**	14	0.917877**	17
Korea, Rep. of	0.899706**	39	0.913377**	37	0.881431**	41
Kuwait	0.891934**	44	0.907576**	42	0.875883**	44
Lithuania	0.890415**	46	0.912134**	39	0.886202**	39
Malta	0.921830**	23	0.931252**	20	0.907454**	25
Morocco	0.832239**	52	0.831793**	52	0.743559**	52
Netherlands	0.861147**	51	0.867568**	51	0.839014**	50
New Zealand	0.935643**	5	0.937342**	12	0.932453**	13
Northern Ireland	0.898839**	40	0.924909**	28	0.888223**	38
Norway	0.868432**	50	0.883755**	49	0.826863**	51
Oman	0.913217**	33	0.925830**	27	0.899009**	31
Poland	0.928352**	16	0.928038**	24	0.910200**	21
Portugal	0.897124**	42	0.911863**	40	0.877296**	42
Qatar	0.930407**	11	0.934431**	16	0.906358**	27
Romania	0.944500**	1	0.950573**	2	0.958504**	3
Russian Federation	0.923280**	20	0.932895**	18	0.945135**	5
Saudi Arabia	0.928567**	14	0.929333**	23	0.941258**	6
Serbia	0.919717**	25	0.939726**	8	0.950364**	4
Singapore	0.930106**	12	0.948798**	3	0.965667**	1
Slovak Republic	0.930876**	9	0.944052**	6	0.958909**	2
Slovenia	0.905688**	37	0.919633**	33	0.934687**	12
Spain	0.908940**	35	0.920993**	32	0.897993**	32
Sweden	0.927344**	17	0.933173**	17	0.908287**	24
Thailand	0.922998**	21	0.935919**	15	0.934886**	11
Tunisia	0.916458**	28	0.921652**	31	0.884036**	40
Turkey	0.930559**	10	0.938878**	10	0.934907**	10
United Arab Emirates	0.939897**	3	0.951230**	1	0.940362**	7
United States	0.941002**	2	0.946638**	5	0.937674**	9
Yemen*	0.897363**	41	0.897853**	45	0.865279**	47
Yemen	0.826299**	53	0.815263**	53	0.728234**	53

*Students were sampled from the sixth grade
** $p < .001$

needs of having more emphasis of STEM education on the *Applying* and *Reasoning* skill training, instead of *Knowledge* memory.

The United States, in particular, showed a coefficient of 0.94 for the correlation of student performance between physics and science at the fourth grade (see Table 7). When science performance was divided into cognitive domains, the correlation coefficients between physics and cognitive domains in science were around the same value (see Table 10), which disconfirmed the Simpson Paradox that postulated different result patterns between the whole subject and subdivisions (Bracey, 2004).

Eighth Grade Comparison

Correlation results between physics and cognitive domains in mathematics. Based on a comparative examination of Tables 9 and 11, correlation coefficients between physics and cognitive domains in mathematics had a similar result between the fourth and eighth grades. In addition, Singapore, South Africa, and Turkey consistently ranked in the top five on the correlation between physics and *Knowing*, *Applying*, and *Reasoning*. When mathematics achievements were aggregated across these cognitive domains, Singapore, South Africa, and Turkey remained among the top five education systems with the highest correlation between physics and mathematics achievements (see Table 11). These examples reconfirmed the non-existence of Simpson Paradox in the comparison of correlation coefficients.

The rankings for the United States also demonstrated little variability on the correlation of student performance between physics and cognitive domains in mathematics. The correlation between physics and cognitive domains placed in 24th, 17th, and 18th place for the *Knowing*, *Applying*, and *Reasoning* parts.

Table 11

Correlation between Physics and Cognitive Domains in Mathematics for 8th Grade Participating Countries

	Physics-Knowing		Physics-Applying		Physics-Reasoning	
Country	*R*	Rank	*R*	Rank	*R*	Rank
Armenia	0.650718**	45	0.656271**	43	0.633398**	43
Australia	0.804131**	8	0.817075**	5	0.802140**	6
Bahrain	0.811785**	7	0.790300**	15	0.789180**	9
Botswana*	0.760319**	26	0.781390**	22	0.746091**	27
Chile	0.819118**	5	0.802962**	7	0.796448**	8
Chinese Taipei	0.797846**	11	0.800583**	8	0.810842**	3
England	0.821635**	4	0.817872**	4	0.808121**	4
Finland	0.755211**	27	0.759901**	29	0.739208**	29
Georgia	0.723437**	38	0.738419**	33	0.721230**	33
Ghana	0.724192**	37	0.697824**	39	0.657908**	41
Honduras*	0.670152**	43	0.655794**	44	0.644351**	42
Hong Kong SAR	0.752297**	29	0.766993**	26	0.758348**	24
Hungary	0.785727**	16	0.792228**	14	0.788097**	10
Indonesia	0.679497**	42	0.673841**	42	0.616174**	45
Iran, Islamic Rep. of	0.800001**	9	0.788574**	18	0.776207**	15
Israel	0.787949**	14	0.795491**	12	0.773296**	17
Italy	0.733800**	34	0.745964**	32	0.720189**	34
Japan	0.746489**	30	0.754877**	31	0.743252**	28
Jordan	0.797386**	12	0.798345**	10	0.766810**	20
Kazakhstan	0.680175**	41	0.692498**	40	0.681264**	39
Korea, Rep. of	0.777001**	22	0.783740**	21	0.778543**	14
Lebanon	0.729626**	35	0.728802**	35	0.737816**	30
Lithuania	0.785772**	15	0.799691**	9	0.780639**	13
Macedonia, Rep. of	0.765722**	25	0.765120**	27	0.752358**	26
Malaysia	0.777089**	21	0.772784**	25	0.759973**	23
Morocco	0.696273**	40	0.691527**	41	0.660213**	40
New Zealand	0.799580**	10	0.794300**	13	0.773313**	16
Norway	0.722283**	39	0.725296**	36	0.719895**	35
Oman	0.794440**	13	0.796932**	11	0.781084**	12
Palestinian Nat'l Auth	0.784328**	18	0.784939**	20	0.760906**	22
Qatar	0.780274**	20	0.789914**	16	0.781237**	11
Romania	0.774459**	23	0.785095**	19	0.769149**	19
Russia Federation	0.743301**	31	0.759176**	30	0.728863**	32
Saudi Arabia	0.742808**	32	0.700850**	38	0.702443**	37
Singapore	0.857423**	1	0.870568**	1	0.863253**	1
Slovenia	0.781270**	19	0.772788**	24	0.765181**	21
South Africa*	0.824305**	2	0.841188**	2	0.802818**	5
Sweden	0.740538**	33	0.731126**	34	0.713389**	36
Syrian Arab Republic	0.652159**	44	0.654977**	45	0.623689**	44
Thailand	0.785450**	17	0.775969**	23	0.754565**	25
Tunisia	0.726528**	36	0.709208**	37	0.694975**	38
Turkey	0.822840**	3	0.822650**	3	0.824565**	2
Ukraine	0.752756**	28	0.763445**	28	0.735064**	31
United Arab Emirates	0.815770**	6	0.815120**	6	0.799486**	7
United States	0.772668**	24	0.789341**	17	0.769932**	18

*Students were sampled from the ninth grade
** $p < .001$

Consequently, the *Knowing* part received a much lower rank than *Applying* and *Reasoning*. Student performance in physics seemed to have a stronger link with the mathematics emphasis on *Applying* and *Reasoning* skills. This pattern was similar to that identified at the fourth grade (see Table 9). A specific set of cognitive skills seemed linked to the correlation of student performance between physics and cognitive domains in mathematics at the fourth and eighth grades.

Correlation results between physics and cognitive domains in science. Similar patterns of correlation were revealed between physics and cognitive domains in science at both fourth and eighth grades. At the eighth grade, Oman, Singapore, Turkey, United Arab Emirates, and United States were the countries with the top five correlation coefficients in the *Knowing*, *Applying*, and *Reasoning* columns of Table 12. Due to the variation in the cognitive domain definitions between mathematics and science, these five countries in Table 12 did not retain their strong correlation ranks in Table 11 except for Singapore and Turkey, which justified the needs for separate examinations of the correlation between physics and cognitive domains in each subject.

Likewise, the correlations for the United States exhibited a little variation between physics and the three cognitive domains in science at the eighth grade. This country was positioned at the second, fourth, and fifth places for the *Knowing*, *Applying*, and *Reasoning* columns, respectively, in terms of the strength of the correlation (see Table 12). The stronger link between physics and *Knowing* seemed to suggest the dependency of rote memory in achieving a better performance in physics. Coincidentally, the U.S. was ranked with the second strongest correlation between physics and *Knowing* in science at the fourth grade (see Table 10). Therefore, the impact of rote memory seemed to be widespread across the grade levels in the U.S.

Table 12

Correlation between Physics and Cognitive Domains in Science for 8th Grade Participating Countries

	Physics-Knowing		Physics-Applying		Physics-Reasoning	
Country	*R*	Rank	*R*	Rank	*R*	Rank
Armenia	0.874394**	39	0.893762**	40	0.879871**	39
Australia	0.941748**	8	0.949907**	6	0.943574**	8
Bahrain	0.922019**	20	0.943566**	13	0.937239**	11
Botswana*	0.913026**	26	0.937899**	19	0.926003**	23
Chile	0.919772**	23	0.927789**	27	0.932056**	18
Chinese Taipei	0.938617**	10	0.945798**	9	0.943692**	7
England	0.941771**	7	0.942646**	14	0.944048**	6
Finland	0.908769**	27	0.905021**	35	0.900079**	35
Georgia	0.857067**	42	0.888883**	42	0.869190**	43
Ghana	0.861106**	40	0.888974**	41	0.871225**	41
Honduras*	0.807409**	45	0.811624**	45	0.822340**	45
Hong Kong SAR	0.925383**	19	0.935858**	20	0.910750**	31
Hungary	0.919817**	22	0.932026**	23	0.926477**	22
Indonesia	0.852861**	43	0.871425**	43	0.856906**	44
Iran, Islamic Rep. of	0.938938**	9	0.945007**	11	0.936190**	13
Israel	0.934865**	11	0.947685**	7	0.936428**	12
Italy	0.898367**	33	0.914962**	33	0.919513**	26
Japan	0.926032**	18	0.939760**	17	0.931343**	19
Jordan	0.934166**	12	0.945955**	8	0.940797**	9
Kazakhstan	0.877590**	38	0.897172**	38	0.877610**	40
Korea, Rep. of	0.934003**	13	0.939209**	18	0.932513**	17
Lebanon	0.891090**	34	0.918914**	32	0.914686**	28
Lithuania	0.913481**	25	0.921361**	30	0.928866**	20
Macedonia, Rep. of	0.914309**	24	0.927823**	26	0.908864**	32
Malaysia	0.941962**	6	0.945424**	10	0.939131**	10
Morocco	0.842823**	44	0.869490**	44	0.870624**	42
New Zealand	0.933799**	14	0.943819**	12	0.933023**	16
Norway	0.887420**	35	0.914841**	34	0.908844**	33
Oman	0.944375**	5	0.950592**	5	0.948888**	4
Palestinian Nat'l Auth	0.930629**	15	0.940754**	16	0.934427**	15
Qatar	0.930621**	16	0.941511**	15	0.934881**	14
Romania	0.901661**	30	0.924590**	29	0.913600**	29
Russia Federation	0.880871**	36	0.921152**	31	0.907744**	34
Saudi Arabia	0.902473**	29	0.901212**	36	0.892858**	37
Singapore	0.964792**	1	0.967286**	1	0.960534**	1
Slovenia	0.904694**	28	0.933632**	22	0.915693**	27
South Africa*	0.920365**	21	0.935733**	21	0.924091**	24
Sweden	0.899862**	31	0.925183**	28	0.923461**	25
Syrian Arab Republic	0.878638**	37	0.895188**	39	0.883385**	38
Thailand	0.927799**	17	0.930349**	24	0.927682**	21
Tunisia	0.859650**	41	0.898014**	37	0.899296**	36
Turkey	0.945000**	4	0.957040**	2	0.951104**	3
Ukraine	0.898661**	32	0.928959**	25	0.913330**	30
United Arab Emirates	0.946911**	3	0.956866**	3	0.956694**	2
United States	0.951803**	2	0.952502**	4	0.945244**	5

*Students were sampled from the ninth grade

** $p < .001$

Summary

This chapter provided the results to address each of the three research questions outlined in Chapter 1. The chapter began with a presentation of the descriptive findings encompassing sample sizes and mean scores for mathematics and science achievement from participating countries in TIMSS at the fourth and eighth grades. The descriptive findings were followed by results for the correlation of student performance between physics and other STEM subjects from multiple dimensions at the fourth and eighth grades. These results assessed the correlation of student performance across STEM subjects, grade levels, and countries.

The data analysis resulted in the identification of specific patterns pertaining to each research question:

1. A positive correlation of student performance between physics and other STEM subjects was evident at the fourth and eighth grade. In comparison to the correlation of student performance between physics and mathematics the linkage tended to be larger for the correlation of student performance between physics and science.
2. Cognitive domains within mathematics and science were positively correlated with physics achievement at the fourth and eighth grade. Correlation coefficients of student performance exhibited little variance between cognitive domains in mathematics and science.
3. Countries with the top five correlation coefficients of student performance varied between and across cognitive domains in mathematics and science at the fourth and eighth grade. Countries with the top five correlation coefficients did not necessarily mirror the ranking of TIMSS mean scores in mathematics and science achievement.

Chapter 5 will provide a more detailed discussion of the findings to support future research recommendations.

CHAPTER 5: CONCLUSION

This chapter is devoted to the discussion of findings corresponding to each research question. The overview of findings is then followed by the implications for practice and suggestions for future research. Finally, this chapter concludes with the main takeaways from the results attained in this research study

Overview of Findings

An innovative approach was taken to analyze existing data from TIMSS 2011 in which the mathematics and science achievement of fourth and eighth grade students was assessed in an international context. The data were analyzed by a canonical correlation of student plausible scores across STEM subjects. An advantage of this method was that it avoided the inflation of type I errors related to the repeated computation of Pearson correlations resulting in a total of 25 correlations between two sets of five plausible scores. More importantly, the methodology employed in this research study overcame the technical issue pertaining to the non-additive nature of correlation coefficients.

Results from this investigation naturally incorporated inquiries on three dimensions. First, this study focused on the between-subject correlation of student performance to confirm the existence of an empirical linkage that might have implications related to the development of NGSS in the United States. Secondly, cognitive domains were examined across the *Knowing*, *Applying*, and *Reasoning* levels of the TIMSS assessment scale to compare the correlation result patterns between the fourth and eighth grade. Third, median correlation values were identified from the cross-country context to examine their connections to student performance in mathematics and science. The comparability of TIMSS findings hinged on its employment of common test items endorsed by research coordinators of each participating education system, regardless of its economic and curricular setting.

In the STEM education domain, inquiry-based learning plays a more critical role than simple fact memorization (Crippen & Archambault, 2012). Because the international test items were not designed to fit a particular curriculum, no student could pull answers to all TIMSS questions from their past memories, and thus, problem-based learning (PBL) techniques were inevitably used by students from different countries. Research on this topic area has revealed that "PBL students under rigorous fact-based testing did not score as well on these types of tests as their non-PBL counterparts" (Nowak, 2007, p. 66). Meanwhile, fact-based testing seemed to fit the cognitive levels of elementary school students at the stage of simple knowledge acquisition. Hence, findings from this study are important for both researchers and practitioners due to the incorporation of the constructivist epistemology in practical PBL and TIMSS assessment of theoretical cognitive levels. In the sections below, the assessment features are presented to address the following three research questions:

1. What is the correlation of student performance between physics and other STEM subjects?
2. What is the correlation of student performance between the fourth and eighth grade?
3. What is the correlation of student performance across countries?

Correlation of Student Performance between Physics and STEM Subjects

The first research question examined the correlation of student performance between physics and other STEM subjects. The findings from the data analysis indicated that there was a positive correlation of student performance between physics and other STEM subjects among all participating countries at both the fourth and eighth grades despite of the international differences in curriculum settings. Luckily, one third of the TIMSS test items were released online to support interpretation of the correlational findings in this investigation.

As an illustration, a mathematics question in Figure 3 was designed to assess student knowledge in *Geometric Shapes and Measures*. At the fourth grade level, students often needed concrete examples to support the problem-solving process. Accordingly, clock-shaped pictures were provided in this question. A word, “clockwise,” was provided to allow students to link the question to a time checking task, a daily experience pertaining to a concept in physics. As a result, items like this are not confined by a problem-solving process in mathematics. This is likely to support knowledge transfer for students between physics and mathematics.

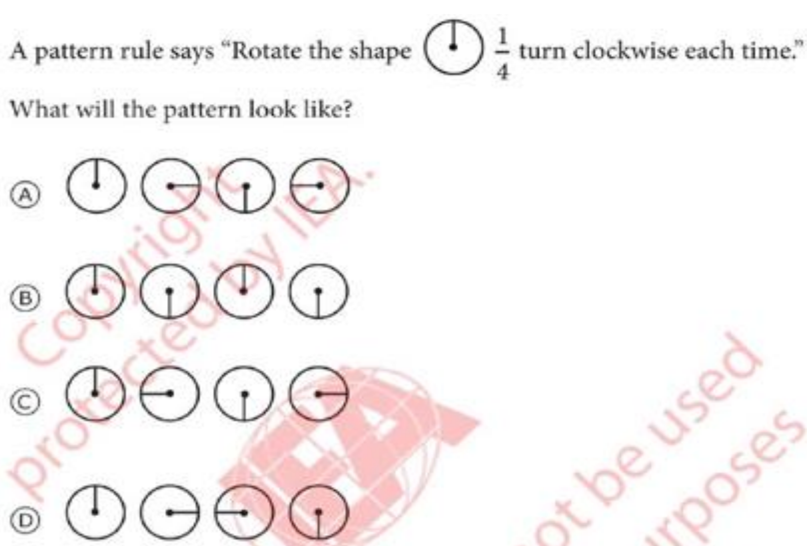

Figure 3. Fourth grade assessment item illustrating the integration of mathematics and physics.
Adapted from TIMSS 2011 User Guide for the International Database: Released Items, Mathematics-Fourth Grade by P. Foy, A. Arora, and G.M. Stanco (Eds.), 2013, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.75. Copyright 2013 by the International Association for the Evaluation of Educational Achievement (IEA), Amsterdam, the Netherlands. Reprinted with permission (see Appendix).

Beyond knowledge acquisition, Figure 4 contains a TIMSS question in the chemistry domain that fit the *Applying* level of cognitive tasks at the eighth grade. While the item came from the topic area of *Classification and Composition of Matters*, the circuit diagram structure was inseparable from student exposure to electricity content in physics.

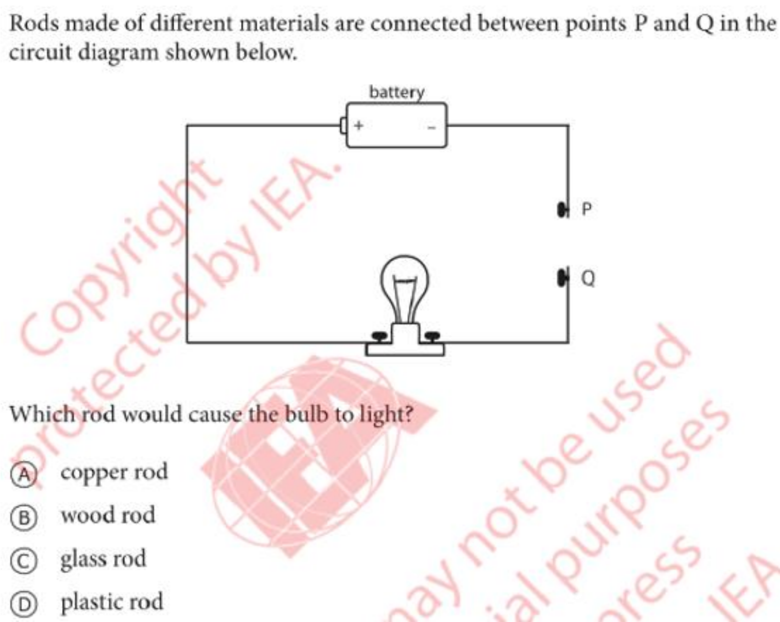

Figure 4. Eighth grade assessment item illustrating the integration of chemistry and physics.
Adapted from TIMSS 2011 User Guide for the International Database: Released Items, Science-Eighth Grade by P. Foy, A. Arora, and G.M. Stanco (Eds.), 2013, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.106. Copyright 2013 by the International Association for the Evaluation of Educational Achievement (IEA), Amsterdam, the Netherlands. Reprinted with permission (see Appendix).

While these assessment items reconfirmed the demand of student learning in both physics and other STEM subjects, students could take the opportunity to actively identify correct answers through the construction of new knowledge, regardless of the curriculum settings in each education system. According to the Constructivist Learning Theory in Chapter 2 (e.g., Khan, 2013), students are viewed as active learners. They can engage in problem-based inquiries to pursue an answer that is aligned with their knowledge composition across different disciplines (Bosse et al., 2010; Czerniak et al, 1999; Mason, 1996). Because not all the schools offered science and mathematics education as a joint subject, additional effort might be needed for some students to bridge the gaps. In this regard, the constructivist epistemology is demonstrated in the research findings to explain the exploratory nature of problem solving according to Vygotsky's scheme on the Zone of Proximal Development (ZPD).

Correlation of Student Performance between

Physics and Cognitive Domains

The second research question examined the correlation of student performance between physics and other STEM subjects across grade levels. Findings from the data analysis showed that there was a positive correlation of student performance between physics and cognitive domains within mathematics and science at the fourth and eighth grades.

As exemplified in Figures 3 and 4, the link between physics and other STEM subjects was evident in the cognitive domains for *Knowing* and *Applying* at the fourth and eighth grades, respectively. The *Knowing* cognitive domain focused on basic "facts, concepts, and procedures" that students should know and the *Applying* cognitive domain focused on the application of "knowledge and conceptual understanding" to solve problems (Mullis et al., 2009, p. 40). These were pertinent examples because fourth graders were simplistically confined by the learning of content at the *Knowing* level while eighth graders gained more knowledge and experienced a switch of school learning toward the application of knowledge.

In addition, the link between physics and other STEM subjects was evident in the cognitive domain for *Reasoning*, which focused on "unfamiliar solutions, complex contexts, and multi-step problems" (Mullis et al., 2009, p. 40). At the fourth grade, an item in physical science is illustrated in Figure 5. This question was designated to the *Reasoning* domain for its demand on scientific predictions on what will occur according to the tabulated data. To solve this problem, students not only needed quantitative reasoning skills in mathematics, but also explored causal relations pertaining to *Classification and Property of Matter* in physics and chemistry.

Maria designed an experiment using salt and water. The results of her experiment are shown in the table.

Amount of Salt Dissolved	Water Volume	Water Temperature	Was Mixture Stirred?
15 grams	50 ml	25° C	Yes
30 grams	100 ml	25° C	Yes
45 grams	150 ml	25° C	Yes
60 grams	200 ml	25° C	Yes

What was Maria studying in her experiment?

- Ⓐ How much salt will dissolve in different volumes of water.
- Ⓑ How much salt will dissolve at different temperatures.
- Ⓒ If stirring increases how fast salt will dissolve.
- Ⓓ If stirring decreases how fast will salt dissolve.

Figure 5. Fourth grade assessment item illustrating the integration of physics and other STEM subjects within the reasoning domain.
Adapted from TIMSS 2011 User Guide for the International Database: Released Items, Science-Fourth Grade by P. Foy, A. Arora, and G.M. Stanco (Eds.), 2013, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.11. Copyright 2013 by the International Association for the Evaluation of Educational Achievement (IEA), Amsterdam, the Netherlands. Reprinted with permission (see Appendix).

Similarly, another example from the *Reasoning* domain is presented in Figure 6. At the same grade level and in the same content domain, this item required students to elaborate on the concept of density in terms of both mass and volume configurations. In combination, the scientific reasoning not only built upon the consideration of variable control in physics experimentation, but also on the quantitative comparison of object sizes across different geometric shapes. While the item might seem simple for adult learners, the cognitive domain was set at the *Reasoning* level due to the hypothesis test on whether more volume corresponded to more weight.

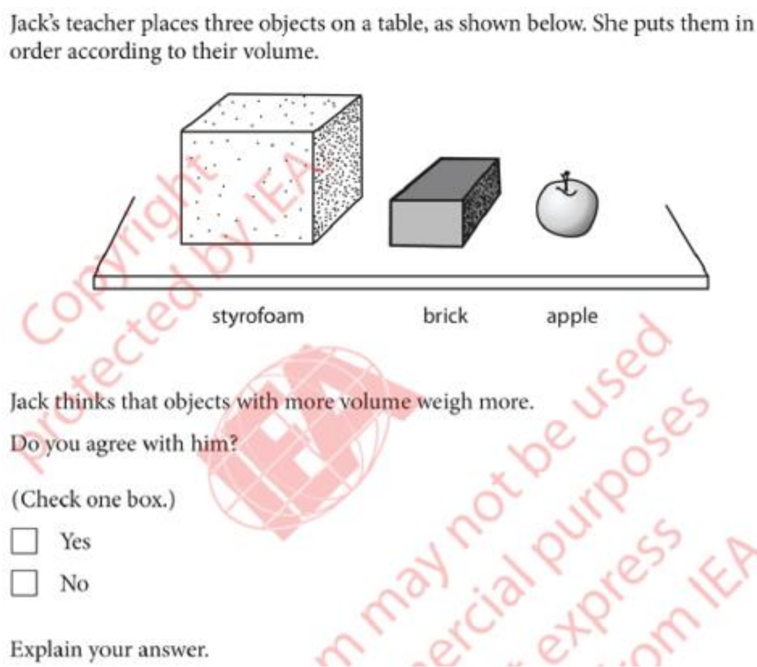

Figure 6. Additional fourth grade assessment item illustrating the integration of physics and other STEM subjects within the reasoning domain.
Adapted from TIMSS 2011 User Guide for the International Database: Released Items, Science- Fourth Grade by P. Foy, A. Arora, and G.M. Stanco (Eds.), 2013, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.85. Copyright 2013 by the International Association for the Evaluation of Educational Achievement (IEA), Amsterdam, the Netherlands. Reprinted with permission (see Appendix).

The linkage between physics and other STEM subjects in the *Reasoning* domain was also embedded in an assessment item for mathematics at the eighth grade. Figure 7 presents an assessment item in the topic area for *equations/formulas and functions* within the content domain for algebra. The weight measurement in the algebraic equation also linked this assessment item to physics. Although test items were set at different cognitive levels, the content could bridge different subjects. Thus, it was not unusual to find TIMSS questions that demanded student inquiries across STEM fields.

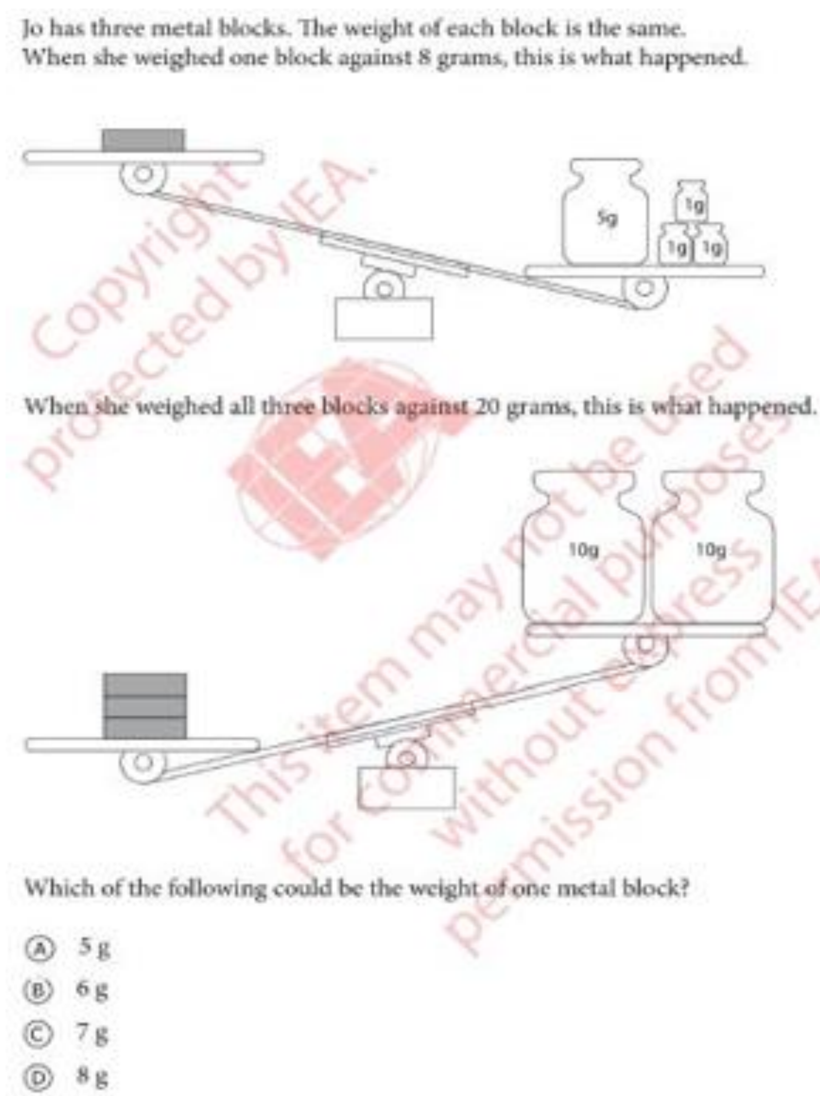

Figure 7. Eighth grade assessment item illustrating the integration of physics and other STEM subjects within the reasoning domain.
Adapted from TIMSS 2011 User Guide for the International Database: Released Items, Mathematics-Eighth Grade by P. Foy, A. Arora, and G.M. Stanco (Eds.), 2013, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.127. Copyright 2013 by the International Association for the Evaluation of Educational Achievement (IEA), Amsterdam, the Netherlands. Reprinted with permission (see Appendix).

While this dissertation is delimited to the relationship of student achievements between physics and other STEM subjects, the root of score connections was not confined within the perspective of physics educators. Beyond physics, Figure 8 displays an assessment item in science at the eighth grade. This assessment item covered the topic area of *Cells and Their Functions* within the content domain for biology. However, the data display in the diagram linked the assessment item to mathematics. Accordingly, the impact of Next Generation Science Standards (NGSS) should not be confined within the perspective of a particular science branch. Instead, the integration of STEM subjects supported the general premise of knowledge transfer between mathematics and science that positions students as active learners (Honey et al., 2014).

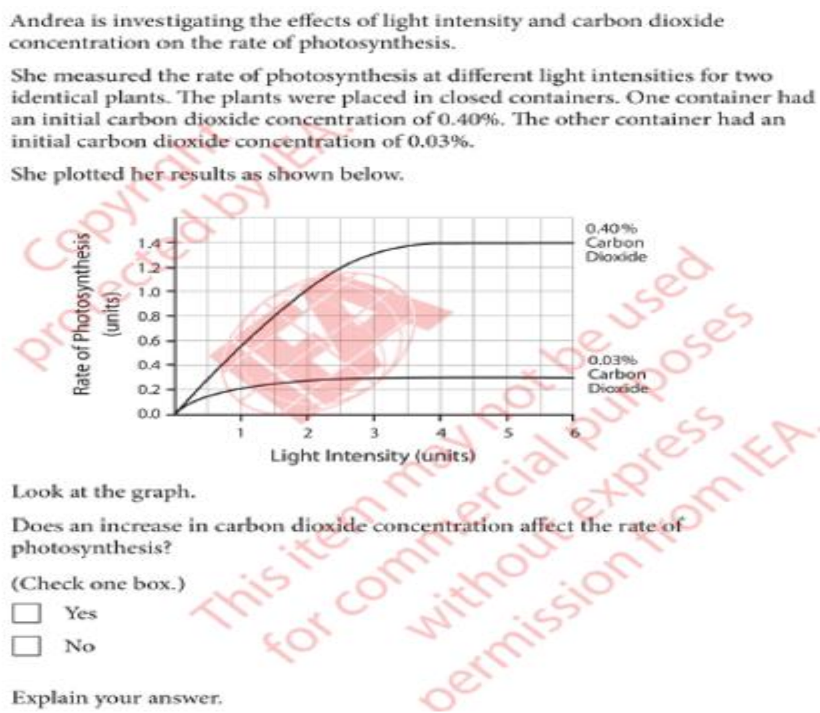

Figure 8. Eighth grade assessment item illustrating the integration of biology and mathematics.

Adapted from TIMSS 2011 User Guide for the International Database: Released Items, Science-Eighth Grade by P. Foy, A. Arora, and G.M. Stanco (Eds.), 2013, TIMSS & PIRLS International Study Center Lynch School of Education: Boston College, p.104. Copyright 2013 by the International Association for the Evaluation of Educational Achievement (IEA), Amsterdam, the Netherlands. Reprinted with permission (see Appendix).

Through this empirical investigation, student performance across the cognitive domains of *Knowing*, *Applying*, and *Reasoning* were found in the correlation of student performance between physics and other STEM subjects at the fourth and eighth grades. This finding is consistent with literature on the cognitive development of students across grade levels. Cognitive development is particularly important in physics education because formal operational reasoning is widely demanded in the learning process (Lawson, 1973; Liberman & Hudson, 1979); however, past studies indicated that students in upper grade levels such as those in the eighth grade often did not reach the formal operational stage (Cantu & Herron, 1978; Renner et al., 1990), which seemed to support the pattern of correlational findings across various cognitive domains in this investigation.

Median Correlation of Student Performance between Physics and Cognitive Domains

The third research question examined the correlation of student performance between physics and other STEM subjects across countries. Findings from a cross-country examination of median correlation values revealed that there was little variability in the correlation of student performance between physics and cognitive domains in mathematics and science at the fourth and eighth grades.

Table 13 includes the median correlation values for student performance between physics and cognitive domains in mathematics at the fourth grade. Although the *Knowing* and *Applying* domain had a similar correlation value, the *Knowing* domain was linked to a larger mean score translating into better student performance in mathematics. This connection suggests that skills training in the *Knowing* domain are desirable.

Table 13

Physics and Cognitive Domains in Mathematics at the Fourth Grade

Cognitive Domain	Country	Median Correlation Value	TIMSS Mean Score
Knowing	England	0.741247	542
Applying	Portugal	0.741002	532
Reasoning	Georgia	0.703638	450

A similar pattern was evident in the median correlation values of student performance between physics and cognitive domains within science. Table 14 reveals that skills training in the *Knowing* domain are recommended as a result of the connection with the largest mean score among those with the median correlation value.

Table 14

Physics and Cognitive Domains in Science at the Fourth Grade

Cognitive Domain	Country	Median Correlation Value	TIMSS Mean Score
Knowing	Azerbaijan	0.916653	438
Applying	Oman	0.925830	377
Reasoning	Qatar	0.906358	394

In comparison to the findings at the fourth grade, there was a slight shift in the connection between cognitive domains and student performance in mathematics and science at the eighth grade. Countries with the median correlation value of student performance between physics and cognitive domains in mathematics at the eighth grade are presented in Table 15. In spite of the similar median correlation value between the Knowing and Applying domain, student performance in mathematics was linked with the Knowing domain based on the larger mean score. This pattern suggests that the Knowing domain has a connection with student performance at both the fourth and eighth grade.

Table 15

Physics and Cognitive Domains in Mathematics at the Eighth Grade

Cognitive Domain	Country	Median Correlation Value	TIMSS Mean Score
Knowing	Romania	0.774459	458
Applying	Thailand	0.775969	427
Reasoning	Malaysia	0.759973	440

Nevertheless, median correlation values in Table 16 indicate that there was a shift in the connection between cognitive domains and student performance in science. Skills training in the *Applying* domain were deemed to be the most appropriate because of the linkage with the largest mean score regardless of the similar correlation value with the *Reasoning* domain. The connection between the *Applying* domain and student performance differed from the pattern identified at the fourth grade.

Table 16

Physics and Cognitive Domains in Science at the Eighth Grade

Cognitive Domain	Country	Correlation Value	TIMSS Mean Score
Knowing	Chile	0.919772	461
Applying	Hungary	0.932026	522
Reasoning	Botswana	0.926003	404

In general, the connections between median correlation values and student performance in mathematics and science suggest that a large correlation value is not necessarily linked to a large mean score. This phenomenon could be interpreted using the three-tier framework of the Curriculum Evaluation Model consisting of the intended, implemented, and attained curriculum. Discrepancies in the connection between cognitive domains and student performance in mathematics and science indicates that there might be an alignment issue between educational goals and instructional practices (Bennett, 2003; McKnight &

Schmidt, 1998; Plomp, 1990) within physics, which make up the intended and implemented curriculum. This discrepancy is ultimately reflected in the outcome of student performance, which is referred to as the attained curriculum. Based on the positive correlation of student performance between physics and cognitive domains in mathematics and science, it could be concluded that pedagogical practices in a cross-country context might vary, resulting in differences of student performance in mathematics and science.

Additionally, the results presented in Chapter 4 indicated that countries with a greater Opportunity to Learn (OTL) in mathematics and science, such as China (Zhang & Yin, 2014), did not have the top five correlation coefficients of student performance between physics and cognitive domains in mathematics and science. The variability between cognitive domains and student performance in mathematics and science ultimately indicated that the OTL, used to evaluate results of student achievement (Cueto, Ramirez, & Leon, 2006; Reeves, Carnoy, & Addy, 2013), was not consistent with the existing literature. This finding further supports the need for an evaluation of curriculum models in a cross-country context to assess the alignment of the intended, implemented, and attained curriculum in relation to the correlation of student performance between physics and other STEM subjects.

Practical Implications

The findings from this study resulted in the identification of three practical implications for STEM education:

(1) Although the positive correlation of student performance between physics and other STEM subjects was general and not associated with a specific education system, the results could serve as a reference for education reform initiatives in STEM education. The United States in particular could use the

empirical evidence from this study to support implementation of the Next Generation State Standards (NGSS), which encourages the integration of more than one STEM subject (Kurson, 2014). This movement could impact student learning because it is currently a national expectation backed by a professional consensus of STEM educators in an international context.

(2) Countries can learn from one another due to the variation in connections between the correlation of student performance and mathematics and science achievement. The variability among countries indicated that a high correlation of student performance was not necessarily a reflection of a high mean score in mathematics and science achievement. This international finding is critical for educators in the U.S. because the comparative results mirror the national landscape of student achievement. In fact, Bracey (1994) indicated that comparisons of student achievement in national and international assessments have shown that particular states are associated with a first world country, whereas others are associated with a third world country. Educators in this case could benefit from international studies to improve the achievement of a diverse student population.

(3) Median correlation values of student performance between physics and cognitive domains in mathematics and science indicated that the correlation of student performance was linked with particular cognitive domains at the fourth and eighth grades. As previously discussed, skills training in the *Knowing* domain are desirable at the fourth grade in mathematics and science, as well as in mathematics at the eighth grade. However, skills training in the *Applying* domain are desirable at the eighth grade in science. The slight shift across grades levels could be attributed to the continuous development of student's cognitive abilities, which is aligned with Piaget's Stages of Cognitive Development and Bloom's

Taxonomy. As a result, the Opportunity to Learn (OTL) played an important role in the U.S. because a large number of high school students were not expected to take courses that expose them to basic knowledge in physics. In fact, White and Tesfaye (2014) indicated that only “four graduates in ten take high school physics” (p.1).

Limitations

Results pertaining to the correlation of student performance between physics and other STEM subjects were limited to a correlation argument. The fact that all countries exhibited a positive correlation of student performance prevented the researcher from attributing the results to a national curriculum. This phenomenon essentially indicated that a positive correlation of student performance could occur in any country regardless of the enforcement of a national curriculum. In addition, the results could not be attributed to a particular curriculum model for an integrated curriculum between physics and other STEM subjects. This research study solely focused on the achieved curricula. Most importantly, TIMSS 2011 was administered prior to the release of NGSS. There is no foundation to postulate the result as an outcome of NGSS in the U.S.

Suggestions for Future Research

Beyond the findings from this investigation, more research can be conducted at multiple levels. At the national level, the assessment framework for the National Assessment of Educational Progress (NAEP) should be re-designed to mirror the concurrent data collection process utilized by TIMSS. This method would give stakeholders in STEM education an opportunity to monitor the relationship of student performance across different subjects.

At the international level, the methodology for this research should be applied to other STEM subjects and future TIMSS studies. Expanding the scope of this investigation could provide stakeholders with a better understanding of the relationship between STEM subjects in a cross-country context. In particular, the methodology can be borrowed from this study to analyze new data released from TIMSS 2015. Through the research articulation, results from TIMSS 2011 could be treated as a pre-test, whereas TIMSS 2015 in addition to forthcoming studies could be treated as a post-test with NGSS as an intervention in the United States.

While findings from this research support an integrated mathematics and science curriculum, it is not known whether students from a particular economic status would benefit from this pedagogical approach. Researchers in this case need to assess the achievement of students using socioeconomic status as an intervening variable. Similarly, it is not known whether particular pedagogical approaches support an integrated curriculum. This warrants the need for an assessment of the implemented curricula. Researchers would essentially need to assess the relationship between instructional practice and student performance in a classroom setting. The examination of implemented curriculum model may include components that support integration of student learning in STEM subjects across education systems.

Conclusion

For several decades, assessments in mathematics and science achievement have provided valuable information for education reform initiatives in a cross-country context. The U.S. in particular has utilized the international findings to garner public attention on STEM education. The national dialogue has become far more critical in the recent years as the U.S. attempts to meet workforce demands by ensuring that students are adequately prepared for careers in the STEM field.

Increasing the number of college degrees in the STEM field now encompasses curriculum integration (Stohlmann, Moore, & McClelland, 2011), which places more importance on the results from this research study. With the emphasis of NGSS on stronger links of student learning outcomes across STEM subjects, this study is delimited to the correlation of TIMSS scores between physics and other STEM subjects, which did not conclusively link higher scores to stronger correlations among different countries. Therefore, local control and creativity should be exercised by STEM educators at the school level to promote student learning through different curriculum designs and implementations that are grounded on student needs and instructional resources available in a particular community.

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