Boston College
Lynch School of Education and Human Development

Department of
Measurement, Evaluation, Statistics, and Assessment

USING TIMSS 2015 TO EXAMINE PARENTAL INFLUENCES ON FOURTH GRADE STUDENTS' SCIENCE ACHIEVEMENT AND ATTITUDES TOWARD LEARNING AND DOING SCIENCE

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VICTORIA A. S. CENTURINO

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Using TIMSS 2015 to Examine Parental Influences on Fourth Grade Students' Science Achievement and Attitudes Toward Learning and Doing Science

By

Victoria A.S. Centurino

Dissertation Director: Ina V.S. Mullis

Abstract

More than ever before, countries are relying on their experts in STEM (Science, Technology, Engineering, and Mathematics) fields to find solutions to serious global problems, such as climate change, hunger, and disease. Unfortunately, the growing demand for these experts is outpacing supply. At each stage in the educational pipeline from the primary grades through university, there is substantial attrition in the number of students studying STEM subjects.

From the early grades, students' home environment has a powerful influence on their science achievement. However, there has been little research into the factors that have the most influence on inspiring young students to continue studying science.

This dissertation extended investigations by Swedish researchers who used TIMSS and PIRLS 2011 data and structural equation modeling to show that that fourth grade students with higher achievement in science had well-educated parents who had many books at home, and spent time engaging their child in early learning activities, such that the child began school with basic skills already developed.

After replicating the Swedish TIMSS and PIRLS 2011 Common Model with TIMSS 2015 data and finding good agreement, additional variables were systematically examined with a focus on the role of attitudes. Extending the explanation of the influence

of parents' education to include their educational expectations for their child and updating the model to include home digital resources elaborated on this Base Model. However, the hypothesis that parents' attitudes toward mathematics and science would have a role in explaining science achievement was not supported. Analyzed either as a second independent variable with parents' education or as a mediating variable, the effect was negligible. Finally, parents' education levels had little or no relationship with the degree to which students like learning science, but a notable relationship with students' confidence in their ability to do science. Clearly, more research into how parents' attitudes and other home factors can influence students' to study science throughout their academic careers is warranted.

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I dedicate this dissertation and all of the work it represents to Karl and Mary Etta Scheribel, my parents, who taught me to love learning, be curious about the world around me and the people in it, ask questions, ferret out answers, and pursue goals with determination.

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Chapter 1: Introduction

Across the world, public awareness of the value of a strong education in STEM (Science, Technology, Engineering, and Mathematics) fields continues to increase (Freeman, Marginson, & Tytler, 2015; Marginson, Tytler, Freeman, & Roberts, 2013). Innovations in technology and science in particular increasingly shape our daily life experiences: the ways we communicate, the food we eat, the modes of transportation we use, and more. We look to STEM professionals to address global issues such as hunger, climate change, energy production, and curtailing the COVID-19 pandemic. In addition, many jobs outside of traditional STEM fields, such as business, professional services, and manufacturing, now require increased understanding of mathematics and science in addition to other skills.

However, there continues to be substantial attrition in the number of students studying STEM subjects at each step along the educational pipeline—from primary through lower secondary, upper secondary, and university (van Tuijl & Van der Molin, 2016). Because the supply of graduates with STEM training is falling short of demand, countries relying on innovation and growth in the knowledge economy for advancement are stymied by a shortage of qualified STEM professionals (Freeman et al., 2015). Policy makers and businesses alike are examining STEM education programs and policies beginning at the earliest levels of education with the goal of retaining more students at the upper levels of education in STEM programs of study and participation in specialist training (Hartung, Porfeli, & Vondrack, 2005; van Tuijl & Van der Molin, 2016).

Most students have their introduction to science learning in the primary grades. Previous research indicates that cultivating interest in science learning in young students is an important first step in building the intellectual momentum that will sustain them through increasingly rigorous coursework in science as they enter secondary grades (George & Kaplan, 1998; Hasni & Potvin, 2015; Bøe, Henriksen, Lyons, & Schreiner, 2011). Similarly, students with strong confidence in their science abilities are much more likely to continue to study science and do well in their science studies (Chen & Pajares, 2010; Saçkes, Trundle, Bell & O'Connell, 2011; Shin et al., 2015). A successful start in science education in primary school can be an important influence on students' attitudes toward STEM subjects throughout their school career.

Considerable research shows that even in the early grades, students' home environment, including parental education, has a powerful influence on their science achievement (see Chapter 2). However, there has been less effort spent on delving into the many aspects of home environment to learn more specifically about which parental and home factors have the most influence on students' educational outcomes. Further study of the home factors influencing students' disposition, perseverance, and achievement in science during the primary grades could indicate ways of increasing students' interest and motivation in studying STEM subjects, so that they continue enrolling in these courses.

This dissertation examines in an international context how parental factors influence students' science achievement in primary school, as well as their attitudes toward learning and doing science. Building on investigations by teams of Swedish researchers, this dissertation uses TIMSS 2015 fourth grade science data to examine how elements of the home context can influence fourth grade students' science achievement and attitudes towards learning and doing science. The previous investigations using data from TIMSS and PIRLS 2011 found that students with higher achievement in the fourth grade had well-educated parents who had many books in the home, and spent time engaging their child in early learning activities, such that the child began school with basic skills already developed. This dissertation extends the TIMSS and PIRLS 2011 Common Model by replicating it with TIMSS 2015 fourth grade science data from 36 countries and including parents' educational expectations for their child, digital resources, and parental attitudes toward mathematics and science as predictors and student attitudes toward learning and doing science as outcomes. The research addresses three questions, shown below.

1.1 Research Questions

1. Does extending and updating the TIMSS and PIRLS 2011 Common Model to include parental expectations for their child's education and digital resources in the home improve our understanding of the relationship between parents' education and students' science achievement at the fourth grade?

2. What role do parents' attitudes toward mathematics and science play in explaining the relationship between parental education and science achievement at the fourth grade?

3. How effective is the extended model in predicting students' attitudes toward learning and doing science at the fourth grade?

1.2 TIMSS (Trends in International Mathematics and Science Study)

TIMSS is a large-scale international assessment of student achievement in mathematics and science at the fourth and eighth grades that has been conducted every four years since 1995. It is directed by the TIMSS & PIRLS International Study Center at Boston College. The TIMSS 2015 Science Assessment, Fourth Grade provides internationally comparable achievement data on topics in life science, physical science, and Earth science included in the curricula of participating countries. The achievement items span three cognitive domains (knowing, applying, and reasoning), which describe a range of cognitive processes involved in learning science concepts, and then applying and reasoning with them (Jones, Wheeler, & Centurino, 2013). The TIMSS 2015 fourth grade science achievement scores were based on student responses to 168 items, including a variety of response formats.

Questionnaires for the participating students, their parents, and their schools accompanied the TIMSS 2015 assessments to gather information on students' contexts for learning science. The TIMSS 2015 Home Questionnaire (IEA, 2016a) for parents of students at the fourth grade, in particular, provided a unique source of data about students' home environment for learning. The TIMSS 2015 Student Questionnaire, Fourth Grade (IEA, 2016b) provided data about how much students like to learn science and how much confidence they have in their ability to do science work.

This dissertation combines TIMSS 2015 achievement and questionnaire data from 36 countries to better understand how elements of the home context work in concert to influence students' science achievement and attitudes towards learning and doing science at the fourth grade.

1.3 Seminal Research Underlying the Dissertation

Research conducted by Gustafsson, Hansen, and Rosén (2012) provided the inspiration for this dissertation as well as the methodological approach that served as the foundation for the research plan. Myrberg and Rosén (2009) used PIRLS (Progress in International Reading Literacy Study) 2001 data to investigate how the level of parental education influenced reading achievement in Sweden using structural equation modeling techniques to construct a mediation model with latent variables from the home environment questionnaire completed by participating students' parents. Myrberg and Rosén found evidence to support the hypothesis that parents with higher levels of education had more books in their home and engaged their children in more early literacy activities, such that the children started school with stronger reading skills that resulted in higher reading achievement at the fourth grade.

Further, Gustafsson et al. (2012) used TIMSS and PIRLS 2011 data from 37 countries to investigate a similar hypothesis for science and mathematics achievement as well as reading achievement. Using the structural equation modeling framework to construct a mediation model with latent variables, they found evidence to support their hypothesized model and identified two mechanisms within the model that explained how parents' level of education influenced student achievement. The simplest chain of influence indicated that the number of books in the home had a substantial direct effect on student achievement. A more nuanced three-link linear chain of influence connected the number of books in the home, the measure of early literacy and numeracy activities in the home, and the measure of children's ability to perform literacy and numeracy tasks at the beginning of primary school with student achievement.

The authors suggested that continued research was necessary to elaborate the explanation of the impact of parents' education level on student achievement, including exploring models with more variables from the TIMSS and PIRLS data sets. For example, it was suggested that the next generation of models could include information about parents' attitudes towards mathematics and science, or their reading habits. Additional student variables could be added to represent their attitudes towards learning mathematics, science, or reading in school or to represent their confidence in their abilities to do mathematics or science or their ability to read.

1.4 The TIMSS 2015 Database

After each TIMSS data collection, the TIMSS & PIRLS International Study Center publishes each student's achievement data together with associated questionnaire data in a large, publically accessible, and fully documented online database. The TIMSS 2015 International Database (TIMSS & PIRLS International Study Center, 2016) is an excellent source of data for this dissertation research. At the fourth grade, it encompasses a high quality measure of students' science achievement together with an array of home environment variables highlighted in the literature as being related to student achievement and attitudes towards learning and doing science.

In addition to responding to the TIMSS 2015 achievement items, students provided basic demographic information and responded to questions about their experiences in school and their attitudes towards mathematics and science in the TIMSS 2015 Student Questionnaire, Fourth Grade (IEA, 2016b). Attitudes about learning science and students' confidence in their abilities to do science are important predictors of whether a qualified student will remain in the STEM pipeline and pursue the coursework and training needed for a career in a STEM-related field (Lyons & Quinn, 2010; Means, Wang, Young, Peters, & Lynch, 2016).

Through the TIMSS 2015 Home Questionnaire (IEA, 2016a), the parents of the students who participated in TIMSS 2015 also provided basic demographic information, as well as retrospective information about their child's educational experiences before they began primary school, information about the home context for supporting their child's learning, and information about their own attitudes towards schooling, mathematics, science, and reading.

The TIMSS 2015 Home Questionnaire also captured important attitudinal data from parents. Results from TIMSS 2015 indicated that there was a strong positive relationship between parents' educational expectations for their children and science achievement at the fourth grade (Martin et al., 2016). Archer et al. (2012) found that parents' aspirations for their children influenced the ways 10- and 11-year-olds began to think about future careers in science. Davis-Kean (2005) also studied parental educational expectations for 10- and 11-year olds using structural equation path modeling and found a substantive and significant path from parental education to student achievement through parental educational expectations.

TIMSS 2015 results showed positive relationships between parents' attitudes towards mathematics and science and their children's attitudes towards learning science and their confidence in their ability to do science (Martin, Mullis, Foy, & Hooper, 2016). Previously, Simpson and Oliver (1990) found that parents' attitudes towards science have an effect on students' attitudes above and beyond the strong effect of school factors and Tanenbaum and Leaper (2003) also demonstrated that parents' beliefs about science can significantly influence their children's interest in and attitudes towards science.

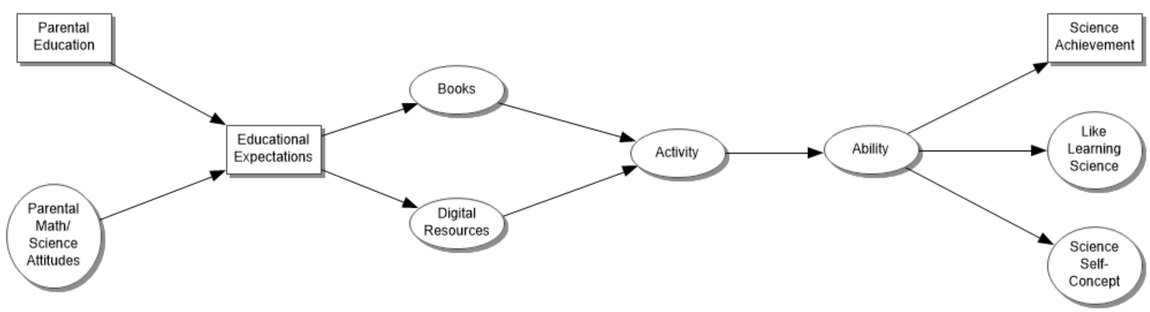
1.5 The Models

The goal of this dissertation research is to use data from TIMSS 2015 to describe how students' home context factors can influence their academic success in science and their attitudes towards learning and doing science at the fourth grade. Home context factors in TIMSS 2015 include parents' level of education and their attitudes towards mathematics and science, the number of books, children's books, and digital resources in the home, and the level of early literacy and numeracy education in the home before their child began primary school. This research lends itself to employing structural equation modeling techniques, particularly path modeling with latent variables, to investigate how important elements of students' home context work individually and together to influence their academic outcomes.

In the planned dissertation analyses, extending the Base Model involves introducing five additional variables in three separate stages to create an updated model that includes attitudinal variables, called the Parental Influence on Student Outcomes in Science Model. In the first stage, two additional mediating variables, parents' educational expectations for their children and digital resources in the home are added. A latent independent variable measuring parents' attitudes towards mathematics and science is added as a second independent variable in the second stage. Finally, in the third stage, two latent student outcome variables measuring how much students like learning science and their confidence in their abilities to do science are added to the original science achievement outcome variable.

The final proposed Parental Influences on Student Outcomes in Science Model, shown in Exhibit 1.1, represents the hypothesis that multiple parental characteristics work together through several mediating home context factors to influence their child's science achievement, attitudes towards learning science subjects and confidence in their ability to do science.

Exhibit 1.1: Schematic of the Hypothesized Parental Influence on Student Outcomes in Science Model



Chapter 2 presents a review of the literature that informed the construction, analysis, and evaluation of the Parental Influence on Student Outcomes in Science Model. The first part of the chapter discusses research related to the variables included in the model. Researchers' reports identify three parent characteristics as strong predictors of positive educational outcomes in science for students: level of education completed, attitudes towards STEM, and educational expectations for their child. Researchers also found that aspects of the home environment such as the number of books and digital resources available, as well as the level of early educational activity in the home, which led to the development of the child's literacy and numeracy abilities before the beginning of primary school, had a positive relationship with student academic outcomes in science.

Additional research into the characteristics of students who sustain an interest in science and ultimately enter STEM careers shows that these students are more likely to be high-achievers in science, like the activity of learning science, and have high confidence in their ability to do the activities of science. The rest of the chapter provides an overview of the Myrberg and Rosén (2009) and Gustafsson et al. (2012) research that inspired this dissertation. The chapter concludes with a discussion of the status of the STEM pipeline internationally.

Chapter 3 presents the details of the modeling process. It begins with a description of the processes used to assemble a master data set from the TIMSS 2015 International Database. As an initial analysis step to confirm the accuracy of the modeling techniques, a preliminary Base Model, derived from the TIMSS and PIRLS 2011 Common Model (Gustafsson et al., 2012), was analyzed using the TIMSS 2015 fourth grade science data. The similarity in the results between this researcher's initial analysis of TIMSS 2015 data using the Gustafsson et al. methods and their results confirmed that it would be appropriate to proceed with the more complex models envisioned for this dissertation. The next sections present the construction and evaluation process for the Base Model, including details on model estimation.

The chapter concludes by describing the three stages used to see if the Base Model could be extended into the proposed Parental Influence on Student Outcomes in Science Model and the model estimation and evaluation processes used at each stage. The first stage examined the possibility of adding two mediators, *Educational Expectations* and *Digital Resources,* into the established Base Model, increasing the number of links in the chain of influence between parental education and students' science achievement in science. The second stage was intended to broaden home influence beyond levels of parents' education by including another an independent variable, *Parental Math/Science Attitudes*. Then, the third stage would add two student attitudinal outcome variables, *Like Learning Science* and *Science Self-Concept*.

Chapter 4 provides the results of each stage of the analysis. Extending the path of the influence of parents' levels of education to include *Educational Expectations* and *Digital Resources* did elaborate on the Base Model. However, despite extensive analysis and reanalysis, *Parental Math/Science Attitudes* showed negligible relationship with science achievement at the fourth grade, as either an independent variable or a mediating variable. Finally, parents' education levels had little or no relationship with the degree to which students *Like Learning Science.* The relationship between parents' education level and students *Science Self-Concept* was stronger than its relationship with *Like Learning Science*, but less strong than its relationship with student achievement. In the end, *Educational Expectations*, *Digital Resources*, and *Science Self-Concept* were retained and incorporated into the Base Model to create the final Parental Influences on Fourth Grade Students Science Achievement and Confidence in Doing Science Model.

Chapter 5 discusses the key findings and their implications for future research extending our understanding of the powerful effects of parents' education on its own and through more home supports for learning. More interesting is considering new avenues for elaborating on the relationships between parents' attitudes and their children's interests and academic achievement in science as well as, more broadly: Is it possible for parents' attitudes have an impact on the number of students choosing careers in STEM subjects?

Chapter 2: Review of the Literature

The current worldwide interest in STEM education together with the high degree of student attrition along the STEM education pipeline as students continue through primary and secondary school and beyond (Marginson et al., 2013) inspired this dissertation research examining how home context can influence academic and attitudinal outcomes in science at the fourth grade. Does the attrition in the number of students interested in STEM education begin in the home before students enter school? Or, is the attrition primarily facilitated by instructional factors as students progress through schooling? For example, using the lens of cultural capital theory and structural equation modeling techniques, Gustafsson et al. (2012) found that parents with higher levels of education had more books in their home, and engaged their child in more early literacy and numeracy activities, such that the child started primary school with stronger literacy and numeracy skills that resulted in higher achievement in mathematics, science, and reading at the fourth grade.

This dissertation, extending the research by Gustafsson et al., benefitted from a wide range of research pertaining to the importance of science learning, home factors that can influence higher student achievement in science, and structural equation modeling techniques.

Chapter 2 summarizes the major findings in six sections. The first section discusses large-scale research identifying home factors related to student achievement. The second section describes large-scale research related to students' liking to learn science and students' confidence in their ability to do science, with the third presenting findings related to parents' attitudes towards science. The fourth summarizes pertinent results from TIMSS. In the fifth, the research using structural equation modeling techniques with TIMSS and PIRLS 2011 data to examine relationships between parental education and student achievement is discussed. The last section situates this dissertation research in the context of the international importance of students choosing careers in STEM fields.

2.1 Large-scale Research Identifying Factors Positively Related to Student Educational Achievement

Focusing on students in the United States, Sirin (2005) performed a meta-analysis of 58 studies published between 1990 and 2000 that examined the relationship between socioeconomic status and the academic achievement of over 100,000 students in kindergarten, primary school, and secondary school. Across the 58 studies, parental education was the most commonly used measure of socioeconomic status. Parental education is considered one of the most stable measures of socioeconomic status because "it is typically established at an early age and tends to remain the same over time" (p.419). In the United States, parental education is also often used as an indicator of parental income because the two are highly correlated. A measure of home resources, such as the number of books in the home, also was used as an indicator of socioeconomic status, but it was much less common across the studies included in the meta-analysis. Four different achievement measures were included across the studies. Of the 58 studies, 45 included a measure of general academic achievement, 58 included a measure of verbal achievement, 57 included a measure of mathematics achievement, and 7 included a measure of science achievement.

Sirin performed several analyses of effect sizes. He reported that, across the studies, the mean size of the relation between socioeconomic status and academic achievement was 0.22 for studies reporting a general measure of achievement. However, for science achievement outcomes, the average effect size was 0.27, which was significantly different from the effect size reported for general achievement outcomes. When the studies were organized according to grade level, the mean effect size of the relation between socioeconomic status and student achievement was 0.19 for kindergarten students, 0.27 for students in primary grades, 0.31 for students in lower secondary grades, and 0.26 for students in upper secondary grades. The pairwise comparisons of the results between the four groups were significant, except for the comparison between the effect size for students in primary grades and students in upper secondary grades, indicating a strengthening of the relationship between socioeconomic status and student achievement as students rise through the grades from kindergarten through lower secondary grades.

Another meta-analysis of six longitudinal data sets (Duncan et al., 2007) examined the relationships among children’s academic skills before they began primary school and their later academic achievement. More than 100,000 students from the United States, United Kingdom, and Canada were included across the six studies. The authors used measures of achievement in mathematics, reading, and attention skills taken before students began primary school to predict achievement in mathematics and reading 3 to 8 years later.

The authors found that early literacy and numeracy skills were among the strongest predictors of academic outcomes in later grades. Early literacy skills such as knowing letters and reading words and early numeracy skills such as knowledge of numbers and counting were found to have some of the strongest positive relationships with later achievement across the studies, with the mean effect sizes between 0.40 and 0.50 for both mathematics and reading. The authors noted that early reading achievement was a better predictor of later reading achievement than it was for later mathematics achievement and early mathematics achievement was a better predictor of later mathematics achievement than it was for later reading achievement. The authors also suggested that early reading achievement would likely be a good predictor of achievement in subjects that included a substantial amount of reading as part of later coursework, such as science.

Melhuish, et al. (2008) performed a longitudinal study of 2,600 children in England to investigate the influence of several variables associated with socioeconomic status, including parents' education, and the home learning environment on literacy and numeracy abilities when the children began primary school and again at the end of the third year of primary school. In this context, aspects of the home learning environment included parents reading to children, using complex language with them, and engaging in additional early literacy and numeracy activities with them.

The results of the analyses indicated that the effect size for mothers' education on literacy achievement at the beginning of primary school was 0.35, and 0.33 three years later. The effect size for mothers' education on numeracy achievement at the beginning of primary school was 0.23, and 0.33 three years later, which was a statistically significant increase. These results agree with others found in the literature.

The effect sizes for the home learning environment on literacy and numeracy achievement at both time points were substantially larger. The effect size for home learning environment on literacy achievement at the beginning of primary school was 0.73, and 0.60 three years later. The effect size for home learning environment on numeracy achievement at the beginning of primary school was 0.65, and 0.50 three years later.

The authors concluded that the results supported the importance of the home learning environment in the development of literacy and numeracy skills in young children. They also concluded that early development of literacy and numeracy skills was an important predictor of further development of these skills during the first few years of schooling.

Rideout, Foehr, and Roberts (2010) examined the amount and nature of digital device use among 2,000 children age 8 to 18 in the United States. Between 2004 and 2009, the amount of media time experienced by these children increased to over 7.5 hours per day. Over the same time, internet access in homes increased such that 84 percent of children age 8 to 18 lived in a home with internet access and 59 percent of children age 8 to 18 had access to high-speed internet at home. In 2009, among children age 8 to 18, the average home had 2.0 computers. As more students gained access to high-speed internet at home, they began to spend increased amounts of their day accessing digital content. Students age 11 to 18 reported increased use of digital devices for research into issues that affected themselves or someone they knew.

Rideout et al. found that students who spent more time accessing digital content reported lower grades in their academic subjects, regardless of age. On average, younger students (age 8 to 10) reported the least amount of digital content use compared with students age 11 to 14 or students age 15 to 18.

Gutnick et al. (2011) considered seven large-scale research studies in their review of children's digital device use and media consumption. Although all studies sampled children in the United States, they varied in size from approximately 1,200 to 20,000 participants and the data were collected between 2006 and 2009. The age of the participants varied from 6 months to 18 years across the seven studies.

The authors presented five key findings that support and extend the findings described in Rideout et al. (2010). First, access to digital media continued to increase across all age groups and children of all ages were consuming increased amounts of digital media each day. Second, although the use of digital devices, such as computers, tablets, and e-readers, was increasing, television remained the dominant media delivery system for children, especially children age 8 to 10. Third, access to newer digital technologies was not the same across the socioeconomic spectrum. Children whose parents were of lower socioeconomic status were less likely to have access to newer technologies such as high speed internet connections and e-readers. Paradoxically, these children were found to consume more media than their counterparts in higher socioeconomic status brackets. Fourth, a major shift in media consumption occurred in children around age 8. At this age, there was a shift away from television consumption towards other digital media, such as content accessible via computers, tablets, and to a lesser extent, smartphones. Finally, the authors found evidence of increased use of mobile technologies such as laptops, tablets, and smartphones, even among children as young as age 2 to 3. In young children, especially, use focused on educational content targeted at building literacy and numeracy skills before the beginning of primary school.

A recent review of international research into the complex relationship between socioeconomic status and language development in children (Pace, Luo, Hirsh-Pasek, & Golinkoff, 2017) considered differences in literacy abilities among children from families of different socioeconomic status levels. Pace et al., found evidence that children from low socioeconomic status families consistently performed blow their more advantaged peers on measures of language development at the start of primary school. Furthermore, the gap between the groups persisted as these students advanced through the primary grades and resulted in generally lower achievement across school subjects for the low socioeconomic status group.

Pace et al. identified two important sources of differences in literacy skills at the start of primary school among young students from families of different socioeconomic status levels. First, students whose parents engaged them in literacy activities such as reading books together before they began formal schooling were more likely to have more advanced literacy skills when they began primary school and have higher academic achievement across school subjects. Second, students whose parents provided a well-resourced home learning environment were also more likely to have more advanced literacy skills when they began primary school. A well-resourced home learning environment included access to books in the home as well as access to digital devices for learning, such as computers, tablets, and e-readers.

Tan, Peng, and Lyu (2019) performed a meta-analysis of over 100 international studies published between 2000 and 2017 to examine relationships between variables describing aspects of students' home environment and their achievement in reading, mathematics, and science. The complex analysis included over 500,000 students across the studies and the authors presented their results in terms of educational stages (kindergarten, primary grades, secondary grades).

Tan et al. defined a total of 17 variables to describe students' home environment, including parental education, parental expectations for their children's education, educational resources in the home (e.g., books, digital devices), parent engagement with children in literacy and numeracy activities before the beginning of primary school (e.g., reading books, telling stories, counting, performing simple arithmetic). Across all of the studies included in the meta-analysis, parental education was the most common variable used to describe students' home environment. The authors computed the effect size of each home environment variable on student achievement in reading, mathematics, and science at each educational stage.

Tan et al. found that the mean effect size of parental education on student achievement across school subjects and educational stages was 0.26. The effect size was largest for kindergarten. The authors suggested more educated parents might contribute to the achievement of impressionable young children by communicating high academic expectations for their children and providing home environments that supported learning. The mean effect size of parental expectations for their children's education on student achievement was 0.30. The effect size did not vary significantly across school subjects and educational stages, and the authors suggested that parental expectations were as influential to young students as they were to older students. The mean effect size of educational resources in the home on achievement across school subjects was 0.20 and did not vary significantly across either school subjects or educational stages.

Tan et al. also found that the effect sizes of the variables describing learning activities in the home differed between kindergarten and primary grades. The mean effect size for parents' engaging their children in learning activities at home and academic success across the school subjects was 0.25 for kindergarten and 0.17 for primary grades, and the difference was significant. The authors proposed that the difference was due to the greater impression the home learning environment made on young children. The mean effect size for the specific activity of parent-child reading at home and academic success across school subjects was 0.22 for kindergarten and 0.17 for early primary grades, and this difference was significant also. Tan et al. proposed that the difference was due to a change in reading habits as children grew older and developed their reading skills.

O'Toole, Kiely, McGillicuddy, O'Brien, and O'Keefe (2019) reviewed international research into the relationships between parental engagement in their children's education and children's academic success during primary school. As one key finding, the authors reported that extensive international research indicated that children achieved greater academic success in all subjects when their parents were actively involved with their education. The authors found that the home learning environment was an important factor in facilitating parent-child interactions both before the child began formal schooling and throughout the primary grades. A number of findings indicated a positive relationships between parental engagement in literacy and numeracy activities with their children before the beginning of formal schooling and the academic success of primary school students.

2.2 Large-scale Research Related to Students' Liking to Learn Science and Students' Confidence in Their Ability to Do Science

George and Kaplan (1998) used data from the United States NELS (National Educational Longitudinal Study) to look for ways that parents and teachers influenced students' attitudes towards science. NELS was designed to collect data about "critical transitions experienced by students" (p. 97) as they progress from primary grades to lower secondary grades and into upper secondary grades. Data about educational processes and outcomes were collected through surveys and tests given to students and through surveys given to parents, teachers, and school administrators. The authors used students as the unit of analysis and their final data set included information from approximately 8,000 students, their parents, and their teachers.

George and Kaplan identified parental education and home resources (e.g., books in the home, a computer in the home) as two important predictors of positive student attitudes towards science. The positive student attitudes towards science construct included indicators of students' liking to learn science, considering science a useful endeavor, and considering science useful for their own futures. In George and Kaplan's model, both parental education and home resources had small positive effects on students' attitudes towards science that were statistically significant (0.11 and 0.05, respectively).

Cleaves (2005) researched factors contributing to older students' attitudes towards learning science based on data from a 3-year longitudinal study designed to examine enrollment patterns in science courses of approximately 100,000 secondary school students in England. Cleaves found that upper-secondary school students who enrolled in science courses were confident in their ability to do the coursework and most planned to enter a STEM-related career field. These students valued science and had good STEM role models in their lives. However, students who avoided enrolling in science courses lacked confidence in their ability to do the coursework. These students did not value science or see how science might be a part of their future lives, except as consumers of technology products. Additionally, these students lacked knowledge about science occupations and the work that scientists do.

Saçkes et al. (2011) analyzed data from the United States Early Childhood Longitudinal Study to explore relationships between students' attitudes towards science and their confidence in their science abilities in early primary grades and their science achievement at the end of third grade. The data set used for the analysis included information from approximately 8,700 students, their teachers, and their parents. Using teachers' observations of student participation in and engagement with science activities during kindergarten science lessons to indicate student confidence in their science abilities, the authors found that kindergarten students confident in their science ability had higher science achievement at the end of third grade.

Hasni and Potvin (2015) developed and validated a questionnaire focused on students' interest in science and its relationships with science teaching methods, family context, and science self-efficacy, defined as confidence in one's ability to perform well in science classes and do well in science-related work. The final instrument was administered to approximately 2,000 Canadian students age 10 to 18 (grades 5-11). Hasni and Potvin found a moderately strong relationship between students' interest in science and their science self-efficacy that was present in each grade level, with a mean effect size of 0.33 across the grades.

Sahin, Ekmekei, and Waxman (2018) investigated factors related to upper-secondary students' intentions to pursue a STEM university degree in a longitudinal study of 1,500 upper-secondary school students from the United States. Students age 15 to 19 were surveyed during the spring of each of their four years of upper-secondary school and asked about their intention to pursue a university degree in a STEM field. The authors also collected data related to current course enrollment, family context, and extra-curricular activities and used these variables in logistic regression models to determine the factors that best predicted intended enrollment in a university STEM major.

Sahin et al. found that students who enrolled in science courses throughout their upper-secondary schooling were more likely to intend to major in a STEM subject at the university level. Additionally, they found that the students who consistently enrolled in upper-secondary school science courses were confident in their ability to do the course work, valued science, and enjoyed learning science. These students also engaged in science activities outside of school. Students who were less likely to intend to pursue a university STEM major took only the required science classes at the upper-secondary level, were not confident in their ability to do science coursework, did not value science highly, and did not engage in science activities outside of school.

2.3 Large-scale Research Related to Parents' Attitudes Toward Science

Archer et al. (2012) explored ways that families shape children's engagement and identification with science using data from the United Kingdom's 5-year longitudinal survey exploring science aspirations and engagement among students age 10 to 14. Known as the ASPIRES project, an online survey was administered to a sample of over 9,000 participants at age 10, with repeated administrations to the same sample at age 12 and age 14. Parents were also surveyed as part of data collection.

Archer et al. found that parents' attitudes towards science played an important role in the development of students' aspirations in science and their confidence in their abilities to do science work. Positive parent attitudes towards science were associated with stronger student aspirations in science, explaining approximately 30 percent of the variance in student aspirations in science. Students whose parents did not express positive attitudes towards science were more likely to perceive a career in a STEM field as "unthinkable" (p. 899). The authors also found that parents' educational aspirations for their children influenced the ways that students age 10 and 11 began to think about future careers in science. Students whose parents made their educational aspirations and expectations for their children clear were more likely to begin thinking about a STEM career at age 10 or 11 than students whose parents did not make their aspirations and expectations clear. Parents' educational aspirations and expectations also influenced students' confidence in their ability to do science. Students whose parents made the possibility of a STEM career "thinkable" (p. 899) were more confident in their ability to do science in school.

Sun, Bradley, and Akers (2012) used data from PISA 2006 to investigate factors related to the science achievement of students in Hong Kong SAR. The PISA 2006 Hong Kong SAR sample contained approximately 4,600 students age 15. Students participated in an assessment of science literacy and provided answers to questionnaire items. Questionnaires were also administered to parents of the students and officials at the schools attended by the students. The authors constructed multilevel models to explore the factors that affect student science literacy scores at both the student and school levels. Student-level factors included parental attitudes towards science and student motivation to pursue a career in a STEM field.

Sun et al. found that positive parental attitudes towards science were a positive and significant predictor of Hong Kong SAR students' science literacy scores. The authors also found that parental attitudes towards science were positively correlated with student motivation to pursue a career in a STEM field.

Parera (2014) extended the analysis performed by Sun et al. to students in 15 countries (not including Hong Kong SAR) and focused the multilevel models on three aspects of parental attitudes towards science as predictors of PISA 2006 student science literacy scores: parents' general value of science, parents' personal value of science, and parents' views of the importance of science. Parera constructed three-level models, with country at level 3, school at level 2 and student at level 1. In addition to measures of parental attitudes towards science as predictors at the student level, Parera included measures of socioeconomic status at the student, school, and country levels.

Parera's findings echoed the results in Sun et al. (2012). In each country, parental attitudes towards science was a positive, significant predictor of student science literacy scores. Parera also found that students from families with different levels of socioeconomic status benefitted equally from having parents with more positive attitudes towards science. That is, students from families with higher socioeconomic status do not benefit more by having parents with more positive attitudes towards science than do students from families with lower socioeconomic status.

2.4 Relevant Findings from TIMSS

2.4.1 Parental Education

A positive relationship between parental education and fourth grade students' science achievement, on average internationally, has been regularly reported over the past two decades of TIMSS assessments (e.g., Martin, Mullis, Gonzalez, & Chronstowski, 2004; Martin, Mullis, Foy, & Stanco, 2012). The TIMSS results consistently show that students with parents who reached the highest levels of education, including completing undergraduate and graduate university degrees, had the highest science achievement at the fourth grade. In the TIMSS 2015 data, internationally, students' whose parents had completed at least an undergraduate university degree had an average score on the TIMSS science achievement scale substantially higher (140 points, which represents more than three years of schooling) than students whose parents had not gone beyond upper-secondary education (Martin et al., 2016).

TIMSS 2015 results also indicate positive, albeit small, relationships between parental education and students' scores on the TIMSS 2015 Students Like Learning Science Scale, Fourth Grade and the TIMSS 2015 Students Confident in Science Scale, Fourth Grade.

2.4.2 Parents' Educational Expectations for Their Children

TIMSS 2015 results indicated a positive relationship between parents' educational expectations for their children and science achievement at the fourth grade, on average internationally. Among the countries participating in TIMSS 2015 at the fourth grade, the average correlation between parents' educational expectations for their children and science achievement was 0.32. Additional TIMSS 2015 results indicated positive, but smaller, relationships between parents' educational expectations for their children and fourth grade students' liking to learn science and their confidence in their ability to do science.

2.4.3 Books and Digital Resources in the Home

The number of books in the home has been a strong predictor of student achievement in TIMSS science at the fourth grade since TIMSS 1995 (e.g., Martin et al., 1998; Martin et al., 2004; Martin et al., 2012; Martin et al., 2016). The TIMSS results consistently show that students who had more books in their homes had higher science achievement at the fourth grade. In TIMSS 2015, the average correlations between the number of books in the home and the number of children's books in the home and science achievement were 0.29 and 0.30, respectively, across participating countries.

The number of books and the number of children's books in the home were also positively related to students' liking to learn science and students' confidence in their ability to do science, but the relationships were not as strong as those between the number of books in the home and science achievement at the fourth grade.

New for TIMSS 2015, parents were asked also about the number of digital devices (e.g., computers, tablets, e-readers) in the home and students were asked about the presence of an internet connection in the home. However, the number of digital devices in the home was not a strong a predictor of student achievement in TIMSS science at the fourth grade. In TIMSS 2015, the average correlation between the number of digital devices in the home and science achievement was 0.16.

2.4.4 Learning Activities and Students' Literacy and Numeracy Abilities before Beginning Primary School

For the first time, TIMSS 2011 included home questionnaire for the parents of participating students that asked about early literacy and numeracy activities in the home. There was a positive relationship between science achievement and parents engaging with their children in these activities before the beginning of primary school in both TIMSS 2011 and TIMSS 2015 (Martin et at., 2012; Martin et al., 2016). In TIMSS 2015, internationally, students' whose parents often engaged with them in early literacy and numeracy activities before the beginning of primary school had an average score on the TIMSS science achievement scale 94 points higher (representing approximately three years of school) than students whose parents never or almost never engaged with them in early literacy and numeracy activities before the beginning of primary school (Martin et al., 2016).

In addition, the home questionnaire asked parents about the extent of their child's literacy and numeracy abilities when beginning of primary school. In both TIMSS 2011 and TIMSS 2015 there was a positive relationship between parents' reports of more literacy and numeracy abilities and students' higher science achievement at the fourth grade (Martin et al., 2012; Martin et al., 2016). In TIMSS 2015, internationally, students who could do literacy and numeracy tasks very well when they began primary school had an average score on the TIMSS science achievement scale approximately 69 points higher (approximately two years of school) than students who could not do literacy and numeracy tasks well when they began primary school (Martinet al., 2016).

2.4.5 Parental Attitudes towards Science

TIMSS 2015 data showed a small positive relationship between parents' attitudes towards mathematics and science and fourth grade students' science achievement, on average internationally. Additionally, parents' attitudes towards mathematics and science had small positive relationships with students' liking to learn science and students' confidence in their ability to do science.

2.5 Using Structural Equation Modeling Techniques to Examine Relationships between Parental Education and Student Achievement

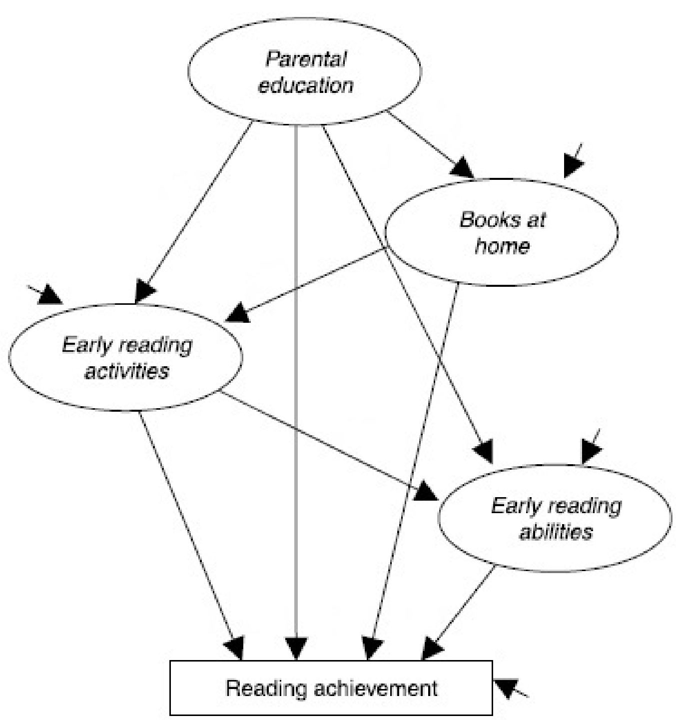
Working with PIRLS 2001 data, Myrberg and Rosén (2009) used Cultural Capital Theory (Bourdieu & Passeron, 1990; Bourdieu, 1986) as a theoretical framework and structural equation modeling procedures for analysis to identify a chronology of relationships by which parental education influenced reading achievement in Sweden. The authors identified parental education and student reading achievement as two important expressions of cultural capital in families. Using PIRLS 2001 measures for parental education and student reading achievement as an independent variable and an outcome variable, respectively, the authors identified three additional elements of cultural capital measured by PIRLS 2001 as potential mediators of the relationship between parental education and reading achievement:

- The number of books at home, measured by the number of books and the number of children's books in the home

- Early reading activities parents participated in with their child before they entered primary school, measured by the frequency parents read books with the child and told stories to the child

- Early reading abilities of the child, measured by how well the child could recognize letters of the alphabet, read some words, and read some sentences before the beginning of primary school

Exhibit 2.1: Structural Mediation Model to Explain the Relationship between Parental Education and Reading Achievement for Swedish Students in PIRLS 2001



Myrberg and Rosén’s (2009) mediation model is shown in Exhibit 2.1. There are several possible indirect paths identified between *Parental education* and *Reading achievement* in the model that go through one or more of the mediating variables. For example, one indirect path goes from *Parental education* to *Early reading abilities* to *Reading achievement*. Another path goes from *Parental education* to *Early reading activities* to *Early reading abilities* to *Reading achievement*. Each possible path from *Parental education* to *Reading achievement* was analyzed and evaluated.

The results of the analysis of the direct, indirect, and total effects showed that there was a strong relationship between *Parental education* and *Reading achievement* mediated by *Books at home*, *Early reading activities*, and *Early reading abilities*. Well-educated parents had more books in their homes, engaged their children in more literacy activities before they began primary school, and these children, logically, were more likely to have stronger reading skills when they began primary school, and had higher achievement in reading when measured by PIRLS in fourth grade.

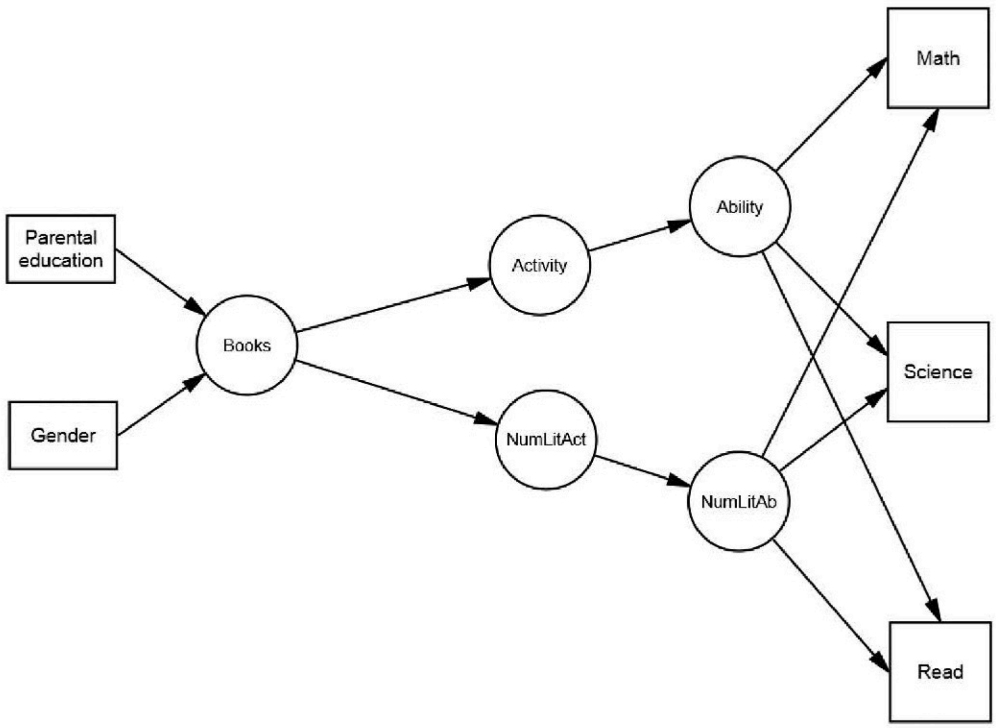
Myrberg and Rosén constructed their model to explain the relationship between one independent variable (*Parental education*) and one outcome variable (*Reading achievement*) in one country. Gustafsson et al. (2012) were able to leverage the work that went into developing the Myrberg and Rosén (2009) model and use the same techniques on data from TIMSS and PIRLS 2011 to explain the relationship between two independent variables (*Parental education* and *Gender*) on three achievement outcome variables (*Math*, *Science*, and *Reading*) in many countries.

In 2011, mathematics and science data collection for TIMSS coincided with reading data collection for PIRLS. In TIMSS and PIRLS 2011, for the first time, the original PIRLS questionnaire for parents asking about students' home environment and home supports for learning reading was expanded to include mathematics and science, providing home context data together with achievement data in mathematics, science, and reading for the same fourth grade students in a large number of countries. Taking advantage of the joint administration of TIMSS and PIRLS in 2011, Gustafsson et al. (2012) extended Myrberg and Rosén's previous work (2009) to 37 countries and three subject areas—fourth grade mathematics, science, and reading. The main purpose of their expanded approach was to examine two sets of relationships in the TIMSS and PIRLS 2011 data:

1. The extent to which parental education and the gender of the student influenced the student's achievement in mathematics, science, and reading internationally
2. The mediating effects of books in the home, parents engaging their child in literacy and numeracy activities before they entered primary school, and the child's ability to perform literacy and numeracy tasks when they began primary school on the relationship between parental education and the gender of the student and the student's achievement in mathematics, science, and reading

Based on Myrberg and Rosén's earlier results (2009), Gustafsson et al. theorized that the structural mediation model shown in Exhibit 2.2 below would best account for the relationships between parental education and gender and achievement in mathematics, science, and reading present in the TIMSS and PIRLS 2011 data.

Exhibit 2.2: The TIMSS and PRILS 2011 Common Model (Gustafsson et al., 2012, p. 200).



In the TIMSS and PIRLS 2011 Common Model, there are two independent variables, *Parental education*, indicating the level of education parents have attained and *Gender*, indicating the gender of the student. The three outcome variables in the model, *Math*, *Science*, and *Read* are achievement scores in fourth grade mathematics, science, and reading from TIMSS and PIRLS 2011.

Between the independent and outcome variables, Gustafsson et al. (2012) hypothesized a set of chronologically arranged mediators to account for the relationship between *Parental education* and *Gender* and student achievement, similar to those proposed previously in Myrberg and Rosén (2009):

- Literacy resources in the home, measured by the number of books and the number of children's books in the home

- Early numeracy and literacy activities in the home before the child entered primary school, measured by two TIMSS and PIRLS 2011 background context scales, TIMSS 2011 Early Numeracy Activities Before Beginning Primary School, Fourth Grade (6 items) and PIRLS 2011 Early Literacy Activities Before Beginning Primary School (9 items)
- The child's abilities in performing numeracy and literacy tasks at the beginning of primary school, measured by two TIMSS and PIRLS 2011 background context scales, TIMSS 2011 Could Do Early Numeracy Tasks When Began Primary School, Fourth Grade (6 items) and PIRLS 2011 Could Do Early Literacy Tasks When Began Primary School (5 items)

Two additional mediators (*NumLitAct* and *NumLitAb*) were included to describe the relative frequency of numeracy and literacy activities in the home and the child's ability to do numeracy tasks better than literacy tasks before the beginning of primary school.

The TIMSS and PIRLS 2011 Common Model represents the hypothesis that parental education and the gender of the student influence the application of family resources towards making books available in the home. The availability of books influences both the general level of numeracy- and literacy-oriented learning activity and the relative emphasis of numeracy or literacy activities before the beginning of primary school, which in turn influence the student's school-oriented abilities at the start of primary school. These abilities in turn influence students' achievement in fourth grade mathematics, science, and reading.

The results of the analysis of the direct, indirect, and total effects brought many interesting relationships to light. Three were of importance in the context of this dissertation research:

1. The relationship between parental education and student achievement in science was mediated via two paths: *Books—Activity—Ability—Science* and *Activity—Ability—Science*, with the latter path bypassing *Books*

2. Internationally, *NumLitAct* and *NumLitAb* did not have a direct relationship with science achievement and the path from *Parental education* to *Science* that contained *NumLitAct* went through *Ability* (*Parental education—Books—NumLitAct—Ability—Science*); the implication was that an emphasis on literacy activities in the home was associated with higher reported levels of numeracy and literacy abilities when students entered primary school, which had a positive effect on achievement

3. There was no direct relationship between *Gender* and any of the student achievement variables internationally, so all of the effect of *Gender* on science (and mathematics and reading) was accounted for by mediating variables

   Gustafsson et al. concluded that their model, while bringing to light important mechanisms by which parental education and gender influence the achievement of fourth grade students, did not fully explain the relationship between home context and achievement. The authors offered several specific suggestions for extending and refining their work, including incorporating more of the information collected from parents and students into the model to expand the explanation (e.g., including parent and student attitudes towards mathematics, science, and reading).

2.6 The STEM Pipeline in an International Context

The ever-increasing pace of scientific and technological advancement has brought increased international attention to the educational pathway for students in the fields of science, technology, engineering, and mathematics. Known as the STEM pipeline, this pathway often begins at home and then is subsequently nurtured through each step of students' educational careers.

2.6.1 Countries' Policies to Encourage STEM Careers

Countries are concerned about the flow of students through the pipeline, because the number of individuals pursuing STEM careers at the end of the pipeline is not sufficient to meet the increasing demand for qualified STEM professionals. For example, a recent report from the Committee on STEM Education of the National Science and Technology Council of the United States (Executive Office of the President, 2018) indicated that the number of job openings in the U.S. in STEM fields is growing at a rate faster than in most other fields, and the demand continues to consistently outpace the supply of trained workers to fill the positions.

Internationally, the imbalance in the supply and demand of skilled labor in STEM fields in OECD member countries dates from the 1980s (Cervantes, 1999). As part of an extensive analysis of science and technology labor markets, Cervantes examined trends in the supply of university graduates in natural science and engineering as a percentage of university graduates in all fields. Two important findings emerged. First, in most of the countries included in the analysis, fewer than 10 percent of all university graduates earned a degree in one of the natural sciences and fewer than 15 percent earned an engineering degree. Second, in some OECD member countries, such as Canada, Finland,

and Japan, the rate at which undergraduates obtained degrees in these STEM fields stagnated between 1985 and 1995, especially in engineering. In other member countries, including New Zealand, Turkey, and the United States, the rate decreased substantially.

Cervantes also examined trends in demand for well-trained workers in STEM fields and reported four key findings. First, a steep increase in STEM-related job creation occurred during the late 1980s and early 1990s. Second, these new jobs were created in areas of the economy outside of traditional STEM fields (e.g., basic research, engineering, natural science, and medical research). Instead, across OECD countries, a large percentage of newly graduated and employed STEM workers entered service sectors of the economy, such as software development, data processing, and telecommunications services. In Japan, the United Kingdom, Germany, and the United States, for example, more STEM-qualified researchers were employed in the business sector than in traditional STEM positions. Third, these new STEM-related service jobs required additional skills and qualifications beyond what is usually acquired during a traditional STEM course of study at the university level. Finally, employment rates among qualified STEM graduates were generally over 90 percent, and in some OECD member countries, close to 100 percent, indicating that these workers were in high demand. These extremely high employment rates indicated a need to increase supply.

Cervantes concluded that, as knowledge-based economies continued to grow and develop and more jobs for STEM-qualified workers were created, the lack of well-trained workers could stifle innovation in science and technology. Cervantes recommended that OECD member countries consider carefully the education and training required to produce qualified, employable STEM professionals and work to establish and cultivate programs and policies to encourage participation in STEM fields. The conclusions and recommendations remain relevant today (Executive Office of the President, 2018).

Marginson et al. (2013), conducted a cross-national study of the STEM pipelines in two dozen countries, including a number of developed economies such as Canada, Finland, France, the Republic of Korea, Portugal, Russia, Singapore, and Sweden. Governments in economically developed countries were universally paying attention to students' STEM participation, especially in secondary and tertiary education. But, there were different approaches. East Asian countries and Singapore, where STEM excellence has been well-established as a priority, reported on ways of encouraging the most capable students to pursue STEM studies. For example, scholarships and other awards were available for highly qualified students who committed to STEM tracks in secondary and tertiary education. In comparison, many western European countries focused on initiating policies to increase the amount and quality of STEM coursework available to students, beginning with STEM coursework in the early primary grades. They also provided teachers with supplementary training in teaching STEM subjects throughout the students' school years. The underling logic was that if teachers improved STEM instruction, more students would develop a sustained interest in STEM subjects and pursue them as careers.

Marginson, et al. also reported widespread evidence of concerns about shortages of workers with STEM-related skills in the labor markets among the countries studied. However, they noted that many of the reported labor market shortages were in occupations that are generally not considered STEM fields, such as professional services, computing services, and communications. Although these employment sectors are not generally considered STEM fields, internationally, employers seek STEM-trained candidates to fill these jobs. Marginson et al. also reported evidence of continued increase in demand for well-trained workers in key STEM and STEM-related sectors of the economy in the European Union, the United States, and East Asian countries between 2010 and 2020. In some countries, the ten-year increase in demand in areas such as mechanical engineering was expected to be 5.5 percent and demand in professional services was expected to increase by almost 14 percent.

Freeman et al. (2015) edited a volume of 13 invited country-level reports on national policies and practices aimed at enhancing STEM labor markets (including TIMSS 2015 participants Chinese Taipei, Japan, the United States, Canada, the United Kingdom, Australia, New Zealand, France, Finland, the Russian Federation, and South Africa). Each country report began with the premise that growth in STEM-related research and innovation in the university/government and private sectors was a national priority. The majority of the reports indicated the inadequate supply of qualified STEM professionals entering the STEM-related sectors of the workforce did not satisfy the demand of the organizations and firms looking to employ them. Most reports indicated that STEM university graduates had higher overall employment rates than average university graduates and reiterated that there were large numbers of job vacancies in most STEM and STEM-related fields.

The range of programs and policies in place to increase the availability of STEM professionals varied across the countries' reports (Freeman et al., 2015). Countries such as the United Kingdom, Canada, Germany, and France enacted policies intended to encourage students to choose STEM studies and enter the STEM labor force. China, Chinese Taipei, Japan, and Korea took a different approach and focused on detailed longterm plans and enacted policies to enhance research and development as well as innovation. In these countries, increased collaboration between education and industry, especially at the university level, was designed to produce well-qualified STEM graduates immediately ready to contribute to research and innovation in their fields. A third approach was evident in Brazil and South Africa. In these countries, policies were designed to improve the overall quality of education and develop the industry and technology sectors. However, despite the concerted efforts of governments, businesses, and colleges and universities, the output of the STEM pipeline continues to disappoint.

2.6.2 Student Characteristics that Predict Entry into STEM Careers

Research has identified important student characteristics that predict successful exits from the STEM pipeline into STEM careers internationally. For example, Tytler and Osbourne (2012) reviewed international research considering the relationships between student attitudes and aspirations towards science and later employment in STEM fields. The authors considered how students' in interest in science evolved as they progressed through schooling from the primary grades to lower secondary grades to upper secondary grades and on to tertiary education. At age 10, when students were at approximately the fourth grade of primary school, interest in science was high regardless of students' level of achievement in science. By age 14, students' interest in pursuing a STEM career had mostly solidified. Students who, at age 14, had expectations of pursuing a STEM career were more than three times more likely to earn a physical science or engineering degree than students whose interest in science had declined by age 14. Additional research into the reasons STEM practitioners entered their respective fields revealed that a majority first began to consider a STEM-related career path between the ages of 11 and 14—at the same time that their interest in science became established. Tytler and Osbourne found a consensus in the research that positive attitudes towards science and towards learning STEM subjects in primary grades catalyzed students into pursuing advanced STEM studies and, ultimately, careers in STEM-related fields.

Tytler and Osbourne reported that students' confidence in their ability to "do" science emerged from the research as an additional important factor in predicting participation in STEM-related careers. As students advanced through science school subjects, those students who had higher confidence in their ability to do science continued to increasingly advanced coursework in science, especially in the physical sciences. Once these students reached post-secondary science coursework, they were also much more likely to earn STEM degrees and enter STEM careers. The authors identified additional, related research that considered the combined effects of students' confidence in their ability to do science, students' understanding of the work of scientists, and students' having good STEM role models on their STEM career choices. They reported evidence that these three factors worked together to influence students' choices to enter STEM careers. Students who had good STEM role models (especially if the role model was also a parent), understood the work that a STEM career entailed, and were confident in their ability to do that work were much more likely to pursue a STEM career.

Tytler and Osbourne also reviewed research relating parent characteristics to students' ultimate pursuit of careers in STEM fields. They reported findings that indicated that students whose parents valued formal schooling and valued the work of STEM practitioners were more likely to pursue STEM careers than students whose parents did not hold these beliefs. They noted, however, that the relationship between parents' values and students' choices was not necessarily straightforward. Advice from parents and other adult role models was found to be more important to students in primary grades than to students in upper secondary grades. Parent or family socioeconomic status was also found to have a strong relationship with students' choices to pursue STEM careers. A large amount of reported evidence suggested that students who persisted in STEM studies at an advanced level and ultimately entered STEM careers were more likely to come from households with higher socioeconomic status.

Wang and Degol (2013) reviewed research on more than two dozen factors shown to influence students' STEM-related choices and then considered characteristics of individuals who successfully navigated the STEM pipeline and pursued careers in STEM fields. The authors described success as being based on "a series of choices and achievements that commence in childhood and adolescence" (p. 2) and identified three major factors contributing to success.

First, confidence in STEM competence was shown to be an important predictor of student choices leading to a STEM-related career. Individuals who gave themselves higher ratings in STEM competence were more likely to enroll in advanced STEM courses, choose a STEM-related course of study at the university level, and enter a STEM field after graduation. Wang and Degol reported evidence that confidence in STEM competence was a necessary but not sufficient predictor of positive STEM pipeline and STEM career choices. Capability alone did not always predict active engagement in STEM course-taking at the university level or taking up a STEM career after graduation. The evidence suggested that students who did not consider themselves capable of pursuing a STEM career sought to limit their engagement with science in academic settings.

Second, Wang and Degol presented evidence that interest in STEM subjects during primary schooling was associated with academic engagement in STEM subjects later in schooling, including at the university level. As was the case with confidence in STEM competence, interest in STEM subjects in school did not always predict a complete path through the STEM pipeline into a STEM career. The evidence pointed to additional factors, such as valuing STEM, understanding the work a STEM career entails, and good STEM role models, interacting with an interest in STEM subjects to produce an individual most likely to enter a STEM career.

Third, Wang and Degol detailed a substantial number of findings asserting the importance of the role that the family and home environment played in shaping individuals' choices at each stage along the STEM pipeline. For example, individuals who were motivated to make choices supporting a STEM career trajectory were more likely to have highly educated parents and come from highly resourced families. The parents of these individuals were also more likely to engage in high quality educational interactions with them at home. Parents' beliefs about the value of education also played a role. Individuals whose parents expected them to attain the highest levels of education were more likely to pursue both university degrees in STEM subjects and careers in STEM fields. Parents' beliefs about the value of STEM subjects contributed to students' STEM-related decision-making. Individuals whose parents valued STEM subjects tended to express an interest in these subjects, like learning them, and have confidence in their abilities to do STEM-related work.

Van Tuijl and van der Molen (2016) reviewed international research related to influences on students' choices to study STEM subjects in school, a necessary precursor to pursuing a STEM career. The authors found evidence that the choices to study STEM subjects at an advanced level were rooted in early childhood experiences. They identified three important and interrelated factors in the body of research that had been shown to play important roles early in students' STEM pipeline trajectories. Knowledge of STEM fields and the work of STEM practitioners was identified as the first factor; students began to define themselves in terms of future occupations early in their schooling. Van Tuijl and van der Molen reported evidence that students as young as fourth grade began shaping their expectations for later careers. They presented additional evidence that increasing students' exposure to authentic STEM activities and broadening students' views of STEM fields resulted in an increased likelihood that students would begin to consider STEM careers.

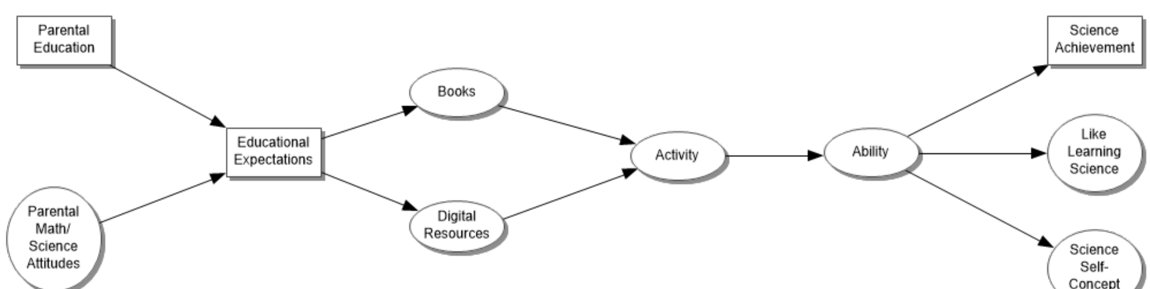
The second factor that emerged from the research involved students' attitudes towards STEM subjects and their perceptions about their suitability to study STEM subjects. Students who showed positive attitudes towards STEM subjects were much more likely to enter the STEM pipeline. However, Van Tuijl and van der Molen indicated that some of the most significant barriers to students' entry into the STEM pipeline resulted from ingrained negative stereotypes (e.g., only boys should study science, math and science are for "nerds"). Additional evidence indicated that it was possible to overcome these negative STEM stereotypes among students, especially if the work began in the early primary grades.

The third factor that Van Tuijl and van der Molen identified in the literature was related to students' beliefs about their abilities in STEM subjects. Students who were confident that they could learn to do the work of a STEM practitioner as they progressed through their science coursework in school were more likely to continue to take STEM courses. The authors reported evidence that introducing formal STEM course work early in the primary grades was positively related to students developing confidence in their abilities to do STEM-related work later in schooling.

Chapter 3: Methods of Analysis

This dissertation research uses structural equation modeling techniques to describe how students' home context can influence their academic success in science at the fourth grade. The research reviewed in Chapter 2 provided insight into important parental characteristics and home context factors that can influence increased student achievement and positive attitudes towards learning and doing science. The proposed Parental Influence on Student Outcomes in Science Model, shown as a simplified schematic in Exhibit 3.1 below, is a path model describing how these parental characteristics and home context factors may work in concert to influence student outcomes in science.

Exhibit 3.1: Schematic of the Proposed Parental Influence on Student Outcomes in Science Model



Research indicates that three important predictors of entry into STEM careers are students' academic achievement in science, positive attitudes towards learning science and confidence in their ability to do science. These constructs are represented as outcomes at the far right of the hypothesized path model shown in Exhibit 3.1 (*Science Achievement*, *Like Learning Science*, and *Science Self-Concept*). At the far left of the hypothesized path model, two main predictors of the student outcomes, parents' educational attainment and parents' attitudes towards mathematics and science, are shown (*Parental Education* and *Parental Math/Science Attitudes*). In the middle of the model, additional variables describing students' home context that have been shown to have positive relationships with the student outcomes are arranged chronologically to indicate how the parent predictors are hypothesized to influence the student outcomes (*Educational Expectations*, *Books*, *Digital Resources*, *Activity*, and *Ability*).

The model shown in Exhibit 3.1 represents the hypothesis that *Parental Education* and *Parental Math/Science Attitudes* influence parental *Educational Expectations* for the child, and these educational expectations in turn influence the extent to which parents make *Books* and *Digital Resources* available to their child in the home, which influences the general level of educational *Activity* in the home before the child begins primary school, which then influences the child's academic *Ability* at the start of primary school, and the child's general level of ability at the start of primary school influences later achievement in fourth grade science as well as how well the student *Likes Learning Science* and their *Science Self-Concept* in terms of how confident they are in their ability to do science. Data from TIMSS 2015 will be used to construct the variables included in the path model and test the hypothesis represented by it.

3.1 Data Source: The TIMSS 2015 International Database

TIMSS assesses students at the fourth and eighth grades every four years in mathematics and science and, less regularly, students at the twelfth grade in advanced mathematics and physics. Given the international interest in student flow through the STEM pipeline at all stages of education, any one of the TIMSS science or TIMSS physics data sets would be a good candidate for analysis. However, information from parents about their attitudes and the home context is only gathered for students participating in TIMSS at the fourth grade. As the review of the literature indicates, home background factors influence students' science achievement, their liking to learn science, and their confidence in their ability to do science. This trifecta of student characteristics together are important predictors of students' entry into and successful exit from the STEM pipeline into employment in a STEM field. Most research into the factors that predict the successful development of STEM-qualified professionals have focused at the top of the pipeline (upper secondary or tertiary education). Little research has been done with students the foundational primary grades to model the "inputs" that students bring with them as they advance into more systematic science study in the lower secondary and then upper secondary grades. Therefore, the TIMSS 2015 fourth grade science data set was chosen for this analysis. At the time this dissertation was written, the TIMSS 2015 data set was the most recently published.

3.1.1 TIMSS Grade 4 Science Achievement Data

Information about student achievement in science at the fourth grade will come from students' responses to the TIMSS 2015 science assessment items. Similar to other large-scale assessments, TIMSS uses item response theory scaling with latent regression to estimate student achievement (von Davier & Sinharay, 2014). This approach uses all available data (students' responses to their TIMSS 2015 science assessment items as well as all of the background data obtained from the students and their parents as part of TIMSS 2015) to estimate the characteristics of the student population. Then, five random draws are made from the estimated ability distribution for each student. These five separate estimates of science achievement (plausible values) are available for each fourth grade student from the TIMSS 2015 International Database (TIMSS and PIRLS International Study Center, 2016) and will be used in the analyses.

3.1.2 TIMSS Grade 4 Background Data

Information about students' contexts for learning science at the fourth grade will come from responses to context questionnaires administered to students and their parents.

The TIMSS 2015 Student Questionnaire, Fourth Grade (IEA, 2016b) asks about aspects of students' lives at home and in school. Students provide basic demographic information and answer questions about their home environment, attitudes towards science, confidence in their abilities to do science, and school learning environment.

The TIMSS 2015 Home Questionnaire (IEA, 2016a) for the parents and caregivers of the fourth grade students taking the TIMSS 2015 assessment asks about students' home context. Parents provide information about their engagement in early literacy and numeracy activities with their child, their child's literacy and numeracy abilities when they began primary school, their own attitudes towards reading, mathematics, and science, their education and occupation, and the availability of resources related to learning in their home.

3.1.3 Countries Included in the Analysis

TIMSS 2015 data from 36 countries and 174,485 students and their parents will be used in this dissertation research. Exhibit 3.2 lists the countries that will be included in the analyses.

Exhibit 3.2: TIMSS 2015 Countries Included in the Analysis

Armenia	Denmark	Italy	Qatar
Bahrain	Finland	Kazakhstan	Russian Federation
Belgium (Flemish)	France	Korea, Rep. of	Saudi Arabia
Bulgaria	Georgia	Kuwait	Serbia
Chile	Hong Kong SAR	Lithuania	Singapore
Chinese Taipei	Hungary	Morocco	Slovak Republic
Croatia	Indonesia	Oman	Spain
Cyprus	Iran, Islamic Rep. of	Poland	Sweden
Czech Republic	Ireland	Portugal	Turkey

Although TIMSS 2015 included 47 countries and 7 benchmarking participants at the fourth grade, eleven countries and the seven benchmarking participants have been excluded from the analysis. The benchmarking participants will not be included because this research focuses on results at the country level and the benchmarking participants are not countries. The eleven countries are not included due to lack of background data from the Home Questionnaire, high missing data rates for one or more variables included in the proposed model, or disproportionately large sample sizes.

The data collected during TIMSS 2015 from each participating country are publically available for researchers to download from the TIMSS 2015 International Database. The database contains the TIMSS 2015 student achievement data files and context questionnaire data files for each country separately. All countries gave permission for their data to be released publically.

3.1.4 Assembly of the Master Data Set

For this dissertation research, the publicly available fourth grade data files will be downloaded from the TIMSS 2015 International Database and will be used for all analyses. Three types of data files will be used: the student science achievement data files containing the five plausible values estimated for each fourth grade student as described previously, the context questionnaire data files containing the students' responses to the TIMSS 2015 Student Questionnaire, Fourth Grade, and the context questionnaire data files containing parents' responses to the TIMSS 2015 Home Questionnaire for each student. The data contained in the TIMSS 2015 International Database files do not include individually identifiable information. Within the data files, all student names have been replaced with identification codes and these codes have been scrambled. Further, in the publicly available database, all variables that could be used to identify the participants have been removed.

All of the analyses related to this dissertation research use a single master data set constructed from the publically available TIMSS 2015 data files downloaded from the TIMSS 2015 International Database for each of the 36 countries listed in Exhibit 3.2 above. The master data set was constructed in three steps.

First, the IEA IDB Analyzer v. 4.0 (IEA, 2017), a data management and analysis tool, was used to select the variables for the analyses from among the TIMSS 2015 achievement and background variables available in each of the individual country database files. Additional variables such as country and student identification codes and sampling weight variables were also included. The resulting data file contained 72 variables with data from 174,485 students.

Next, a missing data analysis was performed on the background variables. The data from each country was considered separately in this analysis. Missing data rates for each of the variables in each country and overall missing data rates are provided in Appendix C. Among the variables from the TIMSS 2015 Home Questionnaire, the average overall missing data rate was 8.2 percent across all 36 countries. The Home Questionnaire variables with the highest missing data rates were Parental Education (9.5 percent missing) and Parents' Educational Expectations for their Children (9.3 percent missing). The missing data rates were much lower among the variables from the TIMSS 2015 Student Questionnaire, Fourth Grade. The average overall missing data rate was 3.2 percent among these variables.

Although the overall missing data rates for the background variables were less than 10 percent across the 36 countries, the missing data rates for the background variables within each country were much more variable. For example, in Korea 13.6 percent of students were missing data for one or more variables, while 41.6 percent of students in Sweden and 72.0 percent of students in Georgia were missing data for one or more variables. For some countries the missing data rates were also much higher for some variables than others, as indicated in the exhibits in Appendix C. Missing data can bias parameter estimates. For this reason, multiple imputation was used to produce a final data set with no missing data. The process used the existing observed data to predict values for the instances of missing data.

Multiple imputation was performed in IBM SPSS Statistics (Version 25) using the Markov Chain Monte Carlo (MCMC) algorithm. The MCMC algorithm works iteratively to incorporate both observed data and already imputed data into predictions for subsequent imputations. The prediction equation for the multiple imputation analyses included each of the 59 background variables from the TIMSS 2015 Home Questionnaire and TIMSS 2015 Student Questionnaire, Fourth Grade and the five variables associated with the plausible values of science achievement. Sampling weights were incorporated into the prediction equation also. The imputation analysis was conducted separately for each country in recognition that the patterns of response to the questionnaires differed among the countries. Once all of the background data was imputed, the data set contained no missing data. Descriptive statistics for the complete data set are presented in Appendix B.

As a third step, four copies of the complete background data were generated, for a total of five identical files. Then, each of the five files was paired with one of the five plausible values measuring science achievement. The master data set consisted of these five files which have the same set of values for each of the background variables and differ only by the estimate of science achievement for each student. All of the analyses will be conducted with these five files using Rubin's (1987) method for combining parameter estimates across plausible values and generating a single estimate of the standard error.

3.2 Establishing a Base Model from Previous Research

As a first step in the process of analyzing the proposed model, a preliminary Base Model was created and analyzed using the master data set. This preliminary analysis demonstrated proof-of-concept for the structural equation modeling techniques planned for analyzing the more complex proposed model. The Base Model included a subset of the variables in the proposed Parental Influence on Student Outcomes in Science Model and was based on the mediation model for TIMSS and PIRLS 2011 data described in Chapter 2.

3.2.1 Variables Included in the Base Model

The variables in the Base Model come from the TIMSS 2015 Home Questionnaire for parents, the TIMSS 2015 Student Questionnaire, Fourth Grade and the students' TIMSS 2015 science achievement at the fourth grade. The questionnaire items and their response spaces are shown in Appendix A.

The Base Model includes one independent variable, *Parental Education*, and one outcome variable, *Science Achievement*.

- *Parental Education* is defined as the highest level of education of either parent.

- *Science Achievement* is the student's science achievement score, represented by five plausible values.

There are three latent variables included as mediating variables in the Base Model: *Books, Activity,* and *Ability*.

- *Books* is a latent variable with two observed variables as its indicators, the number of books in the home (X_1) and the number of children's books in the home (X_2).

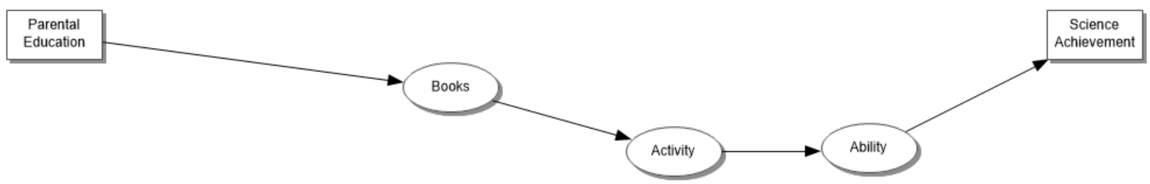
- *Activity* is a latent variable with the 16 variables representing the items from the TIMSS 2015 Early Literacy and Numeracy Activities Before Beginning Primary School Scale, Fourth Grade (Martin et al., 2016, pp. 15.28-15.32) (X_3 ... X_{18}) as its indicators.

- *Ability* is a latent variable with the 11 variables representing the items from the TIMSS 2015 Could Do Literacy and Numeracy Tasks When Began Primary School Scale, Fourth Grade (Martin et al., 2016, pp. 15.25-15.27) (X_{19} ... X_{29}) as its indicators.

3.2.2 The Structural Model Describing Hypothesized Relationships in the Base Model

The structural model for the Base Model shown in Exhibit 3.3 replicates an explanation for the relationship between parental education and science achievement represented by the mediation model for TIMSS and PIRLS 2011 data described in Chapter 2.

Exhibit 3.3: Schematic of the Base Model



The Base Model reflects a chronologically arranged pattern of relationships among variables describing how the relationship between parents' education and student academic achievement at the fourth grade is mediated by the availability of books in the home, learning activities parents engaged in with their children before the beginning of primary school, and the school-oriented abilities of children at the beginning of primary school. The Base Model represents the hypothesis that the level of parents' education (*Parental Education*) influences the extent to which literacy materials (*Books*) are available in the home, which, in turn, influences the general level of educational activity (*Activity*) in the home before the child begins primary school, which influences the child's literacy and numeracy abilities (*Ability*) at the start of primary school, which then influences the child's later achievement in fourth grade science (*Science Achievement*).

The schematic of the Base Model shown in Exhibit 3.3 shows only the observed *Parental Education* and *Science Achievement* variables together with the three latent mediating variables (*Books*, *Activity*, and *Ability*). The observed indicators of the latent variables were omitted for clarity. The schematic also shows only a small subset of the relationships among the variables, again for clarity. The Base Model estimated in the preliminary analysis was a "saturated" mediation model in which the relationship between each variable in the model and every other variable to the right of it was measured. For example, in addition to the relationships shown by the arrows in the schematic, the relationships between *Parental Education* and *Books*, *Activity*, *Ability*, and *Science Achievement* were measured; the relationships between *Books* and *Activity*, *Ability*, and *Science Achievement* were measured; and so on. Estimating the saturated mediation model provides the information needed to determine the total, direct, and indirect effects among the variables present in the model.

3.2.3 Estimation of the Base Model

The model estimation process for the Base Model followed the general approach taken by Gustafsson et al. (2012) using the master data set. The pooled TIMSS 2015 fourth grade science data from all 36 countries was used to estimate an international version of the Base Model. Mplus v. 8.4 (Muthén & Muthén, 2019) latent variable modeling software was used to estimate model parameters. *Mplus* is well suited to modeling TIMSS data because it can take into account the nested structure of the data (i.e., students nested in countries) and the five plausible values estimated for the science achievement of each student.

Two-level estimation techniques available in Mplus were used to estimate the Base Model, with country as the between-level (Level 2) and students within each country as the within-level (Level 1). The two-level approach was used to eliminate differences among the country means. A saturated model (variances and covariances among the variables only) was estimated at the country level (Level 2) and the saturated mediation path model was estimated at the student level (Level 1). Each variable except *Science Achievement*, the outcome variable, was grand mean centered in the analysis.

Several features of Mplus in addition to two-level estimation techniques were employed to estimate the Base Model. Maximum likelihood with robust standard errors (MLR) estimation was used to correct for the underestimation of standard errors that results from deviations from multivariate non-normality in the data. The properties of the MLR estimator and the low levels of kurtosis present in even the binary variables allowed all of the variables to be treated as continuous in the analysis. Because of the complex sampling procedures used in TIMSS, sampling weights are included in the analysis, and individual students have the TIMSS 2015 HOUWGT applied to their data. For each student, a sampling weight is calculated that is the inverse of the selection probability of that student, taking into account the probability of selection for each school, classroom, and student participating in TIMSS 2015 and adjusted for nonresponse. HOUWGT is scaled such that the weighted sample corresponds to the actual sample size in each country. The clustering of students within schools was not explicitly modeled in this analysis. While it is possible to construct three-level models with students clustered in schools and schools clustered in countries, the increased complexity would results in substantial challenges for estimation and interpretation. Finally, the five plausible values of science achievement are used for each student. During the analysis, Mplus performed the estimation steps five times, once for each plausible value, and then averaged the results while accounting for the imputation variance in the standard errors (Schafer & Olsen, 1998).

3.2.4 Results of the Base Model Estimation

3.2.4.1 Overall Model Fit

Model estimation terminated normally in Mplus. When evaluating the overall fit of a structural equation model, generally the chi-square test of overall model fit is the first consideration. As expected for a model estimated from such a large data set, the chi-square test was significant ($p < 0.000$), with a mean of 31791.29 (df = 426) across the five estimates and a standard deviation of 352.06. Strictly speaking, a significant chi-square test should lead to a rejection of the model as not fitting the data. However, the chi-square test statistic is extremely sensitive to large sample sizes, and a data set such as this with 174,485 cases would return a significant result regardless of the actual differences between the observed and predicted covariance matrices.

Mplus also provides estimates of fit indices that are least sensitive to large sample sizes. Root Mean Square Error of Approximation (RMSEA) and Standardized Root Mean Square Residual (SRMR) are both appropriate indices to use to evaluate the fit of models to large data sets. RMSEA is a measure of the degree of deviation between the model and the data that accounts for both the sample size and the complexity of the model. Models that fit the data well have RMSEA values below 0.05. The Base Model has a mean RMSEA estimate of 0.02 with a standard deviation less than 0.001. SRMR measures the deviation between the elements of the covariance matrix observed in the data set and the covariance matrix implied by the model. Models that fit the data well have SRMR values below 0.08. The Base Model has a mean SRMR value of 0.07 for the within level with a standard deviation of less than 0.001. Taken together, these fit statistics provide evidence that the model provides an adequate representation of the data.

3.2.4.2 The Latent Mediation Variables

The Base Model included three latent mediating variables, *Books*, *Activity*, and *Ability*, shown in Exhibit 3.3. The standardized factor loadings for each of the indicator variables are shown in Exhibit 3.4. All of the factor loadings were statistically significant ($p < 0.001$).

Exhibit 3.4: Standardized Factor Loadings for the Latent Mediating Variables in the Base Model

	Standardized Latent Variable Factor Loadings		
Indicator	*Books*	*Activity*	*Ability*
X_1	0.81 (0.02)		
X_2	0.78 (0.02)		
X_3		0.50 (0.02)	
X_4		0.48 (0.02)	
X_5		0.38 (0.02)	
X_6		0.62 (0.01)	
X_7		0.44 (0.02)	
X_8		0.50 (0.02)	
X_9		0.59 (0.01)	
X_{10}		0.60 (0.01)	
X_{11}		0.56 (0.01)	
X_{12}		0.56 (0.01)	
X_{13}		0.66 (0.01)	
X_{14}		0.59 (0.01)	
X_{15}		0.59 (0.01)	
X_{16}		0.52 (0.02)	
X_{17}		0.49 (0.01)	
X_{18}		0.58 (0.01)	
X_{19}			0.68 (0.02)
X_{20}			0.82 (0.01)
X_{21}			0.80 (0.01)
X_{22}			0.70 (0.02)
X_{23}			0.73 (0.02)
X_{24}			0.80 (0.01)
X_{25}			0.43 (0.03)
X_{26}			0.50 (0.02)
X_{27}			0.52 (0.02)
X_{28}			0.43 (0.02)
X_{29}			0.44 (0.01)

Standard errors appear in ().

For the latent variable *Books*, there were two indicators, the number of books in the home (X_1) and the number of children's books in the home (X_2). Both of these indicators had strong and comparable relationships with the latent variable (0.81 and 0.78, respectively).

For the latent variable *Activity*, there were 16 indicators (X_3 ... X_{18}). The activities represented by these indicators are listed in Appendix A, Exhibit A.3. The loadings for these indicators were between 0.38 (X_5, Sing songs) and 0.66 (X_{13}, Play with number toys), with most of the indicators showing a moderately strong relationship with the latent variable.

For the latent variable *Ability*, there were 11 indicators (X_{19} ... X_{29}). The abilities represented by these indicators are listed in Appendix A, Exhibit A.4. The loadings for these indicators were between 0.43 (X_{25}, Count by himself/herself and X_{28}, Do simple addition) and 0.82 (X_{20}, Read some words). Most of the *Ability* indictors show a strong relationship with the latent variable.

The factor loadings for the indicators of the latent mediation variables in the Base Model are consistent with previously published results. The standardized factor loadings for the indicators in *Books* are consistent between the Base Model estimated here and the TIMSS and PIRLS 2011 Common Model reported by et al. (2012), as shown in Exhibit 3.5.

Exhibit 3.5: Standardized factor loadings for *Books* in the Base Model and the TIMSS and PIRLS 2011 Common Model

Indicator	Standardized Factor Loadings for *Books*	
	Base Model	TIMSS and PIRLS 2011 Common Model
X_1	0.81 (0.02)	0.80
X_2	0.78 (0.02)	0.80

Standard errors are shown in (). Standard errors were not reported by Gustafsson et al.

The standardized factor loadings for the indicators in *Activity* are consistent with published component loadings for each item in the TIMSS 2015 Early Literacy and

Numeracy Activities Before Beginning Primary School Scale, Fourth Grade (Martin et al., 2016) as shown in Exhibit 3.6.

Exhibit 3.6: Standardized Factor Loadings for *Activity* in the Base Model and the TIMSS 2015 Early Literacy and Numeracy Activities Before Beginning Primary School Scale, Fourth Grade

Indicator	Standardized Loadings for *Activity*	
	Base Model Factor Loadings	TIMSS 2015 Scale (Mean Component Loadings[1])
X_3	0.50 (0.02)	0.52 (0.07)
X_4	0.48 (0.02)	0.52 (0.06)
X_5	0.38 (0.02)	0.43 (0.08)
X_6	0.62 (0.01)	0.64 (0.03)
X_7	0.44 (0.02)	0.46 (0.08)
X_8	0.50 (0.02)	0.55 (0.07)
X_9	0.59 (0.01)	0.63 (0.04)
X_{10}	0.60 (0.01)	0.62 (0.05)
X_{11}	0.56 (0.01)	0.58 (0.06)
X_{12}	0.56 (0.01)	0.60 (0.05)
X_{13}	0.66 (0.01)	0.69 (0.04)
X_{14}	0.59 (0.01)	0.62 (0.06)
X_{15}	0.59 (0.01)	0.61 (0.07)
X_{16}	0.52 (0.02)	0.55 (0.08)
X_{17}	0.49 (0.01)	0.51 (0.08)
X_{18}	0.58 (0.01)	0.61 (0.04)

For the Base Model factor loadings, standard errors are shown in (). For the TIMSS 2015 mean component loadings, standard deviations are shown in ().

The standardized factor loadings for the indicators in *Ability* are consistent with published component loadings for each item in the TIMSS 2015 Could Do Early Literacy and Numeracy Tasks Before Beginning Primary School Scale, Fourth Grade (Martin et al., 2016) as shown in Exhibit 3.7.

[1] The component loadings for 35 of the 36 countries included in this dissertation analysis were averaged and the mean component loadings for the TIMSS 2015 scale are reported for each indicator. The component loadings for Armenia were not available at the time of the TIMSS 2015 publication, so they are not included in the average.

Exhibit 3.7: Standardized Factor Loadings for *Ability* in the Base Model and the TIMSS 2015 Could Do Early Literacy and Numeracy Tasks Before Beginning Primary School Scale, Fourth Grade

Indicator	Standardized Loadings for *Ability*	
	Base Model Factor Loadings	TIMSS 2015 Scale (Mean Component Loadings[2])
X_{19}	0.68 (0.02)	0.75 (0.04)
X_{20}	0.82 (0.01)	0.82 (0.03)
X_{21}	0.80 (0.01)	0.81 (0.03)
X_{22}	0.70 (0.02)	0.74 (0.06)
X_{23}	0.73 (0.02)	0.78 (0.04)
X_{24}	0.80 (0.01)	0.81 (0.03)
X_{25}	0.43 (0.02)	0.54 (0.11)
X_{26}	0.50 (0.02)	0.63 (0.12)
X_{27}	0.52 (0.02)	0.64 (0.13)
X_{28}	0.43 (0.02)	0.52 (0.08)
X_{29}	0.44 (0.01)	0.53 (0.07)

For the Base Model factor loadings, standard errors are shown in (). For the TIMSS 2015 mean component loadings, standard deviations are shown in ().

3.2.4.3 Effects of Parental Education

The total effect of *Parental Education* on *Science Achievement* is the sum of the direct effect of *Parental Education* on *Science Achievement* and the indirect effects of *Parental Education* on *Science Achievement* and is equal to 0.30. The direct effect of *Parental Education* on *Science Achievement* is 0.20 and the total indirect effect of *Parental Education* on *Science Achievement* is 0.10. The indirect effects account for 33 percent of the total effect.

The direct effect represents effects of *Parental Education* that the mediating latent variables *Books*, *Activity*, and *Ability* cannot account for. Ideally, in a mediation model, the direct effect between the independent and dependent variable would be close to zero,

[2] The component loadings for 35 of the 36 countries included in this dissertation analysis were averaged and the mean component loadings for the TIMSS 2015 scale are reported for each indicator. The component loadings for Armenia were not available at the time of the TIMSS 2015 publication, so they are not included in the average.

indicating that the mediating variables explain the relationship. A non-zero direct effect in a mediation model implies that the mediating variables have not completely accounted for the effect of the independent variable on the dependent variable and that there may be "room" in the model for additional explanatory factors to account for at least some of the direct effect. In the case of the Base Model, the mediating variables provide an incomplete explanation for the relationship between *Parental Education* and *Science Achievement*.

Books is an important mediating variable, with a moderately strong relationship with *Parental Education* (0.39). There is also a direct effect of *Books* on *Science Achievement* (0.21) that is comparable to the direct effect of *Parental Education* on *Science Achievement* (0.20).

Parental Education had an indirect effect on *Science Achievement* via *Books*, *Activity*, and *Ability*. The effects in this sequence were fairly strong (0.39, 0.25, 0.43, 0.17) and agree with findings from the TIMSS and PIRLS 2011 Common Model analysis (Gustafsson et al., 2012) and the research findings reviewed in Chapter 2. An additional path from *Parental Education* to *Science Achievement* via *Activity* and *Ability* also showed substantive indirect effects (0.17, 0.43, 0.17).

The path coefficients in the Base Model are consistent with the path model coefficients in the TIMSS and PIRLS 2011 Common Model as shown in Exhibit 3.8.

Exhibit 3.8: Standardized Path Coefficients in the Base Model and the TIMSS and PIRLS 2011 Common Model

Relationship	Standardized Path Coefficients	
	Base Model	TIMSS and PIRLS 2011 Common Model
Parental Education—Science Achievement	0.20 (0.01)	0.23
Parental Education—Books	0.39 (0.04)	0.47
Parental Education—Activity	0.17 (0.02)	0.08
Books—Activity	0.25 (0.02)	0.33
Books—Science Achievement	0.21 (0.02)	0.22
Activity—Ability	0.43 (0.02)	0.42
Ability—Science Achievement	0.17 (0.02)	0.19

Standard errors are shown in (). Standard errors were not reported in Gustafsson, Hansen, and Rosén (2012).

3.2.5 Discussion of the Base Model Analysis

The results of the Base Model analysis provide evidence of the viability of the application of these analysis techniques to the Parental Influence on Student Outcomes in Science Model proposed in Exhibit 3.1. The two-level model implemented in Mplus converged under the MLR estimator. When looking at the Base Model overall, the RMSEA and SRMR values of 0.02 and 0.07, respectively, indicate adequate overall model fit. The standardized factor loadings for the indicators of each of the latent variables, *Books, Activity*, and *Ability* are consistent with values previously published by Gustafsson et al. (2012) and Martin et al. (2016). In addition, the path coefficients in the Base Model are consistent with those previously published by Gustafsson et al. Because these techniques of variable definition, model estimation, and model evaluation were sufficiently successful at replicating these published results, they are used to construct and analyze the Parental Influence on Student Outcomes in Science Model introduced in Exhibit 3.1.

3.3 Extending the Base Model

3.3.1 Introducing New Variables

The first step in transforming the Base Model into the Parental Influence on Student Outcomes in Science Model is to introduce five new variables in addition to the variables already defined for the Base Model (*Parental Education*, *Books*, *Activity*, *Ability*). These new variables come from the TIMSS 2015 Home Questionnaire for parents and the TIMSS 2015 Student Questionnaire, Fourth Grade. The questionnaire items and their response spaces are shown in Appendix A.

- *Educational Expectations* is defined as the level of education parents expect their child to attain.
- *Digital Resources* is a latent variable that has as its indicators the number of digital information devices in the home and the presence of an internet connection in the home.
- *Parental Math/Science Attitudes* is a latent variable with the 8 variables representing items from the TIMSS 2015 Parental Attitudes Toward Mathematics and Science Scale, Fourth Grade (Martin et al., 2016, pp. 15.48-15.52) as its indicators.
- *Like Learning Science* is a latent variable with the 9 variables representing items from the TIMSS 2015 Students Like Learning Science Scale, Fourth Grade (Martin et al., 2016, pp. 15.108-15.112) as its indicators.

- *Science Self-Concept* is a latent variable with the 7 variables representing items from the TIMSS 2015 Students Confident in Science Scale, Fourth Grade (Martin et al., 2016, pp. 15.98-15.102) as its indicators.

3.3.2 Application of Analysis Methods Developed for the Base Model to the Parental Influence on Student Outcomes in Science Model

Analysis of the Parental Influence on Student Outcomes in Science Model will proceed generally according to the processes developed for the Base Model analysis. Rather than adding all of the new variables all at once, however, they are added in three stages.

The first stage in constructing the Parental Influence on Student Outcomes in Science Model involves adding the observed mediation variable *Educational Expectations* and the latent mediation variable *Digital Resources* into the Base Model to test whether the expanded set of mediating variables accounts more completely for the effects of *Parental Education.* The Stage 1 Model estimation in Mplus uses the approach previously described for the Base Model. In addition to using fit indices to assess overall model fit, the percentage of the direct effect of *Parental Education* accounted for by the indirect effects will be evaluated. For non-nested models, this approach can provide evidence that a model containing more variables offers a better explanation of the relationship between independent and dependent variables (MacKinnon, 2008; Preacher & Kelley, 2011; Montanaro & Bryan, 2014; Briki, 2017).

The second stage in constructing the Parental Influence on Student Outcomes in Science Model involves adding a second independent variable, *Parental Math/Science Attitudes*. At this stage, the hypothesis represented by the model shifts from the proposition that *Parental Education* alone is driving the effects on *Science Achievement* to an expanded view of multiple parental characteristics working together to influence the academic achievement of children in science. Parental attitudes towards STEM areas have been shown to positively influence children's achievement in science and also influence children's approach to learning science and confidence in their ability to do science. This Stage 2 Model also will be estimated in Mplus and evaluated for overall model fit. The total, direct, and indirect effects also will be evaluated.

The final stage of construction on the Parental Influence on Student Outcomes in Science Model involves adding two additional student outcome variables, *Like Learning Science* and *Science Self-Concept*. The final, full Parental Influence on Student Outcomes in Science Model will be estimated and evaluated in Stage 3 as previously described. The final model represents the hypothesis that not only do multiple parental characteristics work in concert in influence children's science achievement, but they also work in concert to influence children's attitudes towards learning science subjects and their children's confidence in their ability to do science.

Chapter 4: Expanding the 2011 Model of the Relationship Between Parents' Level of Education and Science Achievement

4.1 Overview of the Research Goals

Chapter **3** described the TIMSS 2015 International Database and how structural equation modeling techniques would be used to investigate expanding the TIMSS and PIRLS 2011 Common Model of the relationship between parents' education and fourth grade students' achievement in science. More specifically, the existing model hypothesizes a chain whereby parents' education levels influence the number of books in the home, which encourages participation in early literacy and numeracy activities before children begin primary school, leading to increased ability to perform literacy and numeracy activities when entering primary school, and higher student achievement at the fourth grade.

The TIMSS and PIRLS 2011 Common Model resulted from an extension of analyses of PIRLS 2001 data conducted by Gustafsson et al. when TIMSS and PIRLS were assessed together in 2011. Using the TIMSS and PIRLS 2011 data, the researchers replicated and extended the original path model 10 years later with reading, mathematics, and science as outcome variables.

The present dissertation research further extends the 2011 Swedish analyses by replicating the TIMSS and PIRLS 2011 Common Model using the TIMSS 2015 data to create the Base Model as explained in Chapter 3. This was the foundation for the following analyses:

1. Examining the effect of adding parents' educational expectations for their child and digital resources as mediating variables to better understand the relationship between levels of Parent's Education and science achievement.

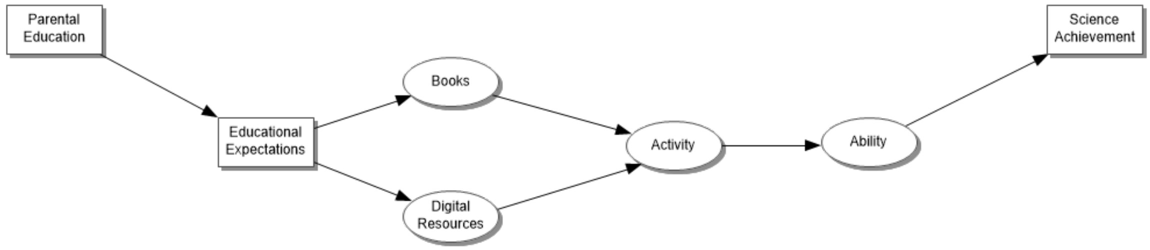
2. Investigating the impact of adding another independent variable, parental attitudes toward mathematics and science, to the expanded path between parents' education and students' science achievement.

3. Investigating the efficacy of the same expanded path model of parents' education for modeling the relationship between parents' characteristics and students' attitudes toward science as well as student science achievement.

4.2 Results for the Stage 1 Model

The Stage 1 Model addresses the first research question: Does extending and updating the TIMSS and PIRLS 2011 Common Model to include parental expectations for their child's education and digital resources in the home improve our understanding of the relationship between parents' education and students' science achievement at the fourth grade? The schematic of the Stage 1 Model shown below in Exhibit 4.1 represents an updated hypothesis about the influence of parental education that includes parental expectations for their child's education and digital resources in the home.

Exhibit 4.1: Schematic of the Stage 1 Model



In the Stage 1 Model, the level of parents' education (*Parental Education*) influences parental expectations concerning their child's education (*Educational Expectations*), which influences the extent to which literacy materials (*Books)* and, of increasing importance, digital devices and an internet connection are available in the home (*Digital Resources*), which, in turn, increases the level of educational learning activities (*Activity*) in the home before the child begins primary school, thus, improving students' literacy and numeracy skills (*Ability*) when they enter school, and then subsequently their average science achievement in the fourth grade.

4.2.1 Findings of the Stage 1 Analyses

As described below, the results of the Stage 1 analyses were positive. The effect of the extended chain of mediators *Educational Expectations—Books* and *Digital Resources—Activity—Abilit*y was more than twice the size of the direct effect of *Parental Education Level* on students' *Science Achievemen*t. The recommendation is to add *Educational Expectations* and *Digital Devices* to the Base Model.

4.2.2 Overall Model Fit for the Stage 1 Model

In TIMSS, each student has five plausible values of science achievement, so Mplus estimated the model parameters five times and averaged the results to produce a single set of model parameters. As expected for a model estimated from such a large data set, the chi-square test was significant ($p < 0.000$), with a mean chi-square value of 35170.80 (df = 510) and standard deviation of 298.60. However, the mean values of RMSEA (0.02, SD < 0.000) and $SRMR_{within}$ (0.06, SD < 0.000) indicate that the model provided an adequate overall representation of the data.

4.2.3 Factor Loadings for the Latent Variables in the Stage 1 Model

The Stage 1 Model included one additional latent mediator, *Digital Resources*, and one additional observed variable, *Educational Expectation*. (In comparison, the Base Model had three latent mediating variables—*Books, Activity*, and *Ability*.) The standardized factor loadings for each of the latent mediating variables (*Books*, *Digital Resources*, *Activity*, and *Ability*) are shown in Exhibit 4.2. All of the factor loadings were statistically significant ($p < 0.001$).

Exhibit 4.2: Standardized Factor Loadings for the Latent Mediating Variables in the Stage 1 Model

	Standardized Latent Variable Factor Loadings			
Indicator	*Books*	*Digital Resources*	*Activity*	*Ability*
X_1	0.82 (0.02)			
X_2	0.77 (0.02)			
X_3		0.49 (0.03)		
X_4		0.32 (0.02)		
X_5			0.50 (0.02)	
X_6			0.48 (0.02)	
X_7			0.37 (0.02)	
X_8			0.62 (0.01)	
X_9			0.44 (0.02)	
X_{10}			0.50 (0.02)	
X_{11}			0.59 (0.01)	
X_{12}			0.59 (0.01)	
X_{13}			0.56 (0.01)	
X_{14}			0.56 (0.01)	
X_{15}			0.66 (0.01)	
X_{16}			0.59 (0.01)	
X_{17}			0.59 (0.01)	
X_{18}			0.52 (0.02)	
X_{19}			0.48 (0.01)	
X_{20}			0.58 (0.01)	
X_{21}				0.68 (0.02)
X_{22}				0.82 (0.01)
X_{23}				0.80 (0.01)
X_{24}				0.70 (0.02)
X_{25}				0.73 (0.02)
X_{26}				0.80 (0.01)
X_{27}				0.43 (0.02)
X_{28}				0.51 (0.02)
X_{29}				0.52 (0.02)
X_{30}				0.43 (0.02)
X_{31}				0.44 (0.01)

Standard errors appear in ().

4.2.4 Relationships in the Stage 1 Model

The total effect of *Parental Education* on *Science Achievement* in the Stage 1 Model was 0.31, consistent with the Base Model. In comparison, the total indirect effect for the Stage 1 Model was 0.22, more than twice the total indirect effect in the Base Model. In the Stage 1 Model, the total indirect effect accounted for approximately 71 percent of the total effect of *Parental Education* on *Science Achievement,* compared with 33 percent found in the Base Model.

Finally, the effect of the extended chain of mediators *Educational Expectations—Books* and *Digital Devices—Activity—Abilit*y was more than twice the size of the direct effect of *Parental Education Level* on students' *Science Achievemen*t.

Educational Expectations had the strongest relationship with *Parental Education* (0.44); *Digital Devices* had the next strongest relationship (0.37), and then *Books* (0.32).

Created as a saturated mediation model in Mplus, the Stage 1 Model included twenty separate direct effects. Exhibit 4.3 presents the estimates of each of the standardized direct effects together with their standard errors. The standardized direct effects estimated for the Base Model are presented for comparison.

Exhibit 4.3: Comparison of Standardized Direct Effects in the Saturated Stage 1 Model with Those of the Base Model

Relationship	Standardized Direct Effect Stage 1 Model	Standardized Direct Effect Base Model
Parental Education — Educational Expectations	0.44 (0.02)	
Parental Education — Books	0.32 (0.03)	0.39 (0.04)
Parental Education — Digital Resources	0.36 (0.02)	
Parental Education — Activity	0.06 (0.02)	0.17 (0.02)
Parental Education — Ability	-0.05 (0.02)*	0.02 (0.02)*
Parental Education — Science Achievement	0.09 (0.01)	0.20 (0.01)
Educational Expectations — Books	0.17 (0.02)	
Educational Expectations — Digital Resources	0.24 (0.03)	
Educational Expectations — Activity	0.11 (0.01)	
Educational Expectations — Ability	0.10 (0.01)	
Educational Expectations — Science Achievement	0.13 (0.01)	
Books — Activity	0.21 (0.02)	0.25 (0.02)
Books — Ability	0.00 (0.02)*	0.03 (0.02)*
Books — Science Achievement	0.18 (0.02)	0.21 (0.02)
Digital Resources — Activity	0.17 (0.03)	
Digital Resources — Ability	0.08 (0.02)	
Digital Resources — Science Achievement	0.17 (0.03)	
Activity — Ability	0.40 (0.02)	0.43 (0.02)
Activity — Science Achievement	-0.02 (0.01)*	0.01 (0.02)*
Ability — Science Achievement	0.14 (0.02)	0.17 (0.02)

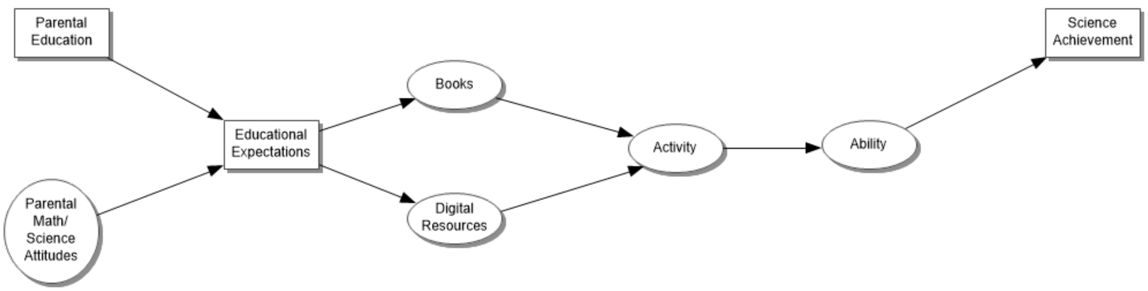
Standard errors are shown in (). *Standardized direct effect was not significant ($p \geq 0.01$)

4.3 Results for the Stage 2 Model

Exhibit 4.4 shows a schematic of the Stage 2 Model. The Stage 2 Model was constructed to address the second research question: What role do parents' attitudes toward mathematics and science play in explaining the relationship between parental education and science achievement at the fourth grade? Building on the successful Stage

1 Model, the Stage 2 Model also included *Parental Math/Science Attitudes* as an additional independent variable.

Exhibit 4.4: Schematic of the Stage 2 Model



4.3.1 Findings of the Stage 2 Analyses

As described below, adding *Parental Math/Science Attitudes* as a second independent variable did not appreciably change the total effect or total indirect effect associated with *Parental Education.* The total effect of *Parental Education* on *Science Achievement* in the Stage 2 Model was 0.29, and the total indirect effect in the Stage 2 Model was 0.21. Both of these values were comparable to the total effect and total indirect effect of *Parental Education* on *Science Achievement* in the Stage 1 Model. The total indirect effect accounted for approximately 72 percent of the total effect in the Stage 2 Model, comparable to the approximately 71 percent reported for the Stage 1 Model. The total effect of *Parental Math/Science Attitudes* on *Science Achievement* was 0.07, which was four times smaller than the total effect of *Parental Education* on *Science Achievement*. These results do not recommend retaining *Parental Math/Science Attitudes* as an independent variable in the modeling process.

To investigate the possibility that *Parental Math/Science Attitudes* could play a mediating role in influencing students' science achievement, a second analysis was conducted, labelled Stage 2 Model A. This model examined whether parents' attitudes towards mathematics and science was an effective mediator of parents' education. However, the total effect of *Parental Education* on *Science* in the Stage 2 Model A was 0.31 and the total indirect effect was 0.23, which was not much better than the 0.29 total effect of *Parental Education* on *Science* and the total indirect effect of 0.21 obtained for the Stage 2 Model (the indirect effect accounted for 74 percent and 72 percent of the total effect, respectively). Unfortunately, after investigating two possible roles for *Parental Math/Science Attitudes* in the model with neither making a substantive contribution, the recommendation is to not add *Parental Math/Science Attitudes*.

The details of the analyses underpinning both the Stage 2 Model and Stage 2 Model A, are shown below, beginning with Stage 2 Model.

4.3.2 Overall Model Fit for the Stage 2 Model

The chi-square test was again significant ($p < 0.000$), with a mean chi-square value of 32076.63 (df = 795) and standard deviation of 95.55. However, the mean values of RMSEA (0.02, SD < 0.000) and $SRMR_{within}$ (0.06, SD < 0.000) indicated that the model provided an adequate overall representation of the data.

4.3.3 Factor Loadings for the Latent Variables in the Stage 2 Model

The Stage 2 Model included one additional latent variable, *Parental Math/Science Attitudes,* as a second independent variable. *Parental Math/Science Attitudes* was based on the eight indicators used to create the TIMSS 2015 Parental Attitude Toward Mathematics and Science Scale, Fourth Grade (Martin et al., 2016). The attitudes represented by these indicators are listed in Appendix A, Exhibit A.6. In the Stage 2

Model, the standardized factor loadings for the indicators in *Parental Math/Science Attitudes* ($X_1 \ldots X_8$) were large (0.62–0.72) and very similar to the component loadings published for TIMSS 2015. Exhibit 4.5 shows the standardized factor loadings for each of the indicator variables for the latent variables included in the Stage 2 Model. All of the factor loadings were statistically significant ($p < 0.001$).

Exhibit 4.5: Standardized Factor Loadings for the Latent Variables in the Stage 2 Model

	Standardized Latent Variable Factor Loadings				
Indicator	*Parental Math/Science Attitudes*	*Books*	*Digital Resources*	*Activity*	*Ability*
X_1	0.62 (0.03)				
X_2	0.67 (0.03)				
X_3	0.68 (0.03)				
X_4	0.72 (0.02)				
X_5	0.69 (0.03)				
X_6	0.68 (0.03)				
X_7	0.70 (0.01)				
X_8	0.67 (0.02)				
X_9		0.80 (0.01)			
X_{10}		0.78 (0.02)			
X_{11}			0.49 (0.03)		
X_{12}			0.32 (0.03)		
X_{13}				0.50 (0.02)	
X_{14}				0.48 (0.02)	
X_{15}				0.37 (0.02)	
X_{16}				0.62 (0.01)	
X_{17}				0.44 (0.02)	
X_{18}				0.50 (0.02)	
X_{19}				0.59 (0.01)	
X_{20}				0.59 (0.01)	
X_{21}				0.56 (0.01)	
X_{22}				0.56 (0.01)	
X_{23}				0.66 (0.01)	
X_{24}				0.59 (0.01)	
X_{25}				0.59 (0.01)	
X_{26}				0.52 (0.02)	
X_{27}				0.49 (0.01)	
X_{28}				0.58 (0.01)	

	Standardized Latent Variable Factor Loadings				
Indicator	*Parental Math/Science Attitudes*	*Books*	*Digital Resources*	*Activity*	*Ability*
X_{29}					0.69 (0.02)
X_{30}					0.82 (0.01)
X_{31}					0.80 (0.01)
X_{32}					0.70 (0.02)
X_{33}					0.73 (0.02)
X_{34}					0.80 (0.01)
X_{35}					0.43 (0.02)
X_{36}					0.51 (0.02)
X_{37}					0.52 (0.02)
X_{38}					0.43 (0.02)
X_{39}					0.44 (0.01)

Standard errors appear in ().

4.3.4 The Stage 2 Model in Comparison with the Stage 1 Model

Adding *Parental Math/Science Attitudes* as an additional independent variable increased the complexity of the Stage 2 Model substantially compared with the Stage 1 Model, but did not appreciably change the total effect or total indirect effect associated with *Parental Education.*

The total effect of *Parental Education* on *Science* in the Stage 2 Model was 0.29, and the total indirect effect in the Stage 2 Model was 0.21. Both of these values were comparable to the total effect and total indirect effect of *Parental Education* on *Science* in the Stage 1 Model. The total indirect effect accounted for approximately 72 percent of the total effect in the Stage 2 Model, comparable to the approximately 71 percent reported for the Stage 1 Model.

The saturated Stage 2 Model included twenty separate direct effects associated with *Parental Education*. Exhibit 4.6 presents the estimates of each of the standardized direct effects together with their standard errors. The standardized direct effects estimated for the Stage 1 Model are presented for comparison. As shown in the exhibit, including *Parental Math/Science Attitudes* as an independent variable in addition to *Parental Education* had little appreciable impact on the direct effects of the variables in the model with *Parental Education* as the sole independent variable (the Stage 1 Model).

Exhibit 4.6: Standardized Direct Effects Associated with *Parental Education* in the Saturated Stage 2 Model (Excluding Direct Effects from *Parental Math/Science Attitudes*) with Those from the Saturated Stage 1 Model Included for Comparison

Relationship	Standardized Direct Effect Stage 2 Model	Standardized Direct Effect Stage 1 Model
Parental Education — Educational Expectations	0.40 (0.02)	0.44 (0.02)
Parental Education — Books	0.34 (0.03)	0.32 (0.03)
Parental Education — Digital Resources	0.36 (0.03)	0.36 (0.02)
Parental Education — Activity	0.01 (0.01)*	0.06 (0.02)
Parental Education — Ability	-0.06 (0.02)	-0.05 (0.02)*
Parental Education — Science Achievement	0.08 (0.01)	0.09 (0.01)
Educational Expectations — Books	0.20 (0.02)	0.17 (0.02)
Educational Expectations — Digital Resources	0.24 (0.02)	0.24 (0.03)
Educational Expectations — Activity	0.07 (0.01)	0.11 (0.01)
Educational Expectations — Ability	0.09 (0.01)	0.10 (0.01)
Educational Expectations — Science Achievement	0.12 (0.01)	0.13 (0.01)
Books — Activity	0.25 (0.02)	0.21 (0.02)
Books — Ability	0.01 (0.02)*	0.00 (0.02)*
Books — Science Achievement	0.19 (0.02)	0.18 (0.02)
Digital Resources — Activity	0.15 (0.03)	0.17 (0.03)
Digital Resources — Ability	0.08 (0.02)	0.08 (0.02)
Digital Resources — Science Achievement	0.16 (0.03)	0.17 (0.03)
Activity — Ability	0.39 (0.02)	0.40 (0.02)
Activity — Science Achievement	-0.02 (0.01)*	-0.02 (0.01)*
Ability — Science Achievement	0.14 (0.02)	0.14 (0.02)

Standard errors are shown in (). *Standardized direct effect was not significant ($p \geq 0.01$)

4.3.5 Comparison Between the Effects of Parents' Education and Parents' Attitudes in the Stage 2 Model

In the Stage 2 Model, compared to the total effect of *Parental Education* on *Science Achievement* (0.29), the total effect of *Parental Math/Science Attitudes* on *Science Achievement* was only 0.07, indicating that this variable is not a strong predictor of TIMSS science achievement at the fourth grade. The total indirect effect of *Parental Math/Science Attitudes* via the mediating variables was negligible (0.03).

Exhibit 4.7 shows the comparison between the standardized direct effects of *Parental Education* and *Parental Math/Science Attitudes* in the Stage 2 Model.

Exhibit 4.7: Standardized Direct Effects of *Parental Education* and *Parental Math/Science Attitudes* in the Stage 2 Model

	Standardized Direct Effects	
Related Variable	*Parental Education*	*Parental Math/Science Attitudes*
Educational Expectations	0.40 (0.02)	0.16 (0.02)
Books	0.34 (0.03)	-0.13 (0.04)
Digital Resources	0.36 (0.03)	0.03 (0.05)*
Activity	0.01 (0.01)*	0.22 (0.02)
Ability	-0.06 (0.02)	0.06 (0.03)*
Science Achievement	0.08 (0.01)	0.04 (0.02)*

Standard errors are shown in (). *Standardized direct effect was not significant ($p \geq 0.01$)

The standardized direct effect of *Parental Education* on both *Educational Expectations* and *Books* was more than twice the size of the direct effect of *Parental Math/Science Attitudes* on these mediators. Furthermore, the direction of the relationship on *Books* was unexpectedly negative for *Parental Math/Science Attitudes*, implying that parents with more positive attitudes towards mathematics and science brought fewer books into the home. Three of the four remaining direct relationships from *Parental Math/Science Attitudes* were not significant (*Digital Resources, Ability*, *Science*

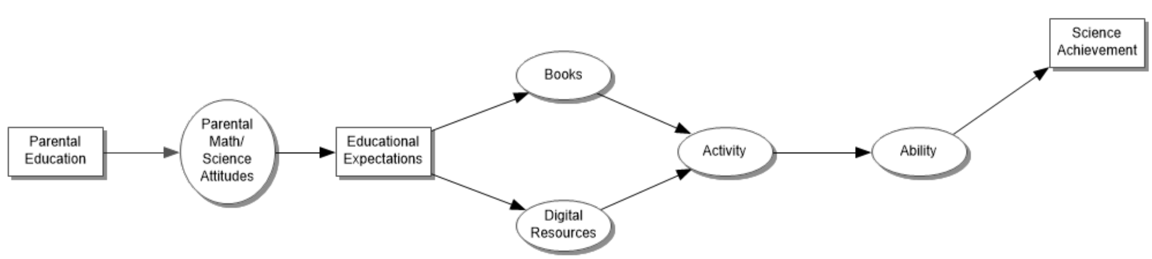
Achievement) and the direct relationship with *Activity*, which did not have a significant relationship with *Parental Education*, was significant and larger than the direct effect of *Parental Math/Science Attitudes* on *Educational Expectations*. Notably, the direct effect of *Parental Math/Science Attitudes* on *Science Achievement* in the Stage 2 Model (0.04) was not significant.

The different patterns in the results related to *Parental Math/Science Attitudes* when the Stage 2 Model was estimated with both *Parental Education* and *Parental Education* as independent variables indicated that the two variables did not appear to operate in the same way in relation to the other variables in the model.

4.3.6 Findings of the Stage 2 Model A

Although the results of the Stage 2 Model estimation did not support the idea of *Parental Math/Science Attitudes* as a separate independent variable working together with *Parental Education* to influence student science achievement, because there was a modest correlation between the two variables (0.29), it seemed worthwhile to explore the possibility of adapting the Stage 2 Model by shifting *Parental Math/Science Attitudes* from an independent to a mediating variable, resulting in the Stage 2 Model A, shown in Exhibit 4.8.

Exhibit 4.8: Schematic of the Stage 2 Model A



Even though the results for *Parental Math/Science Attitudes* as a mediating variable in the Stage 2 Model A were no more informative than the results for it as an independent variable in the Stage 2 Model, the details of the analyses of Stage 2 Model A follow.

4.3.6.1 Model Fit

The chi-square test for this model was significant ($p < 0.000$), with a mean chi-square value of 32060.46 (df = 795) and standard deviation of 210.50. However, the mean values of RMSEA (0.02, SD < 0.000) and $SRMR_{within}$ (0.06, SD < 0.000) indicated that the model provided an adequate overall representation of the data.

4.3.6.2 Factor Loadings

The Stage 2 Model A contained five latent mediation variables, *Parental Math/Science Attitudes, Books*, *Digital Resources, Activity*, and *Ability* in addition to the observed mediation variable, *Educational Expectations*. The standardized factor loadings for each of indicators of the latent variables were unchanged from those reported in Exhibit 4.5.

4.3.6.3 Direct Effects

The Stage 2 Model A included 27 separate direct effects. Exhibit 4.9 presents the estimates of each of the standardized direct effects together with their standard errors. Standardized direct effects estimated for the Stage 2 Model are presented for comparison.

Exhibit 4.9: Standardized Direct Effects in the Saturated Stage 2 Model A Compared with Those in the Stage 2 Model

Relationship	Standardized Direct Effect Stage 2 Model A	Standardized Direct Effect Stage 2 Model
Parental Education—Parental Math/Science Attitudes	0.29 (0.03)	
Parental Education—Educational Expectations	0.40 (0.02)	0.40 (0.02)
Parental Education — Books	0.34 (0.03)	0.34 (0.03)
Parental Education — Digital Resources	0.36 (0.03)	0.36 (0.03)
Parental Education — Activity	0.01 (0.01)*	0.01 (0.01)*
Parental Education — Ability	-0.06 (0.02)	-0.06 (0.02)
Parental Education — Science Achievement	0.08 (0.01)	0.08 (0.01)
Parental Math/Science Attitudes — Educational Expectations	0.16 (0.02)	
Parental Math/Science Attitudes — Books	-0.13 (0.04)	
Parental Math/Science Attitudes — Digital Resources	0.03 (0.05)*	
Parental Math/Science Attitudes — Activity	0.22 (0.02)	
Parental Math/Science Attitudes — Ability	0.06 (0.03)*	
Parental Math/Science Attitudes — Science Achievement	0.04 (0.02)*	
Educational Expectations — Books	0.20 (0.02)	0.20 (0.02)
Educational Expectations — Digital Resources	0.24 (0.02)	0.24 (0.02)
Educational Expectations — Activity	0.07 (0.01)	0.07 (0.01)
Educational Expectations — Ability	0.09 (0.01)	0.09 (0.01)
Educational Expectations — Science Achievement	0.12 (0.01)	0.12 (0.01)
Books — Activity	0.25 (0.02)	0.25 (0.02)
Books — Ability	0.01 (0.02)*	0.01 (0.02)*
Books — Science Achievement	0.19 (0.02)	0.19 (0.02)
Digital Resources — Activity	0.15 (0.03)	0.15 (0.03)
Digital Resources — Ability	0.08 (0.02)	0.08 (0.02)
Digital Resources — Science Achievement	0.16 (0.03)	0.16 (0.03)
Activity — Ability	0.39 (0.02)	0.39 (0.02)
Activity — Science Achievement	-0.02 (0.02)*	-0.02 (0.02)
Ability — Science Achievement	0.14 (0.02)	0.14 (0.02)

Standard errors are shown in (). *Standardized direct effect was not significant ($p \geq 0.01$)

Although *Parental Education* and *Parental Math/Science Attitudes* had a moderately strong relationship (0.29), the relationships between *Parental Math/Science*

Attitudes and most of the other variables were not as substantive. The direct effects between *Parental Math/Science Attitudes* and *Digital Resources*, *Ability*, and *Science* were indistinguishable from zero. There were weak relationships between *Parental Math/Science Attitudes* and *Educational Expectations* and *Books*. The relationship between *Parental Math/Science Attitudes* and *Activity* was only slightly stronger.

The results of estimating the Stage 2 Model A indicate that parents' attitudes toward mathematics and science do not predict science achievement in the fourth grade any better than did the Stage 2 Model. Given that neither attempt to include *Parental Math/Science Attitudes* in the model was successful, this variable was not added to the Stage 1 Model.

4.3.7 *Parental Math/Science Attitudes* in relation to Student Attitudes Toward Science

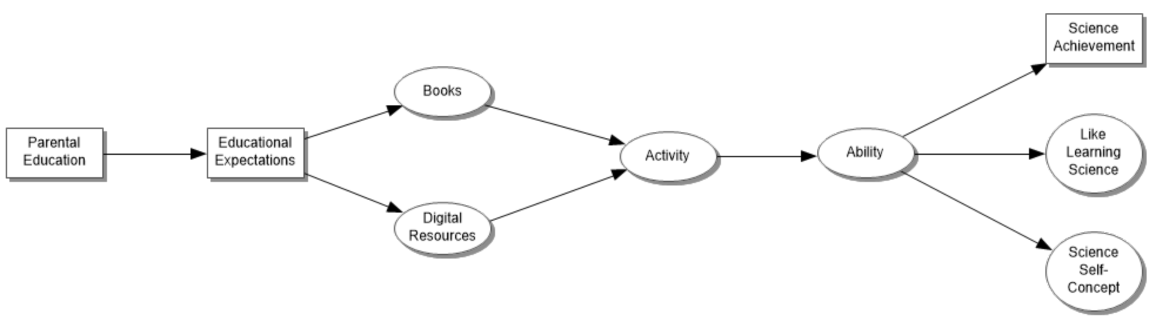
Although *Parental Math/Science Attitudes* did not enhance our understanding of the relationship between *Parental Education* and *Science Achievement*, its role in predicting student attitudes was examined by substituting it for *Parental Education* in the Stage 3 Model (see Exhibit 4.10 in next section). The results indicated that the parents' attitudes variable was not a strong predictor of fourth grade students' liking to learn science or their confidence in their ability to do science. The total effect of *Parental Math/Science Attitudes* on *Like Learning Science* was 0.06 and on *Science Self-Concept*, was 0.09. The total indirect effect associated with the two attitudinal outcome variables was 0.02 and 0.06, respectively. The magnitudes of the total effects and indirect effects indicated that *Parental Math/Science Attitudes* had little influence on *Like Learning Science* and *Science Self-Concept*.

4.4 Results for the Stage 3 Model

The Stage 3 Model addresses the third research question: How effective is the extended model in predicting students' attitudes toward learning and doing science at the fourth grade? Entering the Stage 3 analysis, the Stage 1 Model remained unchanged because the investigations in Stage 2 found that adding *Parental Math/Science Attitudes* did not add any explanatory power, as described in the preceding section. Thus, necessarily the Stage 3 Model extended the Stage 1 Model (rather than the Stage 2 Model) to predict the degree to which fourth grade students' like to learn science and their level of confidence in their abilities to do science, as well as their science achievement.

Exhibit 4.10 shows a schematic of the proposed Stage 3 Model, which is the Stage 1 Model with two additional student attitude outcome variables.

Exhibit 4.10: Schematic of Stage 3 Model



This model represents the hypothesis that the level of parents' education (*Parental Education*) influences not only fourth grade student achievement (*Science Achievement*) through the mechanisms of the Stage 1 Model, but also their liking for learning science (*Like Learning Science*) and their confidence in their ability to do science (*Science Self-Concept*). The model estimation process applied in Stages 1 and 2 was applied to create the Stage 3 Model as a saturated mediation model in *Mplus*.

4.4.1 Findings of the Stage 3 Analyses

As described in the following sections, the results of the Stage 3 Analyses were mixed. The total effects of *Parental Education* on *Science Achievement* were comparable to the results at Stages 1 and 2. However, the total effects of *Parental Education* on *Like Learning Science* were close to zero, but the total effects of *Parental Education* on *Science Self-Concept* were half the size of the total effects of *Parental Education* on *Science Achievement*. The recommendation is to retain *Science Self-Concept* as an outcome variable in the final model and discard *Like Learning Science*.

4.4.2 Overall Model Fit for the Stage 3 Model

The chi-square test was again significant ($p < 0.000$), with a mean chi-square value of 94215.03 (df = 1143) and standard deviation of 1666.74. However, the mean values of RMSEA (0.02, SD < 0.000) and $SRMR_{within}$ (0.06, SD < 0.000) indicate that the model provided an adequate overall representation of the data.

4.4.3 Factor Loadings for the Latent Variables in the Stage 3 Model

Because the Stage 3 Model was based on the Stage 1 Model, it includes the same four latent mediating variables, *Books*, *Digital Resources, Activity*, and *Ability* in addition to the observed *Educational Expectations* variable. However, it also included two new latent outcome variables, *Like Learning Science* and *Science Self-Concept.*

Like Learning Science was based on the nine indicators that form the TIMSS 2015 Students Like Learning Science Scale, Fourth Grade (Martin et al., 2016). The attitudes represented by these indicators are listed in Appendix A, Exhibit A.7. The standardized factor loadings for the indicators in *Like Learning Science* (X_{32}...X_{40}) ranged from 0.50 to 0.88 and were similar to the component loadings published for TIMSS 2015.

Science Self-Concept was based on the seven indicators used to form the TIMSS 2015 Students Confident in Science Scale, Fourth Grade (Martin et al., 2016). The attitudes represented by these indicators are listed in Appendix A, Exhibit A.7. The standardized factor loadings for the indicators in *Science Self-Concept* (X_{41}...X_{47}) ranged from 0.40 to 0.74 and were consistent with the component loadings published for TIMSS 2015. Exhibit 4.11 shows the standardized factor loadings for each of the indicator variables for the latent variables included in the Stage 3 Model. All of the factor loadings were statistically significant ($p < 0.001$).

Exhibit 4.11: Standardized Factor Loadings for the Latent Variables in the Stage 3 Model

	Standardized Latent Variable Factor Loadings					
Indicator	*Books*	*Digital Resources*	*Activity*	*Ability*	*Like Learning Science*	*Science Self-Concept*
X_1	0.81 (0.02)					
X_2	0.77 (0.02)					
X_3		0.49 (0.03)				
X_4		0.32 (0.03)				
X_5			0.50 (0.02)			
X_6			0.48 (0.02)			
X_7			0.37 (0.02)			
X_8			0.62 (0.01)			
X_9			0.44 (0.02)			
X_{10}			0.50 (0.02)			
X_{11}			0.59 (0.01)			
X_{12}			0.59 (0.01)			
X_{13}			0.56 (0.01)			
X_{14}			0.56 (0.01)			
X_{15}			0.66 (0.01)			
X_{16}			0.59 (0.01)			
X_{17}			0.59 (0.01)			
X_{18}			0.52 (0.02)			
X_{19}			0.48 (0.01)			
X_{20}			0.58 (0.01)			
X_{21}				0.68 (0.02)		
X_{22}				0.82 (0.01)		
X_{23}				0.80 (0.01)		
X_{24}				0.70 (0.02)		
X_{25}				0.73 (0.02)		
X_{26}				0.80 (0.01)		
X_{27}				0.43 (0.03)		
X_{28}				0.51 (0.02)		
X_{29}				0.52 (0.02)		
X_{30}				0.43 (0.02)		
X_{31}				0.44 (0.01)		

	Standardized Latent Variable Factor Loadings					
Indicator	*Books*	*Digital Resources*	*Activity*	*Ability*	*Like Learning Science*	*Science Self-Concept*
X_{32}					0.80 (0.02)	
X_{33}					0.50 (0.03)	
X_{34}					0.57 (0.03)	
X_{35}					0.68 (0.01)	
X_{36}					0.88 (0.01)	
X_{37}					0.81 (0.02)	
X_{38}					0.57 (0.02)	
X_{39}					0.51 (0.02)	
X_{40}					0.80 (0.01)	
X_{41}						0.49 (0.05)
X_{42}						0.70 (0.01)
X_{43}						0.71 (0.01)
X_{44}						0.52 (0.04)
X_{45}						0.40 (0.03)
X_{46}						0.74 (0.01)
X_{47}						0.69 (0.01)

Standard errors appear in ().

The factor loadings for the indicators of the latent mediating variables *Books*, *Digital Devices*, *Activity*, and *Ability* were the same as the values reported for the Stage 1 Model in Exhibit 4.2. Most of the indicators of *Like Learning Science* showed strong relationships with the latent variable. The indicators of *Science Self-Concept* showed moderately strong to strong relationships with the latent variable.

4.4.4 Relationships in the Stage 3 Model

The three outcome variables were positively related to each other, but the relationships among them varied in strength. *Like Learning Science* and *Science Self-Concept* were moderately correlated (0.62). The relationship between *Student*

Achievement and *Like Learning Science* and *Science Self-Concept* were weaker (0.13 and 0.31, respectively).

The total effects of *Parental Education* in the Stage 3 Model on *Science Achievement, Like Learning Science,* and *Science Self-concept* were 0.31, 0.02, and 0.15, respectively. The ability of *Parental Education* to predict *Science Achievement* was consistent with the Stage 1 model, unaffected by including the two student attitude outcomes. With a total effect of .02, *Parent Education* showed almost no ability to predict *Like Learning Science.*

The total indirect effects were 0.22, 0.02, and 0.12 for *Science Achievement, Like Learning Science,* and *Science Self-Concept*, respectively. The total indirect effect accounts for approximately 71 percent of the total effect for *Science Achievement*, and approximately 80 percent of the total effect for *Science Self-Concept*. The 71 percent of the total effect on *Science Achievement* accounted for by the *Educational Expectations—Books* and *Digital Resources—Activity—Ability* chain of mediators is consistent with the results found in the Stage 1 analyses. The mediation chain accounts for 80 percent of the small total effect (0.15) of *Parental Education* on *Science Self-Concept*.

The saturated path model estimated for the Stage 3 Model included 32 separate direct effects, shown in Exhibit 4.12.

Exhibit 4.12: Standardized Direct Effects in the Stage 3 Model

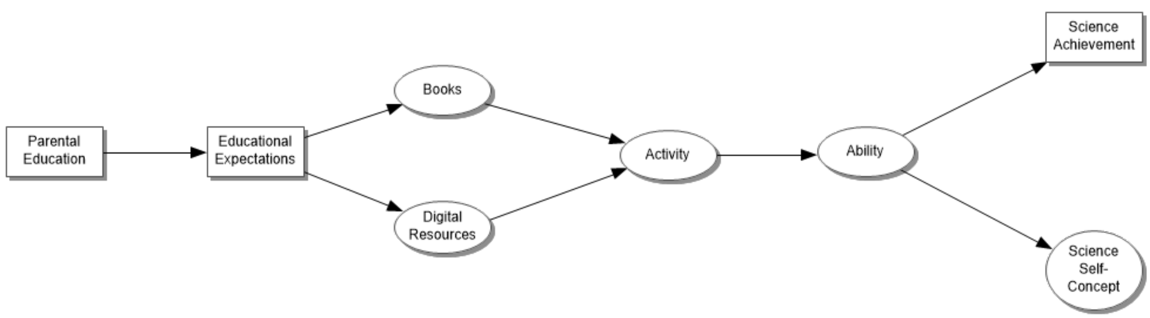
Relationship	Standardized Direct Effect
Parental Education — Educational Expectations	0.44 (0.02)
Parental Education — Books	0.32 (0.03)
Parental Education — Digital Resources	0.36 (0.03)
Parental Education — Activity	0.06 (0.02)
Parental Education — Ability	-0.05 (0.02)*
Parental Education — Science Achievement	0.09 (0.01)
Parental Education — Like Learning Science	0.00 (0.01)*
Parental Education — Science Self-Concept	0.03 (0.01)
Educational Expectations — Books	0.17 (0.02)
Educational Expectations — Digital Resources	0.24 (0.03)
Educational Expectations — Activity	0.11 (0.01)
Educational Expectations — Ability	0.10 (0.01)
Educational Expectations — Science Achievement	0.13 (0.01)
Educational Expectations — Like Learning Science	0.04 (0.01)
Educational Expectations — Science Self-Concept	0.10 (0.01)
Books — Activity	0.21 (0.02)
Books — Ability	0.00 (0.02)*
Books — Science Achievement	0.18 (0.02)
Books —Like Learning Science	-0.01 (0.01)*
Books — Science Self-Concept	0.07 (0.01)
Digital Resources — Activity	0.17 (0.03)
Digital Resources — Ability	0.08 (0.02)
Digital Resources — Science Achievement	0.17 (0.02)
Digital Resources —Like Learning Science	-0.02 (0.01)*
Digital Resources —Science Self-Concept	0.06 (0.02)
Activity — Ability	0.40 (0.02)
Activity — Science Achievement	-0.02 (0.01)*
Activity —Like Learning Science	0.06 (0.01)
Activity — Science Self-Concept	0.02 (0.01)
Ability — Science Achievement	0.14 (0.02)
Ability — Like Learning Science	0.02 (0.01)
Ability — Science Self-Concept	0.09 (0.01)

Standard errors are shown in (). *Standardized direct effect was not significant ($p \geq 0.01$)

4.5 The Final Model: Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science

The results of the Stage 3 Model analysis indicated that the level of parents' education (*Parental Education*) influences fourth grade students' achievement in science (*Science Achievement*) and their confidence in their ability to do science *(Science Self-Concept*) through the mechanisms of the Stage 1 Model. Exhibit 4.13 shows a schematic of the final Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science Model.

Exhibit 4.13: Schematic of the Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science Model



The model estimation process applied at each stage of this analysis was applied to create this final model in Mplus and confirm that the relationships among the variables identified in the saturated mediation model in Stage 3 persisted after *Like Learning Science* was removed.

4.5.1 Overall Model Fit for the Final Model

The chi-square test was again significant ($p < 0.000$), with a mean chi-square value of 56071.23 (df = 755) and standard deviation of 287.35. However, the mean values of RMSEA (0.02, SD < 0.000) and $SRMR_{within}$ (0.06, SD < 0.000) indicate that the model provided an adequate overall representation of the data.

4.4.2 Factor Loadings for the Latent Variables in the Final Model

The final Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science Model includes five of the latent variables from the Stage 3 Model, *Books*, *Digital Resources, Activity*, *Ability,* and *Science Self-Concept.* Exhibit 4.14 shows the standardized factor loadings for each of the indicator variables for the latent variables included in the Final Model. All of the factor loadings were statistically significant ($p < 0.001$).

Exhibit 4.14: Standardized Factor Loadings for the Latent Variables in the Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science Model

	Standardized Latent Variable Factor Loadings				
Indicator	*Books*	*Digital Resources*	*Activity*	*Ability*	*Science Self-Concept*
X_1	0.82 (0.02)				
X_2	0.77 (0.02)				
X_3		0.49 (0.03)			
X_4		0.32 (0.03)			
X_5			0.50 (0.02)		
X_6			0.48 (0.02)		
X_7			0.37 (0.02)		
X_8			0.62 (0.01)		
X_9			0.44 (0.02)		
X_{10}			0.50 (0.02)		
X_{11}			0.59 (0.01)		
X_{12}			0.59 (0.01)		
X_{13}			0.56 (0.01)		
X_{14}			0.56 (0.01)		
X_{15}			0.66 (0.01)		
X_{16}			0.59 (0.01)		
X_{17}			0.59 (0.01)		
X_{18}			0.52 (0.02)		
X_{19}			0.48 (0.01)		
X_{20}			0.58 (0.01)		
X_{21}				0.68 (0.02)	
X_{22}				0.82 (0.01)	
X_{23}				0.80 (0.01)	
X_{24}				0.70 (0.02)	
X_{25}				0.73 (0.02)	
X_{26}				0.80 (0.01)	
X_{27}				0.43 (0.02)	
X_{28}				0.51 (0.02)	
X_{29}				0.52 (0.02)	
X_{30}				0.43 (0.02)	
X_{31}				0.44 (0.01)	

	Standardized Latent Variable Factor Loadings				
Indicator	*Books*	*Digital Resources*	*Activity*	*Ability*	*Science Self-Concept*
X_{32}					0.41 (0.05)
X_{33}					0.73 (0.01)
X_{34}					0.72 (0.01)
X_{35}					0.44 (0.03)
X_{36}					0.33 (0.03)
X_{37}					0.78 (0.01)
X_{38}					0.71 (0.01)

Standard errors appear in ().

The factor loadings for the indicators of the latent variables *Books*, *Digital Devices*, *Activity*, *Ability,* and *Science Self-Concept* were consistent with the values reported for the Stage 3 Model in Exhibit 4.11.

4.4.3 Relationships in the Final Model

The total effects of *Parental Education* in the final Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science Model on *Science Achievement* and *Science Self-Concept* were 0.31, and 0.15, respectively, consistent with the results found in the Stage 3 Model analyses. The total indirect effects were consistent also (0.22 for *Science Achievement* and 0.12 for *Science Self-Concept*).

The saturated path model estimated for the Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science Model included 26 separate direct effects, shown in Exhibit 4.15.

Exhibit 4.15: Standardized Direct Effects in the Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science Model

Relationship	Standardized Direct Effect
Parental Education — Educational Expectations	0.44 (0.02)
Parental Education — Books	0.32 (0.03)
Parental Education — Digital Resources	0.36 (0.03)
Parental Education — Activity	0.06 (0.02)
Parental Education — Ability	-0.05 (0.02)*
Parental Education — Science Achievement	0.09 (0.01)
Parental Education — Science Self-Concept	0.03 (0.01)
Educational Expectations — Books	0.17 (0.02)
Educational Expectations — Digital Resources	0.24 (0.03)
Educational Expectations — Activity	0.11 (0.01)
Educational Expectations — Ability	0.10 (0.01)
Educational Expectations — Science Achievement	0.13 (0.01)
Educational Expectations — Science Self-Concept	0.10 (0.01)
Books — Activity	0.21 (0.02)
Books — Ability	0.00 (0.02)*
Books — Science Achievement	0.18 (0.02)
Books — Science Self-Concept	0.07 (0.01)
Digital Resources — Activity	0.17 (0.03)
Digital Resources — Ability	0.08 (0.02)
Digital Resources — Science Achievement	0.17 (0.02)
Digital Resources —Science Self-Concept	0.07 (0.02)
Activity — Ability	0.40 (0.02)
Activity — Science Achievement	-0.02 (0.01)*
Activity — Science Self-Concept	0.02 (0.01)
Ability — Science Achievement	0.14 (0.02)
Ability — Science Self-Concept	0.09 (0.01)

Standard errors are shown in (). *Standardized direct effect was not significant ($p \geq 0.01$)

4.6 Summary of Results

Taken together, the results at each stage of the model construction process provide evidence for whether or not to include variables in the model.

Adding parents' educational expectations for their child and a measure of the digital resources available in the home in Stage 1 expanded the explanation of the relationship between parents' education and students' science achievement established in the Base Model. The Stage 1 Model accounted for more than twice the percentage of the overall effect of parents' education on students' achievement in science than was accounted for in the Base Model.

Including parents' attitudes towards mathematics and science as a second independent variable in the Stage 2 Model did not improve the prediction of students' science achievement at the fourth grade. Also, adding *Parental Math/Science Attitudes* in the model as a mediating variable rather than as an independent variable (Stage 2 Model A) did not appreciably improve our understanding of the effects of parents' level of education on students' science achievement. The results of the Stage 2 analysis did not provide sufficiently compelling evidence to retain *Parents' Math/Science Attitudes* in the model at Stage 3.

The analysis of the Stage 3 Model indicated little relationship between parents' education and students' liking to learn science. The relationship between parents' education and students' confidence in their ability to do science was about half as strong as the relationship between parents' education and science achievement. The link between parents' education and students' liking to learn science was essentially zero and the model indicated a total effect of 0.15 for the *Parental Education—Science Self-*

Concept relationship, compared with a total effect of 0.31 for the *Parental Education—Science Achievement* relationship. The results of the Stage 3 analysis indicated that *Like Learning Science* should not be included in the final model, but that *Science Self-Concept* should be retained.

The results of the analysis of the final Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science Model indicated that the improvements and extensions to the Base Model found in Stage 1 and Stage 3 persisted. The Final Model both improves our understanding of the relationship between parents' education and students' science achievement and predicts students' confidence in their ability to do science at the fourth grade.

Chapter 5: Discussion

Science is our best hope of solving some of the world's major problems, such as environments becoming hazardous to their inhabitants, people having limited access to clean water and suffering from poor nutrition, the threats to the survival of land and marine species, and the struggle to end the global COVID-19 pandemic. Yet, students leave the STEM pipeline at every stage of their school careers from primary school through university. A number of strategies to retain students in STEM subjects (science, technology, engineering, and mathematics) have been initiated through special programs run by schools, university scholarships, as well as significant efforts at the national level, but no matter how many incentives are offered the supply of scientific specialists is continues to fall behind demand.

The attrition in students continuing to study science through their schooling appears to be related, at least in part, to their deteriorating attitudes toward the subject, which begins between fourth and eighth grades. TIMSS 2015 found that, on average, the majority of fourth grade students around the world like learning science: 56% "very much," 33% "somewhat," and 11% "not at all." By eighth grade for countries teaching general science, the "like learning science" percentages eroded to: 37% "very much," 44% "somewhat," and 19% "not" (separate science countries had similar results). When asked if they were "confident in science" fourth grade students reported: 40% "very," "42% "somewhat," and 18% "not." The eighth grade (general science) percentages indicate a loss in science confidence: 22% "very," 39% "somewhat," and 40% "not" (Martin et al., 2016). Results from a study of upper secondary school students in England found that the students opting out of science courses did not value science or see how science was part of their future lives (Cleaves, 2005). Similarly, United States high school students not intending a STEM major in university did not value science, were not confident in their science ability, and avoided taking science classes (Sahin et al., 2018).

In an attempt to better understand how homes and schools could foster more enduring attitudes towards science, this dissertation used TIMSS 2015 data from 36 countries to examine how fourth grade students' home context influenced their attitudes toward learning science in addition to their science achievement. Building on considerable large-scale research that relates elements of students' home context, such as parental education, expectations, and attitudes to students' academic outcomes, this dissertation extended the model relating parents' education levels to academic outcomes developed by Gustafsson et al (2012). Using data from TIMSS and PIRLS 2011, that model investigated the hypothesis that parents with higher levels of education had more books in their home and engaged their children in more early literacy and numeracy activities, such that the children started school with stronger academic skills that resulted in higher achievement at the fourth grade.

5.1 The Base Model and Stage 1 Model: Additional Mediating Variables Enriched the Explanation

The analyses began by replicating the TIMSS and PIRLS 2011 Common Model using the pooled data from the TIMSS 2015 countries, and produced results with good agreement. The chain of home support relationships identified by Gustafsson et al. (2012) researchers to explain the connection between parental education and student achievement in science continued to hold in TIMSS 2015. The Stage 1 Model then elaborated the chain of home support relationships by adding parents' expectations for their child's education and digital resources in the home.

Parents' expectations for the educational attainment of their child have been shown to be a strong predictor of academic achievement across cultures (e.g., Shin et al., 2015). Analysis of the Stage 1 Model showed adding *Educational Expectations* resulted in an increase in how much of the relationship between *Parental Education* and students' *Science Achievement* was explained. Logically, the factor—parents' expectations for their child's education—influences the decisions they make in establishing their child's home learning environment from their child's birth until their child begins primary school (and beyond).

The proliferation of online resources to support the development of children's academic skills indicated the addition of *Digital Resources* to complement *Books* and modernize the mediation chain between parents' education and science achievement. As internet connections and devices enabled to access these connections become ever more ubiquitous across the world, children begin to access online resources well before they begin primary school (Rideout et al., 2010). The analyses showed *Digital Resources* to be at least as important as *Books* in the explanation of the relationship between parents' education and students' achievement in science. In time, it is conceivable that digital resources will surpass the explanatory power of books, and will be considered as an essential home element in future research.

5.2 The Stage 2 and Stage 3 Models: Mediation Chain Less Successful at Explaining Attitudes than Achievement

The models constructed in Stage 2 and Stage 3 (each building on the Stage 1 Model) were not successful in either predicting students' science achievement or their attitudes toward learning science, respectively. The Stage 3 Model had some success in predicting students' confidence in their ability to do science.

Findings from previous research suggested that including parents' attitudes toward mathematics and science in the model would further develop the explanation of the relationship between *Parental Education* and students' *Science Achievement* (e.g., Archer et al., 2012; Sun et al., 2012). Because examining the role of parents' attitudes on students' science achievement was an important focus of this dissertation, the results of the Stage 2 analyses were disappointing. Essentially, adding *Parental Math/Science Attitudes* as a second independent variable together with *Parental Education* showed no change in the percentage of the total effect of *Parental Education* accounted for by the mediation chain compared to *Parental Education* alone in the Stage 1 Model (72 percent compared to 71 percent, respectively), and the total effect of *Parental Math/Science Attitudes* on *Science Achievement* was negligible.

A follow-up analysis, Stage 2 Model A, included *Parental Math/Science Attitudes* as an additional mediating variable rather than a second independent variable, but once again the results showed that adding parents' attitudes did not appreciably improve the ability of the model to account for the relationship between *Parental Education* and *Science Achievement* (74 percent of the total effects accounted for in Stage 2 Model A and 71 percent of the total effected accounted for in the Stage 1 Model).

One possible explanation for the Stage 2 models' inability to capture a substantive set of relationships between *Parental Math/Science Attitudes* and the other variables in the model is that parents' attitudes about STEM subjects may become more impactful only as students grow older and their STEM studies (especially their science studies) become more rigorous. Countries' descriptions of their science curricula published in the *TIMSS 2015 Encyclopedia: Education Policy and Curriculum in Mathematics and Science* (Mullis, Martin, Goh, & Cotter, 2016) show that at the fourth grade the scope and depth of science studies varies substantially among the 36 countries included in this dissertation analysis. Parents' extent of sharing their views about science as a school subject may vary in proportion to the prominence of science in the school program at the fourth grade. The few studies focusing on factors influencing young students' subject-specific academic achievement (e.g., Tan et al., 2019) indicated that parents were more likely to have subject-specific discussions with older students and more likely to have more general discussions and interactions about school and learning with younger students.

Finally, the Stage 3 Model included two student attitudinal variables—students' liking to learn science and students' confidence in doing science—as outcomes in addition to science achievement. The total effects were negligible between *Parental Education* and *Like Learning Science* (0.02) and small between *Parental Education* and *Science Self-Concept* (0.15). Finding little or no relationship between parents' education levels and students' attitudes toward science is unexpected, given previously published findings. However, considering students' overall context for learning across the countries included in the TIMSS 2015 analysis, science tends to receive much less emphasis in the fourth grade curriculum than reading or mathematics. Science lessons may be difficult for students to distinguish from other lessons (e.g., a reading lesson that features an informational science text), such that students' attitudes toward science at fourth grade generally reflect their overall positive attitudes toward school. The small correlations between *Science Achievement* and *Like Learning* Science and *Science Self-Concept* in the Stage 3 Model (0.13 and 0.31, respectively) hint that students' attitudes toward science do not yet have a strong connection to their science achievement. However, students' confidence in their ability to do science likely has more of a positive impact on science achievement than liking to learn the subject, even at a young age. Their attitudes toward science in particular may not start to develop until they begin to have formal science lessons. Then, as the science curriculum becomes more rigorous, the quality of students' academic work may drop, and along with it their attitudes and confidence. Clearly, more research is required to unravel the complex relationships underlying students attitudes toward science and identify the factors most likely to instill appreciation of the value of science.

5.3 The Final Model: Successes of Stage 1 and Stage 3 Analyses Combined

The final Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science Model combined the enhanced explanation of the relationship between parents' education and student achievement in science at the fourth grade established in Stage 1 and the extended application of the mediation model to a student attitudinal outcome (*Science Self-Concept*) successfully established in Stage 3. The *Educational Expectations—Books* and *Digital Resources—Activity—Ability* mediation chain accounted for comparable percentages of the total effect of *Parental Education* on both the achievement and the attitudinal outcome (71 percent and 80 percent, respectively), indicating that the mediating variables provided a plausible, if incomplete, explanation for the relationships between *Parental Education* and *Science Achievement* and *Science Self-Concept*. However, these relationships were not comparably strong; the total effect of *Parental Education* on *Science Achievement* was 0.31 and the total effect of *Parental Education* on *Science Self-Concept* was only 0.15. At the fourth grade, parents' education has a stronger relationship with their child's achievement than the child's confidence in their ability to do their academic work in science. Confidence in STEM competence becomes more closely related to science achievement as students grow older (Saçkes et al., 2011; Cleaves, 2005; Sahin et al., 2018). Additional research into the parental and home environment factors related to the development of young students' confidence in their academic abilities, particularly in science, is indicated.

5.4 Additional Limitations and Avenues of Further Research

The data from a single administration of TIMSS, such as TIMSS 2015, is cross-sectional and thus not suited to establishing causality. As a result, definitive statements about causality are not possible from these findings.

An additional limitation that opens an avenue of further research is related to the choice of variables included in the models at each stage. At each stage of the analysis, partial mediation of the independent variable(s) was observed, indicating that the hypothesized relationship between the independent and dependent variables was not yet complete. Further research in this area could involve updating the TIMSS Home

Questionnaire to include additional elements of the home context that may further contribute to our understanding of the relationship between the home context and students' academic and attitudinal outcomes in science.

The expected relationships absent in the results of the Stage 2 and Stage 3 analyses when the countries were considered in aggregate might emerge when the models are applied to the data from each country individually. A logical next step would be to apply these models to the data from each country separately. Gustafsson et al. (2012) took this approach with the data from TIMSS and PIRLS 2011 and found that when each country was considered individually, in nearly all of the countries the effect of parental education on achievement in mathematics, science, and reading could be partially explained by the mechanism that underpins the Base Model in this dissertation research. However, for each country, there were differences among the relative strengths of the relationships between the variables that added country-specific nuance to each explanation. It is likely that a similar re-analysis of the TIMSS 2015 data would also reveal country-specific results that pooling the data obscured.

It is possible to take individual country analyses a step further and perform latent class analyses on the data. For example, students could be clustered into distinct groups based on their parents' patterns of response to latent variables' indicators in these models and the differences in the modeled relationships among the groups investigated (e.g., do students whose parents engaged them often in numeracy activities before the beginning of primary school show a stronger relationship between *Parental Education* and *Educational Expectations*?). Similarly, students could be clustered into distinct groups based on their patterns of response to the *Science Self-Concept* indicators, for example, and their parents' patterns of response to the *Activity* indicators compared. These additional analyses could further enrich the explanations of the relationship between *Parental Education* and student science outcomes at the country level.

Latent class analysis techniques could also be used to cluster countries based on attributes of their education systems (e.g., tracking/streaming students, centralization of the education system, organization of science courses) and the modeling process used in this dissertation applied to investigate how the relationships in the models differ among the clusters.

TIMSS is designed to measure trends in student achievement at the country level, which opens up an additional direction for future research. Longitudinal structural equation modeling techniques could be applied to TIMSS data to examine whether the parental characteristics, home environment factors, and student achievement and attitudes considered in this dissertation research have changed over time. It may also be possible to examine whether the strengths of the relationships among the variables in the models analyses here have changed over time. The form and strength of these changes can be modeled in the structural equation modeling framework as well. Are these changes, for example, linear or curvilinear? Are they the same across subgroups of interest?

In addition to the Home Questionnaire and the Student Questionnaire, TIMSS administers a Teacher Questionnaire to participating students' teachers to gather data about students' school context for learning science. An additional direction for extending this dissertation research could expand the model further to encompass the school context as well as the home context. Findings in the literature reviewed in Chapter 2 indicated that the home context has a strong influence on young students' academic achievement and attitudes towards school and learning and that the home and school contexts can reinforce each other (positively or negatively) or work against each other (George & Kaplan, 1998; Cleaves, 2005; Hasni & Potvin, 2015). Including elements of students' classroom context for learning science and developing their confidence in their ability to do science is a natural extension of the final Parental Influences on Fourth Grade Students' Science Achievement and Confidence in Doing Science Model.

This dissertation research used TIMSS 2015 fourth grade science data to take advantage of the home context data provided by the TIMSS 2015 Home Questionnaire, which is unique to TIMSS at the fourth grade. However, in 2015, TIMSS also was administered at the eighth grade and at the twelfth grade (TIMSS Advanced 2015 Physics). Although TIMSS 2015 eighth grade science and TIMSS Advanced 2015 Physics did not offer the Home Questionnaire, some of the variables included in these dissertation models are available in each of the TIMSS 2015 data sets, especially the student attitude variables. It would be possible to extend this research to examine differences in the relationships between parents' education and student achievement in and attitudes toward science across the grade levels. Such analyses would provide more insight into three important stages in the STEM pipeline: entry at the fourth grade, transition between lower and upper secondary school at the eighth grade, and transition between upper secondary and university (the top of the pipeline) at the twelfth grade. If such additional research proves fruitful, the resulting explanations of the relationship between the home context and student achievement and attitudes could be valuable as a basis for country-specific policies and programs that influence the flow of students in the STEM pipeline.

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Appendix A: TIMSS 2015 Questionnaire Items

The variables in the Base, Stage 1, Stage 2, Stage 2A, and Stage 3 Models come from the TIMSS 2015 Home Questionnaire (IEA, 2016a) for parents, the TIMSS 2015 Student Questionnaire, Fourth Grade (IEA, 2016b), and the students' TIMSS 2015 Grade 4 Science achievement estimates. The questionnaire items from which the variables are derived appear in Exhibits A.1–A.7.

Exhibit A.1: TIMSS 2015 Home Questionnaire Question 20 (*Parental Education*)

20

What is the highest level of education <u>completed</u> by the child's father (or stepfather or male guardian) and mother (or stepmother or female guardian)?

*Check **one** circle in each column.*

	Child's father	Child's mother
a) Did not go to school	○	○
b) Some <Primary education—ISCED Level 1 or Lower secondary education—ISCED Level 2>	○	○
c) <Lower secondary education—ISCED Level 2>	○	○
d) <Upper secondary education—ISCED Level 3>	○	○
e) <Post-secondary, non-tertiary education—ISCED Level 4>	○	○
f) <Short-cycle tertiary education—ISCED Level 5>	○	○
g) <Bachelor's or equivalent level—ISCED Level 6>	○	○
h) <Postgraduate degree: Master's—ISCED Level 7 or Doctor—ISCED Level 8>	○	○
i) Not applicable	○	○

Exhibit A.2: TIMSS 2015 Home Questionnaire Questions 13-15 and TIMSS 2015 Grade 4 Student Questionnaire Question G5 (*Books* and *Digital Resources*)

13

About how many books are there in your home? (Do not count ebooks, magazines, newspapers, or children's books.)

*Check **one** circle only.*

- 0–10 --- ◯
- 11–25 --- ◯
- 26–100 --- ◯
- 101–200 --- ◯
- More than 200 --- ◯

14

About how many children's books are there in your home? (Do not count children's ebooks, magazines, or school books.)

*Check **one** circle only.*

- 0–10 --- ◯
- 11–25 --- ◯
- 26–50 --- ◯
- 51–100 --- ◯
- More than 100 --- ◯

15

How many digital information devices are there in your home? Count computers, tablets, smartphones, smart TVs, and e-readers. (Do not count other devices.)

*Check **one** circle only.*

- None --- ◯
- 1-3 devices --- ◯
- 4-6 devices --- ◯
- 7-10 devices --- ◯
- More than 10 devices --- ◯

G5

Do you have any of these things at your home?

*Fill **one** circle for each line.*

	Yes	No
a) A computer or tablet of your own	◯	◯
b) A computer or tablet that is shared with other people at home	◯	◯
c) Study desk/table for your use	◯	◯
d) Your own room	◯	◯
e) Internet connection	◯	◯
f) Your own mobile phone	◯	◯
g) A gaming system (e.g., PlayStation®, Wii®, XBox®)	◯	◯

Exhibit A.3: TIMSS 2015 Home Questionnaire Question 2 (*Activity*)

2

Before your child began primary/elementary school, how often did you or someone else in your home do the following activities with him or her?

*Check **one** circle for each line.*

	Often	Sometimes	Never or almost never
a) Read books	○	○	○
b) Tell stories	○	○	○
c) Sing songs	○	○	○
d) Play with alphabet toys (e.g., blocks with letters of the alphabet)	○	○	○
e) Talk about things you had done	○	○	○
f) Talk about what you had read	○	○	○
g) Play word games	○	○	○
h) Write letters or words	○	○	○
i) Read aloud signs and labels	○	○	○
j) Say counting rhymes or sing counting songs	○	○	○
k) Play with number toys (e.g., blocks with numbers)	○	○	○
l) Count different things	○	○	○
m) Play games involving shapes (e.g., shape sorting toys, puzzles)	○	○	○
n) Play with building blocks or construction toys	○	○	○
o) Play board or card games	○	○	○
p) Write numbers	○	○	○

Exhibit A.4: TIMSS 2015 Home Questionnaire Questions 7–8 (*Ability*)

7

How well could your child do the following when he/she began the <first grade> of primary/ elementary school?

*Check **one** circle for each line.*

	Very well	Moderately well	Not very well	Not at all
a) Recognize most of the letters of the alphabet	◯	◯	◯	◯
b) Read some words	◯	◯	◯	◯
c) Read sentences	◯	◯	◯	◯
d) Read a story	◯	◯	◯	◯
e) Write letters of the alphabet	◯	◯	◯	◯
f) Write some words	◯	◯	◯	◯

8

Could your child do the following when he/she began the <first grade> of primary/elementary school?

*Check **one** circle for each line.*

	Not at all	Up to 10	Up to 20	Up to 100 or higher
a) Count by himself/herself	◯	◯	◯	◯
b) Recognize written numbers	◯	◯	◯	◯
c) Write numbers	◯	◯	◯	◯

	Yes	No
d) Do simple addition	◯	◯
e) Do simple subtraction	◯	◯
f) Count money	◯	◯
g) Measure lengths or heights	◯	◯

Items (f) and (g) above were not included in this analysis due to their poor psychometric qualities in TIMSS 2015.

Exhibit A.5: TIMSS 2015 Home Questionnaire Question 21 (*Educational Expectations*)

21

How far in his/her education do you expect your child to go?

*Check **one** circle only.*

- Finish <Lower secondary education—ISCED Level 2> --- ◯
- Finish <Upper secondary education—ISCED Level 3> --- ◯
- Finish <Post-secondary, non-tertiary education—ISCED Level 4> --- ◯
- Finish <Short-cycle tertiary education—ISCED Level 5> --- ◯
- Finish <Bachelor's or equivalent level—ISCED Level 6> --- ◯
- Finish <Postgraduate degree: Master's—ISCED Level 7 or Doctor—ISCED Level 8> --- ◯

Exhibit A.6: TIMSS 2015 Home Questionnaire Question 16 (*Parental Math/Science Attitudes*)

16

How much do you agree with these statements about mathematics and science?

*Check **one** circle for each line.*

	Agree a lot	Agree a little	Disagree a little	Disagree a lot
a) Most occupations need skills in math, science, or technology	◯	◯	◯	◯
b) Science and technology can help solve the world's problems	◯	◯	◯	◯
c) Science explains how things in the world work	◯	◯	◯	◯
d) My child needs mathematics to get ahead in the world	◯	◯	◯	◯
e) Learning science is for everyone	◯	◯	◯	◯
f) Technology makes life easier	◯	◯	◯	◯
g) Mathematics is applicable to real life	◯	◯	◯	◯
h) Engineering is necessary to design things that are safe and useful	◯	◯	◯	◯

Exhibit A.7: TIMSS 2015 Grade 4 Student Questionnaire Questions MS4 and MS6 (*Like Learning Science* and *Science Self-Concept*)

MS4

How much do you agree with these statements about learning science?

*Fill **one** circle for each line.*

	Agree a lot	Agree a little	Disagree a little	Disagree a lot
a) I enjoy learning science	◯	◯	◯	◯
b) I wish I did not have to study science	◯	◯	◯	◯
c) Science is boring	◯	◯	◯	◯
d) I learn many interesting things in science	◯	◯	◯	◯
e) I like science	◯	◯	◯	◯
f) I look forward to learning science in school	◯	◯	◯	◯
g) Science teaches me how things in the world work	◯	◯	◯	◯
h) I like to do science experiments	◯	◯	◯	◯
i) Science is one of my favorite subjects	◯	◯	◯	◯

MS6

How much do you agree with these statements about science?

*Fill **one** circle for each line.*

	Agree a lot	Agree a little	Disagree a little	Disagree a lot
a) I usually do well in science	◯	◯	◯	◯
b) Science is harder for me than for many of my classmates	◯	◯	◯	◯
c) I am just not good at science	◯	◯	◯	◯
d) I learn things quickly in science	◯	◯	◯	◯
e) My teacher tells me I am good at science	◯	◯	◯	◯
f) Science is harder for me than any other subject	◯	◯	◯	◯
g) Science makes me confused	◯	◯	◯	◯

Appendix B: Descriptive Statistics

Exhibit B.1 presents the means, standard deviations, and minimum and maximum values for each of the independent, mediating, indicator, and dependent variables and used in the analysis, calculated from the pooled imputed data of all 36 countries. Each variable has been coded such that higher values imply a higher level on the construct measured, except for the dummy variable indicating the presence of an internet connection in the home, where no internet connection = 0 and the presence of an internet connection = 1. The plausible values of *Science* achievement have been divided by 100 to make estimation less computationally intensive.

Exhibit B.1: Descriptive Statistics

Variable	Mean	SD	Minimum Value	Maximum Value
Parental Education	3.50	1.43	0	5
Parental Math/ Science Attitudes				
Need STEM skills				
Science and technology solve	3.51	0.75	1	4
problems				
Science explains how things work	3.36	0.80	1	4
My child needs mathematics to	3.48	0.76	1	4
get ahead	3.42	0.81	1	4
Learning science is for everyone				4
Technology makes life easier	3.38	0.84	1	
Mathematics is applicable in real	3.51	0.77	1	4
life	3.55	0.73	1	4
Engineering is necessary to	3.52	0.75	1	4
design safe and useful things				
Educational Expectations	4.66	1.50	1	6
Books				
Books in the home	2.76	1.34	1	5
Children's books in the home	2.69	1.34	1	5

Exhibit B.1: Descriptive Statistics (continued)

Variable	Mean	SD	Minimum Value	Maximum Value
Digital Resources				
Number of digital devices in the home	1.93	1.06	0	4
Internet connection	0.79	0.41	0	1
Activity				
Read books	2.39	0.63	1	3
Tell stories	2.39	0.64	1	3
Sing songs	2.30	0.71	1	3
Play with alphabet toys	2.28	0.71	1	3
Talk about things you had done	2.52	0.61	1	3
Talk about what you had read	2.23	0.67	1	3
Play word games	2.20	0.70	1	3
Write letters or words	2.34	0.68	1	3
Read aloud signs and labels	2.29	0.71	1	3
Say counting rhymes or sing counting songs	2.18	0.73	1	3
Play with number toys	2.23	0.71	1	3
Count different things	2.47	0.64	1	3
Play games involving shapes	2.43	0.67	1	3
Play with building blocks	2.46	0.68	1	3
Play board or card games	2.25	0.70	1	3
Write numbers	2.38	0.66	1	3
Ability				
Recognize letters of the alphabet	2.27	0.89	0	3
Read some words	1.93	1.00	0	3
Read sentences	1.56	1.08	0	3
Read a story	1.33	1.09	0	3
Write letters of the alphabet	2.11	0.94	0	3
Write some words	1.88	1.00	0	3
Count by himself/herself	2.00	0.92	0	3
Recognize written numbers	1.83	0.95	0	3
Write numbers	1.75	0.98	0	3
Do simple addition	0.79	0.41	0	1
Do simple subtraction	0.67	0.47	0	1
Science	4.9984	1.0495	0.05	8.7787
(5 plausible values)	4.9842	1.0538	0.05	8.5988
	4.9870	1.0561	0.05	8.3766
	4.9764	1.0626	0.05	8.6814
	4.9972	1.0524	0.05	8.6701

Exhibit B.1: Descriptive Statistics (continued)

Variable	Mean	SD	Minimum Value	Maximum Value
Like Learning Science				
I enjoy learning science				
I wish I did not have to study				
science	3.45	0.86	1	4
Science is boring	3.20	1.09	1	4
I learn many interesting things in	3.28	1.03	1	4
science	3.61	0.76	1	4
I like science				
I look forward to learning science	3.45	0.88	1	4
in school	3.28	0.96	1	4
Science teaches me how things in				
the world work	3.64	0.70	1	4
I like to do science experiments				
Science is one of my favorite	3.63	0.75	1	4
things	3.21	1.01	1	4
Science Self-Concept				
I usually do well in science	3.39	0.81	1	3
Science is harder for me than for many of my classmates	3.05	1.09	1	3
I am just not good at science	3.12	1.07	1	3
I learn things quickly in science	3.32	0.87	1	3
My teacher tells me I am good at science	3.11	0.95	1	3
Science is harder for me than any other subject	3.13	1.09	1	3
Science makes me confused	3.19	1.08	1	3

Appendix C: Missing Data

Exhibit C.1 presents the extent of data missing from each of the variables in each country. Across all of the countries, the vast majority had less than 50 percent of their students missing data on one or more variables. Missing data in all parent variables was the most common missing data pattern across the countries, but in almost all cases, this pattern affected less than 10 percent of students. In 18 countries, only information about parents' education was missing. In all of the cases, less than 3 percent of students were affected. In 11 countries, only information about parents' educational expectations for their child was missing. In almost all of these cases, less than 3 percent of students were affected. These patterns of missingness could not be attributed to any particular student characteristic. No other patterns of missingness affected more than five countries.

Exhibit C. 1: Missing Data Rates by Country

	Percent Missing Data				
Variable	Armenia	Bahrain	Belgium (Flemish)	Bulgaria	Chile
Parental Education	17.0	15.2	9.5	2.8	21.3
Parental Math/ Science Attitudes					
Need STEM skills					
Science and technology solve					
problems	15.7	10.6	10.0	2.6	19.4
Science explains how things work	16.4	10.4	10.7	3.3	19.4
My child needs mathematics to get	17.5	10.6	10.4	4.2	19.8
ahead	15.6	10.7	10.3	3.1	19.3
Learning science is for everyone					
Technology makes life easier	16.3	11.1	10.5	3.9	20.0
Mathematics is applicable in real	16.5	10.7	10.7	3.3	19.5
life	15.8	10.4	10.5	3.0	19.4
Engineering is necessary to design	16.5	10.4	11.1	3.4	19.6
safe and useful things					
Educational Expectations	17.6	11.6	15.9	3.0	20.6
Books					
Books in the home	14.4	10.0	9.0	2.0	18.7
Children's books in the home	14.2	10.1	8.7	1.9	18.8
Digital Resources					
Number of digital devices in the home	14.2	9.4	8.5	1.9	18.4
Internet connection	5.6	1.8	1.9	1.8	1.7
Activity					
Read books	15.2	11.0	9.0	2.9	19.6
Tell stories	16.6	10.3	8.9	2.7	19.5
Sing songs	18.5	12.2	8.9	3.6	19.8
Play with alphabet toys	17.6	9.7	9.0	2.6	18.7
Talk about things you had done	17.6	10.1	8.6	2.7	18.9
Talk about what you had read	17.3	9.9	9.1	2.9	18.9
Play word games	17.6	10.2	9.3	3.1	19.0
Write letters or words	17.3	10.1	9.0	2.9	19.2
Read aloud signs and labels	16.7	10.3	9.2	2.8	18.7
Say counting rhymes or sing counting songs	17.6	10.2	9.4	2.6	18.8
Play with number toys	17.1	9.8	9.0	2.8	19.0
Count different things	18.2	11.6	9.2	2.8	20.0
Play games involving shapes	17.1	10.0	8.7	2.5	18.7
Play with building blocks	17.4	10.0	8.9	2.4	19.1
Play board or card games	17.2	10.0	8.9	2.5	18.8
Write numbers	16.4	9.9	8.7	2.1	18.6

Exhibit C.1: Missing Data Rates in Each Country (continued)

Variable	Percent Missing Data				
	Armenia	Bahrain	Belgium (Flemish)	Bulgaria	Chile
Ability					
Recognize letters of the alphabet	15.2	10.0	9.8	2.4	18.9
Read some words	18.8	10.0	9.7	3.3	19.2
Read sentences	19.7	10.3	10.0	3.7	19.7
Read a story	20.9	10.4	10.0	3.9	19.9
Write letters of the alphabet	17.6	10.1	9.6	3.1	19.2
Write some words	18.6	9.9	9.7	3.4	19.1
Count by himself/herself	15.3	12.1	9.5	2.9	22.8
Recognize written numbers	17.2	12.5	9.7	3.4	23.4
Write numbers	17.6	12.6	10.0	3.5	23.6
Do simple addition	14.4	11.1	9.4	2.6	22.2
Do simple subtraction	14.6	11.1	9.3	2.7	22.4
Like Learning Science					
I enjoy learning science					
I wish I did not have to study	11.2	3.3	1.5	1.9	3.0
science	17.5	4.0	1.8	2.4	3.6
Science is boring	19.2	5.0	2.5	3.1	4.4
I learn many interesting things in science	15.8	4.8	2.2	2.6	4.1
I like science	16.5	4.4	2.3	3.0	4.1
I look forward to learning science in school	16.3	4.3	2.0	2.6	4.1
Science teaches me how things in the world work	16.6	4.2	2.1	2.6	4.1
I like to do science experiments	16.9	4.2	1.9	2.9	3.9
Science is one of my favorite things	16.2	3.6	1.7	2.5	3.8
Science Self-Concept					
I usually do well in science	12.8	4.4	1.9	2.0	4.8
Science is harder for me than for many of my classmates	16.8	4.5	2.4	2.7	5.1
I am just not good at science	18.0	5.6	3.0	2.9	5.4
I learn things quickly in science	16.8	5.5	3.0	2.8	5.7
My teacher tells me I am good at science	17.5	5.2	2.8	2.8	5.5
Science is harder for me than any other subject	18.1	5.0	2.3	2.7	5.2
Science makes me confused	18.0	4.5	2.2	2.7	5.2

Exhibit C.1: Missing Data Rates in Each Country (continued)

	Percent Missing Data				
Variable	Chinese Taipei	Croatia	Cyprus	Czech Republic	Denmark
Parental Education	2.2	2.2	8.3	5.0	12.0
Parental Math/ Science Attitudes					
Need STEM skills					
Science and technology solve problems	1.8	1.8	8.1	5.1	12.2
Science explains how things work	2.3	2.8	8.3	5.4	12.7
My child needs mathematics to get	2.6	3.1	8.6	5.8	13.2
ahead	2.5	2.4	7.9	5.3	12.5
Learning science is for everyone					
Technology makes life easier	2.5	3.4	8.4	5.5	12.7
Mathematics is applicable in real	2.4	2.3	8.0	5.7	12.7
life	2.0	2.0	7.8	5.1	12.3
Engineering is necessary to design	2.3	2.3	8.6	5.7	12.9
safe and useful things					
Educational Expectations	1.9	3.1	9.1	6.1	13.8
Books					
Books in the home	0.9	1.6	6.4	4.4	11.9
Children's books in the home	1.0	1.6	6.4	4.2	12.0
Digital Resources					
Number of digital devices in the home	0.9	1.4	6.3	4.9	11.9
Internet connection	0.6	1.1	2.0	0.7	2.9
Activity					
Read books	2.7	1.7	6.6	4.5	12.2
Tell stories	3.2	1.5	6.7	4.8	12.3
Sing songs	3.3	1.8	7.2	5.0	12.4
Play with alphabet toys	2.9	1.6	6.8	4.6	12.4
Talk about things you had done	2.4	1.5	7.0	4.6	12.3
Talk about what you had read	2.7	1.8	6.8	4.7	12.5
Play word games	2.7	1.6	7.1	4.9	12.5
Write letters or words	3.4	1.6	7.3	4.8	12.5
Read aloud signs and labels	3.0	1.6	7.4	4.8	12.6
Say counting rhymes or sing counting songs	2.6	1.6	7.1	4.8	12.6
Play with number toys	2.5	1.6	7.2	4.7	12.5
Count different things	3.4	2.1	6.9	5.1	12.5
Play games involving shapes	2.7	1.7	7.2	4.7	12.4
Play with building blocks	2.5	1.6	7.1	4.7	12.4
Play board or card games	2.1	1.5	6.8	4.6	12.4
Write numbers	2.4	1.5	6.7	4.6	12.5

Exhibit C.1: Missing Data Rates in Each Country (continued)

Variable	Percent Missing Data Chinese Taipei	Croatia	Cyprus	Czech Republic	Denmark
Ability					
Recognize letters of the alphabet	1.7	1.4	7.3	4.6	12.6
Read some words	2.5	1.6	7.6	4.9	12.8
Read sentences	2.5	2.0	7.9	5.1	12.9
Read a story	2.7	1.9	8.1	5.3	12.8
Write letters of the alphabet	2.1	1.6	7.3	4.8	12.7
Write some words	2.2	1.5	7.5	4.9	12.7
Count by himself/herself	2.5	1.9	9.6	4.4	13.0
Recognize written numbers	2.8	1.7	9.8	5.0	13.6
Write numbers	2.8	2.0	10.1	5.1	13.8
Do simple addition	2.0	1.6	9.4	4.5	12.9
Do simple subtraction	2.0	1.6	9.4	4.6	13.0
Like Learning Science					
I enjoy learning science					
I wish I did not have to study	0.5	0.8	1.7	0.5	3.8
science	0.8	1.4	2.0	0.9	4.1
Science is boring	1.6	1.6	2.5	1.8	4.8
I learn many interesting things in science	1.5	1.2	2.2	1.0	4.7
I like science	1.2	1.5	2.4	1.0	4.5
I look forward to learning science in school	1.1	1.2	2.0	1.2	4.2
Science teaches me how things in the world work	0.9	1.3	1.8	0.8	4.1
I like to do science experiments	1.0	1.5	1.8	1.3	4.0
Science is one of my favorite things	0.6	1.0	1.7	0.7	4.0
Science Self-Concept					
I usually do well in science	0.4	1.2	1.8	0.8	4.3
Science is harder for me than for many of my classmates	0.6	1.3	2.0	1.1	4.7
I am just not good at science	1.7	2.4	2.5	1.6	4.8
I learn things quickly in science	2.2	2.1	2.6	2.2	5.0
My teacher tells me I am good at science	1.7	2.0	2.4	1.6	6.0
Science is harder for me than any other subject	0.6	1.4	2.0	1.2	4.4
Science makes me confused	0.5	1.4	1.9	0.9	4.2

Exhibit C.1: Missing Data Rates in Each Country (continued)

	Percent Missing Data				
Variable	Finland	France	Georgia	Hong Kong SAR	Hungary
Parental Education	5.6	15.5	7.1	6.7	7.1
Parental Math/ Science Attitudes					
Need STEM skills					
Science and technology solve					
problems	5.7	14.2	5.4	5.0	5.2
Science explains how things work	6.0	14.8	7.5	5.2	5.4
My child needs mathematics to get	6.0	14.6	7.5	5.5	5.6
ahead	5.8	14.5	5.6	5.1	5.1
Learning science is for everyone					
Technology makes life easier	6.1	14.8	6.1	5.6	5.6
Mathematics is applicable in real	6.0	15.4	7.7	5.4	5.3
life	5.9	14.5	5.3	5.3	5.2
Engineering is necessary to design	6.1	15.6	7.5	5.2	5.3
safe and useful things					
Educational Expectations	6.7	20.2	10.2	5.5	7.2
Books					
Books in the home	5.5	13.9	2.9	5.1	4.7
Children’s books in the home	5.5	13.7	3.0	5.0	4.6
Digital Resources					
Number of digital devices in the home	5.5	13.3	3.1	4.9	5.0
Internet connection	0.8	1.8	2.1	0.7	0.6
Activity					
Read books	5.5	13.7	4.1	5.3	5.4
Tell stories	5.7	13.9	7.7	5.4	4.9
Sing songs	5.9	14.4	8.6	5.9	5.2
Play with alphabet toys	5.9	13.8	8.1	5.9	5.3
Talk about things you had done	5.7	13.6	7.2	5.6	4.9
Talk about what you had read	5.7	13.9	7.0	5.8	5.4
Play word games	5.8	13.9	8.2	5.7	5.0
Write letters or words	5.7	13.6	6.6	5.5	5.3
Read aloud signs and labels	5.7	13.8	6.6	6.0	5.2
Say counting rhymes or sing counting songs	5.7	13.7	7.1	5.7	4.9
Play with number toys	5.7	14.0	6.8	5.4	5.1
Count different things	6.0	14.5	8.8	6.3	4.9
Play games involving shapes	5.6	13.6	7.6	6.1	5.0
Play with building blocks	5.7	13.7	6.9	5.7	4.7
Play board or card games	5.6	13.4	7.7	5.5	4.8
Write numbers	5.7	13.5	5.6	6.0	4.9

Exhibit C.1: Missing Data Rates in Each Country (continued)

Variable	Percent Missing Data: Finland	France	Georgia	Hong Kong SAR	Hungary
Ability					
Recognize letters of the alphabet	5.7	13.9	5.0	4.8	5.2
Read some words	5.7	14.0	9.2	4.8	5.6
Read sentences	5.8	14.2	10.7	5.1	5.9
Read a story	5.7	14.4	12.2	4.9	6.1
Write letters of the alphabet	5.6	13.9	8.3	4.7	5.5
Write some words	5.6	13.9	8.7	4.7	5.4
Count by himself/herself	6.6	15.7	4.6	6.4	5.0
Recognize written numbers	7.0	16.2	7.8	6.8	5.5
Write numbers	6.9	16.5	8.2	6.7	5.5
Do simple addition	6.4	14.9	4.1	6.2	4.9
Do simple subtraction	6.5	15.2	4.6	6.3	5.0
Like Learning Science					
I enjoy learning science					
I wish I did not have to study	0.9	2.4	3.6	0.6	0.6
science	0.9	2.8	5.7	0.6	0.8
Science is boring	1.0	3.7	7.1	1.0	1.8
I learn many interesting things in science	1.1	3.0	4.8	0.8	1.1
I like science	1.3	3.6	5.2	0.8	1.3
I look forward to learning science in school	1.1	3.2	5.6	1.2	1.0
Science teaches me how things in the world work	1.0	2.9	5.5	0.6	0.7
I like to do science experiments	1.0	3.2	5.3	0.9	0.7
Science is one of my favorite things	1.0	2.6	5.1	0.8	0.8
Science Self-Concept					
I usually do well in science	1.2	2.9	3.6	0.8	0.6
Science is harder for me than for many of my classmates	1.4	3.3	5.6	0.8	1.1
I am just not good at science	1.8	4.0	6.4	1.6	1.4
I learn things quickly in science	1.7	4.1	6.2	1.8	1.3
My teacher tells me I am good at science	1.8	4.6	6.7	2.0	1.4
Science is harder for me than any other subject	1.3	3.5	6.5	1.0	1.2
Science makes me confused	1.7	3.5	6.3	0.7	0.8

Exhibit C.1: Missing Data Rates in Each Country (continued)

	Percent Missing Data				
Variable	Indonesia	Iran, Islamic Rep. of	Ireland	Italy	Kazakhstan
Parental Education	8.7	3.3	7.3	9.6	1.5
Parental Math/ Science Attitudes					
Need STEM skills					
Science and technology solve problems	4.2	2.2	7.3	7.7	1.3
Science explains how things work	6.0	2.4	7.5	8.0	2.5
My child needs mathematics to get	6.1	3.4	7.6	8.0	2.6
ahead	5.4	2.1	7.3	7.8	1.9
Learning science is for everyone					
Technology makes life easier	5.6	2.7	7.3	8.3	2.8
Mathematics is applicable in real	5.7	2.9	7.6	8.6	3.0
life	5.6	2.2	7.5	8.0	2.1
Engineering is necessary to design safe and useful things	5.6	2.5	7.3	8.0	2.9
Educational Expectations	6.1	1.9	7.8	12.2	1.2
Books					
Books in the home	5.5	1.9	6.9	7.1	0.4
Children's books in the home	5.5	2.0	6.8	7.2	0.6
Digital Resources					
Number of digital devices in the home	4.7	1.8	6.7	6.7	0.3
Internet connection	3.3	2.9	1.3	2.2	1.1
Activity					
Read books	3.8	4.9	7.3	8.4	1.0
Tell stories	5.0	5.2	7.5	8.1	2.7
Sing songs	5.6	6.8	8.1	7.8	3.8
Play with alphabet toys	5.3	4.4	7.3	8.2	2.1
Talk about things you had done	5.4	4.2	7.3	7.7	3.2
Talk about what you had read	4.9	4.9	7.3	8.1	3.0
Play word games	5.7	5.0	7.5	7.7	2.3
Write letters or words	5.0	5.5	7.3	7.8	1.6
Read aloud signs and labels	5.1	4.4	7.5	8.1	2.2
Say counting rhymes or sing counting songs	4.9	5.7	7.3	8.0	2.4
Play with number toys	5.8	4.4	7.4	7.9	2.0
Count different things	6.5	4.4	7.5	8.4	2.4
Play games involving shapes	5.2	3.7	7.4	8.0	2.1
Play with building blocks	5.4	3.2	7.4	8.4	2.0
Play board or card games	5.2	4.5	7.3	7.8	2.4
Write numbers	4.6	3.9	7.1	7.7	1.7

Exhibit C.1: Missing Data Rates in Each Country (continued)

	Percent Missing Data				
Variable	Indonesia	Iran, Islamic Rep. of	Ireland	Italy	Kazakhstan
Ability					
Recognize letters of the alphabet	4.4	3.5	7.1	6.9	1.8
Read some words	5.3	5.2	7.2	7.6	4.1
Read sentences	5.9	6.3	7.4	7.5	4.9
Read a story	6.0	6.1	7.4	7.5	5.1
Write letters of the alphabet	5.8	3.6	7.2	7.0	3.4
Write some words	5.8	6.6	7.1	7.0	4.3
Count by himself/herself	4.2	5.0	7.7	8.1	1.7
Recognize written numbers	5.7	2.2	8.2	8.5	3.8
Write numbers	6.4	2.7	8.5	8.6	3.9
Do simple addition	3.7	2.6	7.9	7.5	1.2
Do simple subtraction	3.9	2.4	7.9	7.6	1.3
Like Learning Science					
I enjoy learning science					
I wish I did not have to study					
science	1.8	3.0	1.2	1.7	0.7
Science is boring	3.1	4.7	1.5	3.9	1.5
I learn many interesting things in	4.0	5.7	2.9	3.0	2.1
science	2.7	3.9	2.0	2.6	1.3
I like science					
I look forward to learning science	3.3	4.6	1.8	2.8	1.6
in school	4.2	3.9	1.7	2.2	1.4
Science teaches me how things in					
the world work	3.5	4.4	1.5	2.4	1.3
I like to do science experiments					
Science is one of my favorite	3.5	3.8	1.6	2.8	1.4
things	3.0	3.6	1.4	2.1	1.1
Science Self-Concept					
I usually do well in science	2.5	3.7	1.6	2.9	0.9
Science is harder for me than for many of my classmates	3.5	5.1	2.1	3.0	1.7
I am just not good at science	4.0	6.3	3.8	3.9	2.4
I learn things quickly in science	3.9	5.5	2.7	4.0	1.9
My teacher tells me I am good at science	3.7	5.2	2.4	3.5	1.6
Science is harder for me than any other subject	3.7	5.4	2.1	4.3	1.7
Science makes me confused	3.8	4.9	1.7	3.2	1.6

Exhibit C.1: Missing Data Rates in Each Country (continued)

Variable	Percent Missing Data				
	Korea, Rep. of	Kuwait	Lithuania	Morocco	Oman
Parental Education	1.2	25.6	14.3	14.4	14.0
Parental Math/ Science Attitudes					
Need STEM skills					
Science and technology solve					
problems	1.4	21.1	14.7	7.6	7.9
Science explains how things work	1.5	21.1	15.1	8.5	8.3
My child needs mathematics to get	1.7	21.1	15.3	9.0	9.1
ahead	1.6	21.1	15.0	8.1	8.2
Learning science is for everyone					
Technology makes life easier	1.9	21.6	15.0	9.6	9.4
Mathematics is applicable in real	1.7	21.2	15.3	8.9	8.4
life	1.6	21.2	14.9	8.4	8.3
Engineering is necessary to design safe and useful things	1.7	20.9	15.3	8.2	8.3
Educational Expectations	0.9	22.3	14.4	10.6	9.4
Books					
Books in the home	0.9	20.6	14.0	9.1	7.2
Children's books in the home	0.8	21.0	14.2	9.4	7.4
Digital Resources					
Number of digital devices in the home	0.8	20.2	13.9	7.0	7.4
Internet connection	0.6	9.0	1.7	8.0	3.0
Activity					
Read books	1.5	22.0	15.0	9.1	10.2
Tell stories	1.2	20.7	15.2	11.0	10.8
Sing songs	2.0	21.9	16.0	11.5	12.8
Play with alphabet toys	1.7	20.3	15.5	9.3	10.4
Talk about things you had done	1.6	20.5	15.5	9.2	10.8
Talk about what you had read	1.6	20.6	16.2	9.4	11.3
Play word games	1.6	20.6	15.9	10.4	11.0
Write letters or words	1.5	20.5	15.0	8.8	10.6
Read aloud signs and labels	1.5	20.3	16.1	9.0	10.8
Say counting rhymes or sing counting songs	1.5	20.4	16.2	9.3	10.6
Play with number toys	1.6	20.3	16.1	9.0	10.6
Count different things	1.7	22.7	15.6	12.6	12.4
Play games involving shapes	1.5	20.4	15.6	9.5	10.7
Play with building blocks	1.5	20.7	15.4	9.5	10.5
Play board or card games	1.4	20.7	15.8	10.0	10.8
Write numbers	1.5	20.3	15.2	8.3	10.1

Exhibit C.1: Missing Data Rates in Each Country (continued)

Variable	Korea, Rep. of	Kuwait	Lithuania	Morocco	Oman
	Percent Missing Data				
Ability					
Recognize letters of the alphabet	2.0	20.0	14.0	9.5	8.6
Read some words	3.1	20.7	14.4	8.6	9.4
Read sentences	2.9	20.7	14.4	9.4	9.6
Read a story	2.9	21.1	14.9	9.7	10.0
Write letters of the alphabet	3.0	20.2	14.5	8.7	9.3
Write some words	3.1	20.5	14.5	8.8	9.3
Count by himself/herself	1.5	22.3	14.1	9.2	9.1
Recognize written numbers	2.3	22.3	14.6	9.8	10.0
Write numbers	2.5	22.4	14.9	9.6	10.2
Do simple addition	1.0	21.2	14.2	6.2	8.2
Do simple subtraction	1.0	21.1	14.2	6.5	8.2
Like Learning Science					
I enjoy learning science					
I wish I did not have to study	0.1	10.3	0.8	7.6	3.7
science	0.3	10.8	1.2	8.9	5.1
Science is boring	0.8	11.7	2.3	9.4	6.0
I learn many interesting things in science	0.5	11.0	1.3	8.5	5.3
I like science	0.9	10.7	1.7	7.8	4.6
I look forward to learning science in school	0.7	10.4	1.2	8.1	4.8
Science teaches me how things in the world work	0.5	10.7	1.4	8.5	4.6
I like to do science experiments	0.5	10.1	1.3	8.6	4.5
Science is one of my favorite things	0.3	10.1	1.0	8.4	4.3
Science Self-Concept					
I usually do well in science	0.4	11.0	1.2	8.2	4.2
Science is harder for me than for many of my classmates	0.4	11.2	1.5	9.4	5.3
I am just not good at science	1.4	11.4	1.9	10.1	6.5
I learn things quickly in science	1.1	11.6	2.2	9.5	5.2
My teacher tells me I am good at science	0.9	11.7	1.9	9.8	5.3
Science is harder for me than any other subject	0.6	11.6	1.4	9.8	5.6
Science makes me confused	0.4	10.9	1.9	9.1	5.4

Exhibit C.1: Missing Data Rates in Each Country (continued)

	Percent Missing Data				
Variable	Poland	Portugal	Qatar	Russian Federation	Saudi Arabia
Parental Education	3.1	4.0	25.1	6.9	10.8
Parental Math/ Science Attitudes					
Need STEM skills					
Science and technology solve					
problems	3.2	3.1	21.2	1.6	15.2
Science explains how things work	3.6	3.6	21.5	2.7	13.7
My child needs mathematics to get	3.9	3.9	21.8	2.3	15.4
ahead	3.6	3.2	21.7	1.8	13.9
Learning science is for everyone					
Technology makes life easier	3.4	4.0	21.8	2.1	15.4
Mathematics is applicable in real	3.7	3.8	21.6	2.0	13.9
life	3.3	3.4	21.6	1.7	13.9
Engineering is necessary to design	3.7	3.5	21.6	2.2	13.6
safe and useful things					
Educational Expectations	3.2	5.0	22.0	6.7	6.8
Books					
Books in the home	3.1	2.7	20.8	1.5	6.9
Children's books in the home	2.9	2.6	21.0	1.2	7.0
Digital Resources					
Number of digital devices in the home	3.1	2.4	20.7	1.3	12.0
Internet connection	0.7	0.7	1.9	0.8	5.6
Activity					
Read books	2.8	3.7	22.4	1.4	14.0
Tell stories	3.1	3.6	22.1	1.9	14.6
Sing songs	3.5	4.5	23.3	2.4	17.6
Play with alphabet toys	3.1	3.3	21.4	1.6	12.2
Talk about things you had done	3.2	3.3	21.6	1.9	13.0
Talk about what you had read	3.1	3.5	21.9	1.6	13.4
Play word games	3.3	3.8	22.0	1.8	8.0
Write letters or words	2.9	3.6	21.9	1.4	7.3
Read aloud signs and labels	3.1	3.4	22.0	1.7	13.1
Say counting rhymes or sing counting songs	3.2	3.5	21.8	1.8	13.7
Play with number toys	3.1	3.6	21.6	1.6	7.0
Count different things	3.0	3.6	23.9	1.7	16.0
Play games involving shapes	3.0	3.0	21.8	1.5	13.5
Play with building blocks	3.0	3.4	21.8	1.6	13.8
Play board or card games	2.8	3.3	21.9	1.7	7.4
Write numbers	2.8	2.9	21.7	1.4	6.4

Exhibit C.1: Missing Data Rates in Each Country (continued)

	Percent Missing Data				
Variable	Poland	Portugal	Qatar	Russian Federation	Saudi Arabia
Ability					
Recognize letters of the alphabet	3.0	3.3	20.8	2.1	6.2
Read some words	3.5	3.9	21.3	2.4	9.3
Read sentences	3.6	4.4	21.5	2.6	9.8
Read a story	4.0	4.6	21.6	3.1	10.3
Write letters of the alphabet	3.3	3.6	21.2	2.0	9.2
Write some words	3.4	3.6	21.3	2.1	9.4
Count by himself/herself	3.4	3.9	21.8	2.6	6.4
Recognize written numbers	3.8	4.6	22.0	2.6	9.2
Write numbers	4.2	4.3	22.1	2.6	9.5
Do simple addition	3.1	3.5	21.1	1.6	5.2
Do simple subtraction	3.2	3.7	21.2	1.9	5.3
Like Learning Science					
I enjoy learning science					
I wish I did not have to study					
science	0.4	0.6	3.4	0.3	6.1
Science is boring	0.8	1.1	4.5	0.9	8.3
I learn many interesting things in	2.0	1.7	5.4	1.1	9.5
science	1.0	1.2	4.7	0.7	8.6
I like science					
I look forward to learning science	1.2	1.2	4.9	0.7	8.4
in school	1.0	0.8	5.0	0.7	8.5
Science teaches me how things in					
the world work	0.7	0.8	4.8	0.6	8.7
I like to do science experiments					
Science is one of my favorite	0.8	0.9	4.3	0.7	8.6
things	0.5	0.7	4.1	0.4	7.8
Science Self-Concept					
I usually do well in science	0.7	0.7	3.9	0.8	8.4
Science is harder for me than for many of my classmates	1.1	1.0	4.9	1.0	9.2
I am just not good at science	1.7	1.8	5.9	1.5	10.5
I learn things quickly in science	1.7	1.6	5.2	1.6	9.6
My teacher tells me I am good at science	1.4	1.4	5.5	1.1	10.4
Science is harder for me than any other subject	1.0	1.0	5.1	1.1	9.8
Science makes me confused	0.9	0.9	4.4	0.8	9.4

Exhibit C.1: Missing Data Rates in Each Country (continued)

	Percent Missing Data				
Variable	Serbia	Singapore	Slovak Republic	Spain	Sweden
Parental Education	4.4	4.6	3.8	14.6	18.7
Parental Math/ Science Attitudes					
Need STEM skills					
Science and technology solve					
problems	3.3	2.6	5.0	11.6	14.3
Science explains how things work	4.4	2.7	6.1	11.8	14.8
My child needs mathematics to get	4.7	2.8	6.1	11.9	14.8
ahead	4.3	2.7	5.8	11.6	14.2
Learning science is for everyone					
Technology makes life easier	4.2	2.8	6.0	12.0	14.2
Mathematics is applicable in real	4.2	2.8	5.7	11.6	15.0
life	4.1	2.7	5.1	11.6	14.3
Engineering is necessary to design	4.4	2.7	6.0	11.8	14.9
safe and useful things					
Educational Expectations	4.0	3.9	5.1	15.3	17.3
Books					
Books in the home	3.0	2.8	3.6	11.1	13.8
Children's books in the home	3.1	2.5	3.5	11.0	13.6
Digital Resources					
Number of digital devices in the home	2.8	2.5	3.8	10.9	13.8
Internet connection	1.5	0.5	1.2	1.0	2.3
Activity					
Read books	3.9	2.5	3.6	11.5	13.8
Tell stories	3.8	2.6	4.1	11.2	13.8
Sing songs	4.6	2.8	4.4	11.5	14.0
Play with alphabet toys	3.5	2.7	3.9	11.2	14.2
Talk about things you had done	3.4	2.7	4.0	11.3	13.9
Talk about what you had read	3.5	3.0	4.3	11.3	14.0
Play word games	3.6	2.7	4.5	11.3	14.1
Write letters or words	3.4	2.6	4.1	11.5	13.8
Read aloud signs and labels	3.6	2.8	4.4	11.2	14.0
Say counting rhymes or sing counting songs	3.6	2.7	4.0	11.6	14.1
Play with number toys	3.2	2.6	4.1	11.5	14.2
Count different things	4.7	3.2	4.9	12.1	14.3
Play games involving shapes	3.4	2.7	4.0	11.4	14.1
Play with building blocks	3.5	2.8	3.9	11.5	14.0
Play board or card games	3.4	2.7	3.8	11.3	13.9
Write numbers	3.2	2.7	3.9	11.2	13.9

Exhibit C.1: Missing Data Rates in Each Country (continued)

	Percent Missing Data				
Variable	Serbia	Singapore	Slovak Republic	Spain	Sweden
Ability					
Recognize letters of the alphabet	3.1	2.4	4.3	11.1	14.1
Read some words	3.9	2.6	5.3	11.3	14.2
Read sentences	4.3	2.7	5.8	11.5	14.9
Read a story	4.0	2.7	6.4	11.5	15.1
Write letters of the alphabet	3.6	2.6	5.1	11.2	14.2
Write some words	3.8	2.7	5.1	11.2	14.3
Count by himself/herself	3.6	3.1	4.3	13.0	14.2
Recognize written numbers	4.4	3.1	5.6	13.5	14.6
Write numbers	4.1	3.3	5.2	13.7	14.9
Do simple addition	3.0	2.9	3.9	12.3	14.1
Do simple subtraction	3.0	2.9	4.1	12.4	14.2
Like Learning Science					
I enjoy learning science					
I wish I did not have to study	1.4	0.4	1.2	1.1	1.3
science	2.0	0.6	1.9	1.6	2.2
Science is boring	2.7	1.1	3.0	2.1	3.5
I learn many interesting things in science	2.3	0.7	1.9	2.0	2.0
I like science	2.1	0.9	2.2	1.7	2.6
I look forward to learning science in school	2.0	0.7	1.7	1.5	1.9
Science teaches me how things in the world work	2.3	0.5	1.7	1.3	2.0
I like to do science experiments	2.2	0.6	1.8	1.4	1.9
Science is one of my favorite things	2.0	0.4	1.4	1.2	1.6
Science Self-Concept					
I usually do well in science	1.8	0.4	0.8	1.1	2.5
Science is harder for me than for many of my classmates	2.1	0.5	1.4	1.6	2.9
I am just not good at science	2.6	1.1	2.3	2.0	3.0
I learn things quickly in science	2.8	1.1	3.2	1.6	2.8
My teacher tells me I am good at science	2.4	0.7	1.5	2.1	3.6
Science is harder for me than any other subject	2.1	0.5	1.1	1.4	2.9
Science makes me confused	2.2	0.5	0.9	1.3	2.1

Exhibit C.1: Missing Data Rates in Each Country (continued)

	Percent Missing Data
Variable	Turkey
Parental Education	4.8
Parental Math/ Science Attitudes	
Need STEM skills	
Science and technology solve	
problems	2.6
Science explains how things work	3.6
My child needs mathematics to get	4.5
ahead	3.5
Learning science is for everyone	
Technology makes life easier	4.1
Mathematics is applicable in real	3.4
life	3.8
Engineering is necessary to design	3.5
safe and useful things	
Educational Expectations	2.5
Books	
Books in the home	2.4
Children's books in the home	2.2
Digital Resources	
Number of digital devices in the	
home	2.1
Internet connection	2.0
Activity	
Read books	3.6
Tell stories	3.8
Sing songs	4.6
Play with alphabet toys	5.4
Talk about things you had done	4.3
Talk about what you had read	4.2
Play word games	4.3
Write letters or words	4.2
Read aloud signs and labels	4.6
Say counting rhymes or sing	4.3
counting songs	
Play with number toys	4.5
Count different things	4.7
Play games involving shapes	4.9
Play with building blocks	5.0
Play board or card games	4.9
Write numbers	3.7

Exhibit C.1: Missing Data Rates in Each Country (continued)

	Percent Missing Data
Variable	Turkey
Ability	
Recognize letters of the alphabet	3.8
Read some words	5.7
Read sentences	6.2
Read a story	6.5
Write letters of the alphabet	4.8
Write some words	5.3
Count by himself/herself	3.2
Recognize written numbers	5.5
Write numbers	5.3
Do simple addition	2.9
Do simple subtraction	3.3
Like Learning Science	
I enjoy learning science	
I wish I did not have to study	0.8
science	1.3
Science is boring	1.7
I learn many interesting things in science	1.7
I like science	1.4
I look forward to learning science in school	1.2
Science teaches me how things in the world work	1.3
I like to do science experiments	1.3
Science is one of my favorite things	1.0
Science Self-Concept	
I usually do well in science	0.9
Science is harder for me than for many of my classmates	1.3
I am just not good at science	2.4
I learn things quickly in science	2.2
My teacher tells me I am good at science	1.7
Science is harder for me than any other subject	1.6
Science makes me confused	1.5

Exhibit C.2 presents the extent of data missing from each of the variables calculated from the pooled data of all 36 countries.

Exhibit C. 2: Missing Data Rates in the Pooled Data

Variable	Percent Missing Data
Parental Education	9.5
Parental Math/ Science Attitudes	
Need STEM skills	7.8
Science and technology solve problems	8.3
Science explains how things work	8.6
My child needs mathematics to get ahead	8.1
Learning science is for everyone	8.5
Technology makes life easier	8.4
Mathematics is applicable in real life	8.0
Engineering is necessary to design safe and useful things	8.4
Educational Expectations	9.3
Books	
Books in the home	7.1
Children's books in the home	7.1
Digital Resources	
Number of digital devices in the home	7.1
Internet connection	2.1
Activity	
Read books	
Tell stories	8.0
Sing songs	8.3
Play with alphabet toys	9.0
Talk about things you had done	8.1
Talk about what you had read	8.1
Play word games	8.3
Write letters or words	8.2
Read aloud signs and labels	8.0
Say counting rhymes or sing counting	8.2
songs	8.2
Play with number toys	8.0
Count different things	8.9
Play games involving shapes	8.1
Play with building blocks	8.1
Play board or card games	8.0
Write numbers	7.7

Exhibit C.2: Missing Data rates in the Pooled Data (continued)

Variable	Percent Missing Data
Ability	
Recognize letters of the alphabet	7.6
Read some words	8.3
Read sentences	8.7
Read a story	8.9
Write letters of the alphabet	8.1
Write some words	8.2
Count by himself/herself	8.2
Recognize written numbers	9.0
Write numbers	9.1
Do simple addition	7.6
Do simple subtraction	7.7
Like Learning Science	
I enjoy learning science	
I wish I did not have to study science	2.3
Science is boring	3.2
I learn many interesting things in science	3.9
I like science	3.2
I look forward to learning science in	3.3
school	3.2
Science teaches me how things in the world work	3.1
I like to do science experiments	3.1
Science is one of my favorite things	2.8
Science Self-Concept	
I usually do well in science	2.8
Science is harder for me than for many of my classmates	3.4
I am just not good at science	4.1
I learn things quickly in science	3.9
My teacher tells me I am good at science	3.9
Science is harder for me than any other subject	3.6
Science makes me confused	3.4