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Aspects of Science Engagement, Student Background, and School Characteristics: Impact on Science Achievement of U.S. Students

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ASPECTS OF SCIENCE ENGAGEMENT, STUDENT BACKGROUND, AND SCHOOL CHARACTERISTICS: IMPACTS ON SCIENCE ACHIEVEMENT OF U.S. STUDENTS

DISSERTATION

A dissertation submitted in partial fulfillment of the requirements of the requirements for the degree of Doctor of Philosophy in the College of Education at the University of Kentucky

By
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Lexington, Kentucky

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Science achievement of U.S. students has lagged significantly behind other nations; educational reformers have suggested science engagement may enhance this critical measure. The 2006 Program for International Student Assessment (PISA) was science-focused and measured science achievement along with nine aspects of science engagement: science self-efficacy, science self-concept, enjoyment of science, general interest in learning science, instrumental motivation for science, future-oriented science motivation, general value of science, personal value of science, and science-related activities.

I used multilevel modeling techniques to address both aspects of science engagement and science achievement as outcome variables in the context of student background and school characteristics. Treating aspects of science engagement as outcome variables provided tests for approaches for their enhancement; meanwhile, treating science achievement as the outcome variable provided tests for the influence of the aspects of science engagement on science achievement under appropriate controls.

When aspects of science engagement were treated as outcome variables, gender and father’s SES had frequent (significant) influences, as did science teaching strategies which focused on applications or models and hands-on activities over-and-above influences of student background and other school characteristics. When science achievement was treated as the outcome variable, each aspect of science engagement was significant, and eight had medium or large effect sizes (future-oriented science motivation was the exception). The science teaching strategy which involved hands-on activities frequently enhanced science achievement over-and-above influences of student background and other school characteristics. Policy recommendations for U.S. science educators included enhancing eight aspects of science engagement and implementing two specific science teaching strategies (focus on applications or models and hands-on activities). Focused implementation of these research findings could enhance both science engagement and science achievement of U.S. students. I identified five key
limitations of my research project: the age of the dataset, the lack of racial/ethnic identifiers, the low proportion of student-level variance accounted for by multilevel models with aspects of science engagement as outcome variables, the lack of class-level measures, and the lack of inclusion of students’ epistemological and fixed/flexible beliefs. These limitations provide opportunities for further investigations into these critical issues in science education.

KEYWORDS: Science Engagement, Science Achievement, Student Background, School Characteristics, Adolescents
ASPECTS OF SCIENCE ENGAGEMENT, STUDENT BACKGROUND, AND SCHOOL CHARACTERISTICS: IMPACTS ON SCIENCE ACHIEVEMENT OF U.S. STUDENTS

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April 27, 2016
To our children, Joseph, Laura Grace, and Jonathan, 
and to their spouses Charlie and Katie.
You have chosen to continue learning and serving as a way of life. 
Mary Jo and I pray that you and your families and those you influence may make similar choices.
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This dissertation benefitted greatly from the wisdom and direction of my Dissertation Chair, Dr. Xin Ma. His training in the methods of multilevel modeling during a course on that topic later led to this research; his ongoing patient assistance was even more critical in developing the project and preparing the dissertation itself. In addition, I also want to thank Dr. Fred Danner for his encouragement to stay the course on this extended project, and to both him and Dr. Kenneth Tyler for their negotiations with the Graduate School to arrange for an extension so that this dissertation could finally be completed. In addition to Drs. Danner and Tyler, I also wish to thank Dr. Jennifer Wilhelm as a member of my committee for her insights on sharpening the understanding of differences between the aspects of science engagement in the research. Thanks as well to Dr. Justin Bathon for his willingness to engage in this process as an outside examiner.

In addition to the essential support provided by the suite of five academic experts above, I would not have finished this work without the remarkable patience of my wife Mary Jo. She went through a similar process with me decades ago in another dissertation, and stood with me through this extended process. All of adult children and their spouses, Joseph Grabau, Laura Grace and Charlie Brill, and Jonathan and Katie Grabau, have been remarkably supportive. Among them, they have earned or are working toward a total of eight University of Kentucky degrees from four different colleges; this degree will be from a fifth such college. As a first generation college student myself, I am glad that my parents encouraged me to go on from my rural roots to a major university, and have been pleased with the academic opportunities involved in that life.
Also, I must acknowledge with profound gratitude the thousands of students with whom I have been privileged to learn over the past decades. I believe that I have learned more from trying to help you learn than I have ever learned on my own. Further, I am very grateful to fellow faculty and staff at the University of Kentucky (especially the College of Agriculture, Food and Environment) and beyond for the sharpening you have provided.

Some of us acknowledge key turning points in our lives when we look back and note that life became different from that point forward. Others will suggest that a given time frame was the start of a lifelong transformation. As I age, I have concluded that an essential key to aging gracefully is living gracefully across the course of one’s life. The point at which I began to understand what such grace-filled living might mean was when I had a personal encounter with Christ at age 19. I am hopeful that those I encounter might see glimpses of his character in my life.
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Chapter One: Statement of the Problem

Science achievement of U.S. students has lagged significantly behind that of many other nations in several standardized international student assessments. For example, U.S. science achievement was significantly below the Programme for International Student Assessment (PISA) average in 2006 (Organization for Economic Cooperation and Development [OECD], 2007b), and was not significantly different from the PISA average in 2009 (OECD, 2010b) or 2012 (OECD, 2014b). Further, while U.S. science achievement on PISA improved from 2006 to 2009 (OECD, 2010b), no further gains were noted on PISA from 2009 to 2012 (OECD, 2014b). Of additional concern is that the gap between U.S. science achievement and that of the top-performing countries/regions has continued to widen; for example, Singapore, Hong Kong, Korea, and Japan, all ranked well ahead of the U.S. in science achievement on PISA 2009 (OECD, 2010b), yet each showed significant gains in science achievement from PISA 2009 to PISA 2012 (OECD, 2014b). Cited in Ma and Ma (2014), Education Secretary, Arne Duncan, called the U.S. PISA 2012 results “a picture of educational stagnation” and stated that

The brutal truth, that urgent reality, must serve as a wake-up call against educational complacency and low expectations. The problem is not that our 15-year-olds are performing worse today than before. The problem is that they’re simply not making progress. Students in many other nations are advancing instead of standing still. In a knowledge-based global economy where education is more important than ever before, both to individual success and collective
prosperity, our students are basically losing ground. We’re running in place as other high performing countries start to lap us.

In an effort to address this science performance issue among U.S. students, some reforms have been recommended, such as improved school resources for science education (Wößmann, 2003), reduced class size and certification of a larger percentage of teachers (Fuchs & Wößmann, 2007), and adoption of enhanced science teaching methods (Perera, 2014). Improvement in affect toward science has also been given significant consideration; for example, with science self-efficacy (Perera, 2014), science self-concept (Lau & Roeser, 2002), instrumental motivation for science (Acosta & Hsu, 2014a), and enjoyment of science (Tang & Neber, 2008). In fact, improving affect is drawing more attention in multiple arenas of education. Math educators are paying increasing attention to the roles of aspects of math engagement in math achievement; for example, the math-focused iteration of PISA 2012 (OECD, 2014c) included ten aspects of math engagement, and research reports based on that extensive engagement-related math achievement dataset are beginning to appear (Scherer & Siddiq, 2015). In a similar way, reading educators are paying increased attention to affective factors (Lee, 2014). Thus, improved affect for science education is now being seen as a very promising strategy to improve science achievement.

Fensham (2009) noted that the inclusion of nine affective, science-related items in PISA 2006 had a political as well as a research intent; that is, OECD wanted to signal to science educators worldwide that the development of positive affect toward science was a favorable goal, as well as to provide opportunities to identify connections between science affect and science achievement. Thus, OECD’s working assumptions (according
to Fensham, 2009) were that: i) positive affect toward science could be developed within students (see also Chen & Pajares, 2010; Tsai, 2000; Ziegler et al., 2014), ii) such positive affect toward science was desirable, and iii) positive affect toward science could enhance science achievement. I adopted the same visions in this current research project.

**Definitions of the Aspects of Science Engagement as well as Science Achievement**

According to Hampden-Thompson and Bennett (2013, p. 1327), *science engagement* “is a multidimensional concept that broadly encompasses three components, namely behavioral engagement, emotional engagement, and cognitive engagement.” In contrast, Chang, Singh, and Mo (2007) and Singh, Granville, and Dika (2002) categorized science engagement in almost exclusively behavioral terms. The more broadly based approach of Hampden-Thompson and Bennett (2013) would seem to have more utility in explaining science achievement, since it takes into account more of the aspects which may influence this key measure. The OECD has taken a similar stance, as it has defined science engagement as covering “self-related cognitions, motivational preferences, emotional factors as well as behavioral-related variables (such as participation in science-related activities in and out of school)” (OECD, 2009, p. 55).

Nine aspects of science engagement were available for study in the 2006 PISA dataset (OECD, 2007a): science self-efficacy, science self-concept, enjoyment of science, general interest in science, instrumental motivation for science, future-oriented science motivation, general value of science, personal value of science, and science-related activities.

OECD intentionally set up four paired aspects of science engagement in their 2006 science-focused study (OECD, 2009). Those pairs were as follows: i) science self-
efficacy and science self-concept, ii) enjoyment of science and general interest in science, iii) instrumental motivation for science and future-oriented science motivation, and iv) general value of science and personal value of science. (The ninth aspect, science-related activities, was not paired with another aspect.) The pairs were intended to test different aspects of science engagement, as noted by the definitions in this section, the prompts provided to students (see Appendix A), and specific differentiations which my text attempts to provide.

Although PISA employs each of the science engagement terms based on a set of items addressed to student respondents, in most cases, OECD (2009) did not provide a specific definition of the aspect of science engagement. In order to properly introduce readers to each of the nine aspects of science engagement in PISA, I developed definitions based on empirical research, supplemented with the PISA items themselves (as shown in Appendix A).

Science self-efficacy was described as a student’s “confidence in performing science-related tasks” (OECD, 2009, p. 464). Based on that concept, Britner and Pajares (2006) found that mastery experiences were most responsible for the formation of science self-efficacy. Chen and Pajares (2010) determined that a student’s belief in her incremental abilities would enhance science self-efficacy; Uitto (2014) related this aspect to a student’s perception of his capacity to put into play acquired knowledge and skills when confronted with new science-based tasks. Thus, a consensus definition for science self-efficacy could be stated as a student’s confidence in performing challenging new science-related tasks.
Science self-concept is a student’s belief that she can easily learn and understand science concepts. Steinmayr, Dinger, and Spinath (2012) argued that the dimensions of science self-concept should be considered as intrinsic task value, importance, and utility. Some authors (e.g., Bhanot & Jovanovic, 2009; Riegle-Crumb, Moore & Ramos-Wada, 2011) identified science self-concept primarily as an expectation for successful achievement in science. Jansen, Schroeders and Lüdtke (2014) considered biology, chemistry and physics self-concepts separately; however, they simply used the PISA 2006 items for science self-concept and replaced “science” with “biology” or “chemistry” or “physics” in their items. The definition for science self-concept could thus be extended as follows: science self-concept is a student’s belief that he can learn, understand, and perform at a high level in science disciplines.

Correlations between science self-efficacy and science self-concept were 0.60 for a 500-student sample of U.S. students and 0.55 for the entire OECD sample (OECD, 2009). Bong and Skaalvik (2003), focused on the more broadly construed comparison of academic self-efficacy and academic self-concept, identified several common features. However, they also noted a number of distinguishing characteristics, namely, that self-efficacy seemed to be more malleable, was less norm-referenced, and tended to focus more on the future compared with past performance. In a math context, Bong, Cho, Ahn, and Kim (2012) emphasized the context-specific performance aspect of self-efficacy relative to an individual student’s sense of disciplinary strength in comparison to a socially-derived frame of reference.

Enjoyment of science is derived from a student’s feelings of fun and happiness when engaging in science learning activities. Shumow, Schmidt, and Zaleski (2013)
adopted this concept to report that students enjoyed science more with hands-on learning activities. Ng, Lay, Areepattamannil, Treagust, and Chandrasegaran (2012) made use of the Trends in International Mathematics and Science Study (TIMSS) survey items to assess science enjoyment; TIMSS items were similar to PISA items but may not have delineated the same level of exuberance as did PISA items. An improved consensus definition is thus: enjoyment of science constitutes a student’s happiness while taking part in science learning activities.

*General interest in science* relates to a student’s expressed desire to learn about an array of science subjects and science methodologies. Areepattamannil (2012a) focused his study of the relationship between science motivation and science achievement of Qatari students exclusively on this aspect of science engagement, using the PISA 2006 items. In a similar way, McConney and Perry (2010) considered science interest of Australian students, using the PISA 2006 aspect as prepared. Larson, Stephen, Bonitz and Wu (2014) provided students with a list of science activities (e.g., “working with plants and animals”, p. 93), and then asked students to respond regarding their level of interest. Swarat, Ortony, and Revelle (2012) were more concerned about a psycho/physiological state of interest; perhaps a more transient feature than what Areepattamannil (2012a) was investigating. Thus, the available research appears to have confirmed the above definition.

Unsurprisingly, correlation between enjoyment of science and general interest in science was 0.73 for a U.S. sample and 0.75 for the complete OECD sample (OECD, 2009). While Anderson and Chen (2016) appear to have recently conflated these related constructs as a single concept (which they refer to as “interest-enjoyment value” p. 57), a
close inspection of their methods and supporting references showed closer alignment of their measure with what I have described as enjoyment of science above. In numerous recent cases (e.g., Ainley & Ainley, 2011a; Jack, Lin, & Yore, 2014; Woods-McConney, Oliver, McConney, Maor, & Schibeci, 2013; Woods-McConney, Oliver, McConney, Schibeci, & Maor, 2014), researchers have utilized the PISA differentiation between enjoyment of science and general interest in science, specifically that enjoyment of science focuses on a student’s affect while involved in school science activities and that general interest in science is assessed based on a student’s reported interest in specific science disciplines. Further, Ainley & Ainley (2011a) identified a transcendent (across four culturally diverse nations) of enjoyment of science on interest in science.

*Instrumental motivation for science* (to learn science) is defined as a student’s cognitive investment in science learning because the student perceives that science will be of value in future study, work, career, or job. Acosta and Hsu (2014a) as well as Hampden-Thomas and Bennett (2013) used this aspect of science engagement directly from PISA 2006. Spearman and Watt (2013) assessed an “extrinsic utility value” of science in their work, based on an expectancy/value framework (p. 223). Farmer, Wardrop, and Rotella (1999) noted that women who wound up in science careers held a higher value for high school science and thus took more elective science courses during their high school years.

*Future-oriented science motivation* focuses on a student’s expressed desire to work, study, or spend her life in an area of science. The comprehensive work of Lupart, Cannon, and Telfer (2004) included items similar to those in PISA which addressed the
perceived future value of science. Riegle-Crumb et al. (2011) also addressed career desires of students in their study.

Instrumental motivation for science and future-oriented science motivation showed correlation in both U.S. (0.67) and overall OECD (0.72) samples (OECD, 2009) from the PISA 2006 science-focused study. Shin et al. (2015) utilized both of these concepts in their recent study with Korean students; they differentiated between instrumental motivation for science as a stepping stone for a future science-related career and future motivation for science as a desire to study or work in a science area in their future. Thus, while the two concepts were related, instrumental motivation left space for a student to operate from a more pragmatic sense, while future motivation was more focused on personal desire.

*General value of science* represents a student’s belief that scientific advances provide benefits to society as a whole. Acosta and Hsu (2014b) used this aspect of science engagement directly from PISA 2006. Khalijah et al. (1995) employed this concept to explore why collegiate-level physics enrollment was declining in Malaysia. They attributed that decline to the perception of Malaysian high school students that physics had only an indirect role in impacting the economy.

*Personal value of science* relates the relevance of science and science topics to students as individuals. Viljaranta, Nurmi, Aunola, and Salmela-Aro (2009) noted that Finnish adolescents who valued science and math were more apt to expect to find themselves in careers which would take advantage of training in those academic areas. Else-Quest, Mineo, and Higgins (2013) measured task value for students on a personal
basis from an expectancy/values framework (see Wigfield & Eccles, 2000, and related
discussion below).

General value of science and personal value of science were closely related in the
2006 PISA study, with the U.S. sample showing a latent correlation of 0.77, while the
OECD sample had a latent correlation of 0.78. Woods-McConney et al. (2013) observed
higher general value of science than personal value of science for both majority and
indigenous students in their study across Australia and New Zealand. General value of
science, as noted above relates to its value to society at large, while personal value of
science relates to individuals. Intriguingly, Vázquez Alonso & Manassero Mas (2009)
found students across many nations to perceive science as valuable for environmental
reasons, but to hold precious little personal value. In some contexts, science teachers
may lack interest in helping their students comprehend the social importance of science
(Lee & Witz, 2009), therefore, forfeiting an opportunity to enhance students’ general
value of science.

*Science-related activities* are a student’s self-chosen science activities outside of
the context of classroom (such as watching TV programs about science or reading
science stories on the internet). Gerber, Cavallo, and Marek (2001) described such
activities as “enriched informal learning environments” (p. 539) and found enhanced
scientific reasoning ability for students who had the benefit of such opportunities.
VanMeter-Adams, Frankenfeld, Bases, Espina and Liotta (2014) identified
extracurricular activities during childhood (such as encounters with nature) as especially
formative, while Ho (2010) centered on children’s experiences with science through
books and television as key factors.
Science achievement, as conceived of by PISA for 15-year-old students, was based on a combined science literacy scale including three subscales: using scientific evidence, identifying scientific issues, and explaining phenomena scientifically (OECD, 2007c). Other international large scale assessments such as TIMSS have considered science achievement of eighth grade students as a composite of student performance on items drawn from the disciplines of biology, chemistry, earth science and physics (Louis & Mistele, 2012; Olson, Martin, & Mullis, 2008). Yet others have considered science achievement to be represented by student grades in science courses (as reported by their schools or instructors [e.g., Cano, García, Berbén, & Justicia, 2014; Else-Quest et al., 2013] or by the students themselves [e.g., Martinez & Guzman, 2013]).

Specifically, OECD (2007c) defined science literacy as the combination of identifying scientific issues and applying appropriate principles to their personal decisions, being able to distinguish between evidence- and opinion-based statements about science issues, and understanding the roles of technologies in one’s culture and environment. According to Bybee and McCrae (2011), the TIMSS instrument has been closely tied to school curricula in science, but PISA has attempted instead to assess science literacy as the “application of knowledge to science- and technology-related life situations” (p. 7). An informal way to describe the skill set addressed by PISA could be as survival skills in an increasingly scientific world. Most educational authorities around the world have regarded PISA science achievement as focused on building of life skills as opposed to purely academic skill sets (Acosta & Hsu, 2014a; Dolin & Krogh, 2010; Hampden-Thompson & Bennett, 2013; Lavonen & Laaksonen, 2009). Geller, Neumann, Boone, and Fischer (2014) argued that Finnish students performed better in a PISA-style
assessment environment than their European peers because of the applications-oriented instruction they routinely received.

**Theoretical Framework of This Study**

Fredricks, Blumenfeld, and Paris (2004) defined school engagement as a meta-construct with high research and conceptual value, consisting of cognitive, emotional and behavioral factors. To these scholars, cognitive engagement included students’ investment in school and therefore a willingness to commit effort to master their work; emotional engagement related to both positive and negative responses to the entire school environment (social and academic) and thus influenced both their connections with the school and their intention to participate in school activities; and finally, behavioral engagement connected with actual participation, both within and beyond the context of the school itself. Notably, the primary outcome of interest in the review of Fredricks et al. (2004) was academic achievement. The comprehensive model of school/academic engagement of Fredricks et al. (2004) was thus inclusive of cognitive (e.g., Wehlage, Rutter, Smith, Lesko, & Fernandez, 1989), emotional (e.g., Lee & Smith, 1995) and behavioral (e.g., Finn, Pannozzo, & Voelkl, 1995) strands. The nine aspects of science engagement in OECD (2009) shared this approach, as have Chen (2005), Demanet and Van Houtte (2014) and Lam et al. (2014). While others have included only behavioral and emotional factors in their approaches (e.g., Green et al., 2012; Skinner, Kindermann, & Furrer, 2009) or simply behavioral factors (e.g., Chang et al., 2007; Singh et al., 2002), the three-stranded approach of Fredricks et al. (2004) appears to have captured more of the full breadth of the factors involved in engagement which could potentially influence academic achievement.
Importance of PISA

On a global scale, PISA has proved to be a remarkably important lever for the promotion of both educational reforms (de Mendizábal & Calero Martínez, 2013; Dolin & Krogh, 2010; Gür, Çelik, & Özoğlu, 2012; Hartong, 2012; Santín & Sicilia, 2015; Waldow, Takayama, & Sung, 2014; Zawistowska, 2014) and economic growth (Bieber & Martens, 2011; OECD, 2010a). Based on the analysis of OECD (2010a), an increase in PISA scores by 25 points for all OECD member nations would result in a global gain of over $100 trillion U.S. across the lifetime of affected students. Bieber and Martens (2011) found that Swiss educational authorities were much more eager to adopt educational reforms than were their U.S. counterparts even though Swiss students scored better than American students. Both U.S. educational leaders and public discourse in the U.S. have seemed to regard PISA as just one of many exams rather than one of transcendent importance, and therefore, there may be room for the U.S. to benefit from the importance of PISA both educationally and economically (Bieber & Martens, 2011).

National school systems in East Asia, along with selected European nations, have been identified as exemplars of science, math, and reading achievement (e.g., Acosta & Hsu, 2014b; Ho, 2010; Lavonen & Laaksonen, 2009; Ma et al., 2013; Sun, Bradley, & Akers, 2012); other nations have looked to these leaders for potential strategies to improve student achievement and thereby economic progress. For example, Bouhlila (2011) made use of PISA results in an effort to understand the reasons underlying below-average science achievement across the entire region of Middle East and North Africa, along with appropriate remedies at the individual and school level. Thus, PISA has immense value in assisting nations in both identifying and correcting shortcomings in
their educational systems; this, of course, has the potential for remarkable economic benefits (Bieber & Martens, 2011; OECD, 2010a).

In particular, the unique confluence of the availability of nine aspects of science engagement as assessed in PISA 2006 (OECD, 2009) affords the science education research community an opportunity to reconsider the potential impact of science engagement beyond its traditional domain (Ainley & Ainley, 2011a, 2011b). This emerging conceptual extension of science engagement (with nine aspects [OECD, 2009] and a meta-construct [Fredricks et al., 2004]) with comprehensive data supplied by PISA has created a valuable research opportunity to apply this expanded notion of engagement to the study of science achievement. Science education researchers are now able to compare the influences of aspects of science engagement on science achievement across nations (Woods-McConney et al., 2014), across a variety of student characteristics for the examination of the role of student background (Areepattamannil, 2012b; Areepattamannil & Kaur, 2013; Sikora & Pokropek, 2012), and across a variety of school factors for the examination of the role of school effects (Basl, 2011).

**Purpose of This Study**

Researchers in the U.S. have begun to make serious efforts to learn from countries/regions which are making greater progress in science education. For example, key factors involved in science achievement in East Asia have been shown to include student use of adaptive learning strategies and school-level disciplinary climate (Ma, Jong, & Yuan, 2013). Ma and Ma (2014) reported a much stronger relationship between learning styles (competitive or cooperative) and mathematics achievement among East Asian students than American students. While it is possible that the particulars of
individual student strategies or school-level policies may not transfer directly from nations successful in promoting science (or mathematics) achievement of their students, the possibility of identifying U.S.-specific student- or school-level factors positively related to science achievement is compelling.

This dissertation research has joined a nation-wide effort to identify better ways to improve science achievement in the U.S. and was particularly inspired by the importance of the affective domain in science education (Ma et al., 2013; Ma & Ma, 2014). Using data from PISA 2006, the latest PISA cycle with a focus on science education of 15-year-olds, this dissertation research will examine science engagement and science achievement, with a focus on individual differences and school effects. Specifically, this research project will be carried out in two steps, the first focusing predominately on science engagement and the second mainly on science achievement. The following research questions will direct the first step of this project:


1b. Are there school effects, over and above individual differences, in aspects of science engagement among U.S. 15-year-olds? Or, do school-level factors influence aspects of science engagement of U.S. 15-year-olds over and above the effects of student background factors?

Once the above two questions have been satisfactorily addressed, I intend to proceed to address science achievement, also in the context of individual differences and
school effects, in relation to the potential influence of science engagement. The following research questions will drive the second step of this research effort:


2c. Are there school effects, over and above individual differences and effects of aspects of science engagement, on science achievement among U.S. 15-year-olds? Or, do school-level factors influence science achievement of U.S. 15-year-olds over and above the effects of student background factors and aspects of science engagement?

**Importance of This Study**

As noted above, science achievement of U.S. students continues to lag well behind that of many other nations, and the U.S. is falling further behind the leaders (OECD, 2014b). Evidence from science self-efficacy and science self-concept in Finland (Lavonen & Laaksonen, 2009), science self-concept in Germany (Steinmayr et al., 2012), and general interest in science in Qatar (Areeppattamannil, 2012a) has provided encouragement that gains in these aspects of science engagement could potentially enhance science achievement of U.S. students. As a first step toward understanding the
potential relationships between science engagement and science achievement, I examined each of the nine aspects of science engagement established and made available in PISA 2006 (science self-efficacy, science self-concept, enjoyment of science, general interest in science, instrumental motivation for science, future-oriented science motivation, general value of science, personal value of science, and science-related activities), using a multilevel modeling approach to identify individual differences and school effects above and beyond individual differences (Ma, Ma, & Bradley, 2008) on those aspects of science engagement as outcome (i.e., dependent) variables. In the second part of my study, science achievement was the outcome variable for nine successive models, each including one of the nine aspects of science engagement. This dissertation research thus provided a powerful mechanism to address the relationship between science engagement and science achievement, and potentially to direct policies and practices toward interventions which may address the problematic situation in U.S. science achievement by addressing the appropriate aspects of science engagement.

Professional grass-root organizations have long been emphasizing the importance of the affect domain in educational reform. The National Science Teachers Association (NSTA, 2003) argued that for substantive science learning to take place, students needed to be engaged on the basis of their preconceptions of how the world functions. Thus, sound science instruction must address student engagement as a first step to the construction of science-oriented conceptions and understandings, and then subsequently progress toward true science literacy (NSTA, 2003). A prior report from the National Commission on Mathematics and Science Teaching for the 21st Century, while expressing a familiar concern about stagnant achievement levels for U.S. students in
science and math, expressed the hope that students would grow in their interest in and valuing of these critical areas through the determined efforts of their teachers (U.S. Department of Education, 2000). In a similar way, the National Council of Teachers of Mathematics (NCTM) has emphasized the involvement of the affective domain as an avenue to enhance math achievement (Stephan et al., 2015). Prior research supportive of the stance by the NCTM has included Ho et al. (2000), related to math anxiety, and McGraw, Lubinski, and Strutchens (2006), tied to math self-concept.

Relatively limited research has focused on the connections between aspects of science engagement and science achievement of U.S. high school students. Some U.S. based research has identified differences among students in aspects of science engagement, without considering science achievement; for example, Greenfield (1996) and Shumow et al. (2013). Only in rare cases (e.g., science-related activities) have American researchers connected aspects of science engagement with science achievement (Gerber et al., 2001). At the high school level, American researchers have noted differences among students in personal value of science (Else-Quest et al., 2013), enjoyment of science (Shumow et al., 2013), and science-related activities (VanMeter-Adams et al., 2014); however, those differences in aspects of science engagement were not related to differences in science achievement. On the other hand, international research relating aspects of science engagement to science achievement has been much more extensive (e.g., Acosta & Hsu, 2014a; Areepattamannil, 2012a; Hampden-Thompson & Bennett, 2013; Ho, 2010; Lavonen and Laaksonen, 2009; McConney & Perry, 2010; Woods-McConney et al., 2013). This dissertation research could therefore
bring important insights to an area of science education area which has lacked substantive
depth in the U.S.

**Organization of This Study**

This dissertation is divided into five chapters. Chapter one provides an
introduction to the study and an overview of possibility that aspects of science
engagement may influence science achievement in the context of student background and
school-level factors. Chapter two develops a comprehensive literature review of the
aspects of science engagement, student background variables, and school-level factors
and their relationships to science achievement. Chapter three elucidates the data sources
chosen and the methodologies implemented to address the research questions. Chapter
four reports and presents the findings of the study and draws inferences based on the
methodologies implemented. Chapter five relates the findings of this study to the
literature review, draws overall conclusions, addresses limitations, and suggests potential
directions for future research.

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Chapter Two: A Review of the Literature

Several theoretical frameworks are discussed as part of the first section of this literature review. The overarching framework of Fredricks et al. (2004) provided a structural basis for including aspects of science engagement drawn from behavioral, cognitive and emotional realms. Fredricks et al. (2004) defined school engagement as a meta-construct with high research and conceptual value, consisting of cognitive, emotional and behavioral factors. To these scholars, cognitive engagement involved students’ investment in school and therefore their willingness to commit effort to master their work; emotional engagement related to both positive and negative responses to the entire school environment (social and academic) and thus influenced both their connections with the school and their intention to participate in school activities; and finally, behavioral engagement connected with actual participation, both within and beyond the context of the school itself.

The comprehensive model of school/academic engagement of Fredricks et al. (2004) was thus inclusive of cognitive (e.g., Wehlage et al., 1989), emotional (e.g., Lee & Smith, 1995) and behavioral (e.g., Finn et al., 1995) strands. Specific individual theoretical frameworks provided various concentrations on key components of the overarching framework of Fredricks et al. (2004). Expectancy/values theory (Wigfield & Eccles, 2000) afforded the foundation for the development of science self-concept, as well as its interrelationship with personal and instrumental values of science. Achievement goal orientation theory (Dweck & Leggett, 1988) situated multiple aspects of science engagement as antecedents or results of performance or mastery goal orientations of students. Epistemic development concepts (Schommer-Aikins, 2004)
ascribed differences among science students in their investment in learning science, in spite of similarly high science self-concepts, to fixed beliefs by some students about how much they could learn. The social-cognitive theoretical framework of Bandura (1986, 1997) supported the development of academic self-efficacy in general; while more recent references (e.g., Britner & Pajares, 2006) pointed toward science self-efficacy in particular.

While the above theoretical frameworks primarily related to an individual student’s degree of science engagement, other theoretical frameworks have been tied primarily to students’ science achievement. For example, stereotype threat could potentially explain academic achievement differences between minority and majority group students (Inzlicht & Schmader, 2012). On the other hand, the lack of opportunity for a given group could influence their preparedness to perform in a given area of academic study (Roemer, 2009).

Differences among students in regard to their aspects of science engagement have been identified. Some researchers evaluated all nine aspects of science engagement as assessed in PISA 2006. For example, in the work of Woods-McConney et al. (2014), Australian students showed slightly lower levels of all nine aspects of science engagement compared with their Canadian peers; further, the Canadian students had a modest advantage in science achievement. Males in both nations scored higher in most measures of science engagement. Other researchers evaluated single aspects of science engagement; for example, in science self-efficacy (Rice, Barth, Guadagno, Smith, & McCallum, 2013), science self-concept (Robnett & Leaper, 2012), enjoyment of science (Shumow et al., 2013), instrumental motivation for science (Greenfield, 1996), personal
value of science (Else-Quest et al., 2013), and science-related activities (VanMeter-Adams et al., 2014). A significant question underlying this study is the degree to which aspects of science engagement are related to science achievement.

As noted in chapter one above, although notable differences in science achievement have been observed between nations/regions (OECD, 2007b, 2010b, 2014b), profound differences in science achievement between individual students have been measured as well (e.g., Chen & Pajares, 2010). Some U.S. based research has connected aspects of science engagement with science achievement (e.g., science-related activities [Gerber et al., 2001]). International research relating aspects of science engagement to science achievement appears to have dwarfed the work done within the U.S. on this relationship (Acosta & Hsu, 2014a; Acosta & Hsu, 2014b; Anagün, 2011; Areepattamannil, 2012a; Areepattamannil, Freeman, & Klinger, 2011; Hampden-Thompson & Bennett, 2013; Ho, 2010; Jack et al., 2014; Jocz, Zhai, & Tan, 2014; Lavonen & Laaksonen, 2009; Lin, Lawrenz, Lin, & Hong, 2012b; McConney & Perry, 2010; Ozel, Caglak, & Erdogan, 2013; Woods-McConney et al., 2013; Woods-McConney et al., 2014).

I note that the terms “individual differences” and “student background” are often used interchangeably. In the context of this dissertation, I have attempted to preferentially employ the term “student background” as much as practical. In the section below on the influence of student background on science engagement, literature which pertains to the nine defined aspects of science engagement (see chapter one) will be included, whether or not researchers also related their findings to measures of science achievement. In the ensuing section related to the influence of student background on
science achievement, only literature which comes outside the context of science engagement will be considered. This is a key point, as my methods (see chapter three) are designed to disentangle the effects of the aspects of science engagement from those of student background.

School-level effects have garnered much more attention in the recent past; this appears to be related to the prospect that practices and policies put into effect at the school level may have more influence on desired outcomes (e.g., academic achievement) than efforts focused on individual students (Wößmann, 2003). Across 39 nations, school-level factors (e.g., school autonomy in decision-making, teaching method selection, and competition from private schools) had more influence on students’ academic achievement than did individual students’ family background (Wößmann, 2003). As noted above for East Asian regions, school disciplinary climate had a profoundly positive influence on science and math achievement (Ma et al., 2013). Comparing 15-year olds from schools in 41 countries, Chiu and Khoo (2005) found that resource availability at all levels (country, school, and student) was related to achievement in science and math. Von Secker (2004) noted a protective influence of science inquiry/hands-on science instruction on science achievement across multiple risk factors of low SES, minority status and female gender; further, the protective influence of this approach was more pronounced for older minority students. Thus, school-level factors have been shown to influence science achievement, making them important targets for an investigation of science motivational constructs. School-level factors can (and should) be categorized as context variables (those related to the physical location, resources, teaching staff, mean student backgrounds, and the like) and climate variables (those related to policies and
procedures implemented at the school, teacher and parent expectations, and the like) (see Ma et al., 2008). Thus, the school-level literature review is organized according to their model, with separate sections for school context and school climate.

Selection of both student background and school-level independent variables was based on availability of those measures in the PISA 2006 database (OECD, 2007a). For student background, I was able to include gender, age, father’s SES, mother’s SES, immigration background, and language spoken at home. This chapter addresses all six of these student background characteristics; however, since relatively few researchers have considered father’s and mother’s SES separately, I chose to group that material under “family SES.”

School-level independent variables available from PISA 2006 (OECD, 2007d, 2007e) for inclusion in this study included nine school context variables and ten school climate variables. Those nine school context variables were as follows: school size, school type, proportion of girls enrolled, school-mean father’s SES, school-mean mother’s SES, proportion of teachers certified, student-teacher ratio, teacher shortage, and quality of educational resources. The ten school climate variables included in this research were: school responsibility for resource allocation, school responsibility for curriculum and assessment, ability grouping, school activities to promote science learning, parent influence, teacher influence, and school means on four types of science teaching (focus on models or applications, hands-on activities, interaction, and student investigations). Note that further details about these independent variables are available in chapter 3 and Appendix B.
Literature availability appears to be relatively modest for school context variables as related to science engagement; hence my review of the literature in that area is brief. In contrast, more research was available relating school climate variables to science engagement; notably, almost all such research related to instructional methods, and could not necessarily be directly tied to the four types of science teaching assessed in my research. Thus, my review of the literature for the influence of school climate variables on science engagement is focused within a single section on science instruction in general.

On the other hand, much more work has been done which relates school context variables to science achievement; I was able to include discussions of school size, school type, proportion of girls in a school, school-level SES (though not subdivided by father’s or mother’s SES), teacher certification, student-teacher ratio, teacher shortage, and quality of educational resources. Thus, with the caveat that school-mean father’s SES and school-mean mother’s SES (considered separately in my study) could not be addressed separately in the review of the literature, all of the other school context variables were discussed as to their relationship with science achievement. In the case of the potential relationships between school climate variables and science achievement, ability grouping, science promotion activities, parental involvement, and teaching strategies were discussed. Note that the literature on teaching strategies does not specifically align to the four types of science teaching presented in PISA 2006, and thus my literature review addresses science teaching in a single section. Thus, the three school climate variables for which I was not able to identify research showing potential
linkages to science achievement were school responsibility for resource allocation, school responsibility for curriculum and instruction, and teacher involvement.

**A Tripartite Basis for Science Engagement: Cognitive, Emotional, and Behavioral Factors**

Fredricks et al. (2004), in their comprehensive review article, defined school engagement as a meta-construct with high research and conceptual value, consisting of cognitive, emotional, and behavioral factors. To Fredricks et al. (2004), cognitive engagement included students’ investment in school and therefore a willingness to commit effort to master their work; emotional engagement related to both positive and negative responses to the entire school environment (social, academic) and thus influenced both their connections with the school and their likelihood to participate; and finally, behavioral engagement was connected with actual participation, both within and beyond the context of the school itself. Further, Fredricks et al. (2004) indicated that students would differ in their levels of commitment in each of those factors, ranging from tacit involvement to deep valuing. Most measures of these three general engagement factors are distinct from one another; that is, few researchers have attempted to build overall composite measures of student engagement. Notably, the primary outcome of interest in the review of Fredricks et al. (2004) was academic achievement.

Fredricks et al. (2004) built their theoretical framework on the basis of then-existing published work in the areas of cognitive, emotional, and behavioral engagement. Wehlage et al. (1989, p. 17) described cognitive engagement as “the psychological investment required to comprehend and master knowledge and skills explicitly taught in schools.” Newman, Wehlage, and Lamborn (1992) also related cognitive engagement to
a psychological investment of students in their own schooling. Meanwhile, Connell and Wellborn (1991) emphasized the cognitive resilience of such engaged students; these students found ways to cope in the face of failure, were flexible problem solvers and continued to work hard in school. An important aspect of emotional engagement was the composite reaction that students had toward their teachers and school environment (Lee & Smith, 1995). Student emotions could be positive (interest, happy) or less so (sad, bored, anxious); of course, such emotions could impact student learning (Connell & Wellborn, 1991). An intriguing consideration was that Fredricks et al. (2004) considered the concept of flow (Csikszentmihalyi, 1988) to represent a high order example of emotional engagement. In other words, when a student is operating in an academic context near the upper limit of her capacity, she may be so fully involved in trying to accomplish the academic tasks at hand that she is unaware of the passage of time or the presence of other students around her (Csikszentmihalyi, 1988). Much of the support for the behavioral strand of a three-part engagement theory has come from Finn (e.g., Finn, 1993; Finn et al., 1995; and Finn & Rock, 1997). Behavioral engagement itself has been described as involvement in academic learning (Birch & Ladd, 1997; Finn et al., 1995), adherence to school rules (Finn & Rock, 1997), or participation in extracurricular activities (Finn, 1993).

Besides the apparent influence of the review of Fredricks et al. (2004) on the science engagement aspects developed for PISA 2006 (OECD, 2009), several subsequent authors have implemented this tripartite view of science engagement (e.g., Chen, 2005; Demanet & Van Houtte, 2014; Lam et al., 2014; Sinatra, Heddy, & Lombardi, 2015). Chen (2005) described academic engagement as a construct including behavioral,
attitudinal and instrumental (that is, cognitive) processes which served together as an internal locus of control for students in the context of a variety of socializing influences (teachers, parents, peers). Demanet and Van Houtte (2014) invoked a perceived control theory to support their study of disengagement; I note that disengagement, to these authors, consisted of behavioral, cognitive and emotional disengagement. Demanet and Van Houtte (2014) focused on school, rather than domain-specific engagement. Lam et al. (2014) developed a student engagement scale involving cognitive, affective/emotional and behavioral aspects, testing their scale on 7th, 8th and 9th grade students from 12 countries. The scale of Lam et al. (2014) provided considerable credibility for student engagement as a meta-construct, and for cognitive, emotional and behavioral dimensions as underlying constructs; in addition, their work included a substantive review of recent literature on student engagement. Note that their work was situated in the broader context of school, rather than in a science or math context. Recently, Sinatra et al. (2015) affirmed the tripartite theoretical approach of Fredricks et al. (2004), situating their work in a person-centered “grain size” of measurement of science engagement in high school (p. 1).

Other authors have cited Fredricks et al. (2004) as their theoretical framework, yet have only included behavioral and emotional factors in their approaches to academic engagement (Green et al., 2012; Skinner et al., 2009). Skinner et al. (2009) presented four aspects of their multidimensional academic engagement construct: behavioral engagement, emotional engagement, behavioral disaffection and emotional disaffection. Their work focused on 3rd through 6th grade students, and did not include a cognitive aspect. An important strength of Skinner et al. (2009) was their recognition that students
can become disengaged as well as engaged in both behavioral and emotional arenas. Green et al. (2012) regarded both Skinner et al. (2009) and Fredricks et al. (2004) as their theoretical frameworks; however, Green et al. (2012) focused only on behavioral and emotional factors contributing to student engagement. Green et al. (2012) measured academic self-concept (which would be regarded as a cognitive engagement aspect); however, they regarded this variable’s relationship with achievement as mediated by academic engagement (consisting of behavioral and emotional components) rather than as part of academic engagement per se. Other researchers have followed the lead of Skinner et al. (2009) and Green et al. (2012) in regarding academic engagement as consisting of only behavioral and emotional factors (e.g., Kahraman, 2014; Lee, 2014). Kahraman (2014) compared behavioral and emotional engagement of 4th and 8th grade students in Turkey, finding that overall engagement declined from 4th to 8th grade. Lee (2014) evaluated student engagement in reading using the 2000 PISA dataset; she considered behavioral (effort) and emotional (sense of belonging) aspects of student engagement and related them to reading achievement of U.S. students.

Singh et al. (2002) emphasized the behavioral component of academic engagement; their focus was on time spent on homework for both math and science by U.S. middle school students. In a similar way, Chang et al. (2007) regarded academic engagement as a behavioral entity; of the four elements which arose through their exploratory factor analysis, only the one related to time spent on homework was significantly (albeit modestly) to achievement. Fan and Williams (2010) argued that schoolwork engagement is most often considered in behavioral terms, rather than in the broader context of emotional, cognitive and behavioral factors presented by Fredricks et
al. (2004). However, Fan and Williams (2010) found that considering cognitive and emotional factors (math self-efficacy and math enjoyment) enhanced their ability to explain the influence of critical variables (such as parents’ educational aspirations for their students which had positive influences on schoolwork engagement, math self-efficacy and math enjoyment).

Surprisingly, some researchers using the PISA 2006 dataset have chosen to describe science engagement in solely behavioral terms (Jack et al., 2014; Lin et al., 2012b; Woods-McConney et al., 2013; Woods-McConney et al., 2014). In each of the above cases, the research teams have taken one of the nine aspects of science engagement (science-related activities outside of school) and equated that aspect alone to science engagement. This is somewhat extraordinary, as OECD (2009) has described science engagement as including behavioral, cognitive and emotional factors. Jack et al. (2014, p. 1089) identified weak relationships between science self-concept, science self-efficacy, science enjoyment and science interest and what they termed “science engagement” (actually science-related activities). Lin et al. (2012b, p. 941), using the 2006 PISA Taiwanese dataset, referred to science-related activities as “leisure time engagement.” Notably, this is an incremental portion of what other authors refer to as science engagement; in this case, a behavioral measure, outside of the context of formal schooling, and not including either cognitive or emotional measures. Thus, its use as an outcome measure as a proxy for science engagement seems questionable at best. In some cases, all (Woods-McConney et al., 2014) or nearly all (Woods-McConney et al., 2013) of the other aspects of science engagement (OECD, 2009) were shown to be correlated to science-related activities outside of school (yet the relationships of these measures with
science achievement were left untested). These correlations lend some support to OECD’s inclusion of science-related activities as part of science engagement.

**Expectancy/Value Theory**

Wigfield and Eccles (2000) compared their expectancy/value theory of student motivation to other then-contemporary concepts, such as academic self-efficacy, interest and intrinsic vs. extrinsic motivation. Essentially, expectancy/value theory indicates that students make academic choices based on two primary underlying factors: i) their expectations for success, and ii) the subjective value which they ascribe to the academic task in front of them, according to the task’s importance, interest and utility. In turn, their expectations for success can be attributed to a complex combination of a student’s short- and long-term demands, academic self-concept, and even their “ideal self” (Wigfield & Eccles, 2000, p. 69). Meanwhile, task value is moderated by students’ affective memories (and to some extent, their expectancies for success). Underneath these student-level factors lie some social inputs, and students’ interpretations/assimilations of those social inputs. Wigfield and Eccles (2000) noted that while their expectancy/value theory involved subjective task value, self-efficacy focused on students’ self-assessment of their ability to perform specific academic tasks. Wentzel and Wigfield (1998) argued that combining self-concept, self-efficacy and expectancy for success together yielded a more robust conceptual construct with a better chance to understand their relationship with students’ academic achievement. Given that expectancy/value theory essentially subsumes self-concept under expectancy, and could be argued to be related to at least some extent to self-efficacy, the argument of Wentzel and Wigfield (1998) was hardly surprising. Wentzel and Wigfield (1998) additionally suggested that social influences
may play a role in developing motivational aspects of students, thus providing an impetus for cultivation of appropriate classroom-level achievement goal orientations; this fits reasonably well with the underlying suite of social inputs to the expectancy/value theory of Wigfield and Eccles (2000).

When confirmatory factor analyses were done for expectancies for success and students’ ability beliefs (in this context, as self-efficacy), expectancies for success and ability beliefs consistently loaded together (Eccles & Wigfield, 1995; Eccles, Wigfield, Harold, & Blumenfeld, 1993). However, students’ joint expectancies/ability beliefs were domain-specific (Eccles et al., 1993; Marsh, Craven, & Debus, 1991). While elementary students could only identify two of the subjective values in the model (interest and utility importance; Wigfield et al., 1997), by middle and high school, students could also respond to the attainment value embedded in the expectancy/values model (Eccles & Wigfield, 1995).

Many subsequent researchers have made use of the expectancy/value theoretical framework to good effect in the areas of science and math. Viljaranta et al. (2009) noted that Finnish adolescents who valued science and math were more likely to expect to find themselves in careers which would take advantage of training in those academic areas. Eccles (2011) affirmed the role of science self-concept and subjective value of science in both educational and occupational decisions by female students. Else-Quest et al. (2013) reported science and math expectations for success, values, and self-concept for both female and male U.S. 10th grade students among four different ethnicities (African-, Asian-, Euro-, and Hispanic-American), finding that Asian-American students had higher achievement in both math and science, males had higher math self-concept and math
expectation for success, and females held higher science values. Simpkins, Davis-Kean, and Eccles (2006) assessed out-of-school math activities of 5th grade U.S. students, observing that such activities positively influenced 6th grade math self-concept, math interest, and math importance. Further, they noted that such activities also were associated with taking a higher number of math courses, beyond what 5th grade math achievement would have predicted. In a longitudinal study, Watt et al. (2012) compared Australian, Canadian, and U.S. high school students for the influence of gender-related motivational processes on high school math course selection and subsequent educational/career plans. Males had higher math self-concept/success expectancy in both Canada and the U.S. than did females; math utility/importance played a greater role in subsequent choices of females. Australian males held a higher intrinsic value for math than did females. In addition, Anderson and Cross (2014) compared students of high ability levels in math with divergent profiles in math self-efficacy and math utility value, finding that significant percentages of such students, highly capable of doing mathematics, placed relatively modest value on this subject. Expectancy/value theory has thus provided an enduring framework for research related to the intersection between student attitudes and achievement in the fields of science and math.

**Achievement Goal Orientation Theory**

Dweck and Leggett (1988) proposed a model which grew out of Dweck’s prior work with academic helplessness (Dweck, 1975), yet extended into adaptive achievement goals as well. This was the foundation for what has subsequently become achievement goal orientation theory. Interestingly, Dweck and Leggett (1988) included cognitive, emotional and behavioral aspects in their work with achievement goal orientations. In a
closely related effort, E. Elliott and Dweck (1988) suggested that students who appeared to be exhibiting helpless behaviors, emotions, and cognitions may have a different goal orientation, one which they named a performance goal orientation. This was in marked contrast to the mastery orientation which Dweck and Leggett (1988) had observed, and was cause for reflection upon the rationale for these student responses to an academic challenge. A then-surprising result of this emergent theory was that a performance-oriented student could interpret a learning challenge as too costly in terms of effort or too likely to result in failure, and thus actively choose not to perform that learning challenge. This orientation was eventually described as performance-avoidance. An unsurprising result of the newly developed theory was that a mastery-oriented student could interpret the same learning challenge as worthy of effort and not consider the possibility of failure; this orientation was later described as mastery-approach. While this initial effort of Dweck and Leggett (1988) emphasized mastery-approach and performance-avoidance, it laid the groundwork for achievement goal orientation. Pintrich (2000) followed along behind them with the development of the concept of performance-approach as an achievement goal orientation; in fact, he considered this orientation to be just as adaptive as a mastery-approach orientation. Like Dweck and Leggett (1988), Pintrich (2000) considered achievement goal orientation to involve cognitive (e.g., self-efficacy), emotional (both negative and positive) and behavioral aspects (e.g., self-handicapping and learning strategy use). A. Elliot (1999) argued for the consideration of a mastery-avoidance orientation, completing the theoretical model. He saw this as the completion of twin streams of thought: mastery/performance and approach/avoidance.
Subsequent research has studied the antecedents (including students’ perceptions of teachers’ achievement goal orientations) and the results (including aspects of science engagement as described by OECD [2009] as well as achievement per se) of achievement goal orientations; much has been learned in both areas—a few examples follow. Potvin and Hasni (2014) considered the longitudinal decline in science motivation from 5th through 11th grade for French-Canadian students; they suggested that this decline may be related to a transition to a more pronounced performance-approach orientation as college preparatory exams loom in the minds of these students. On the other hand, Pantziara and Philippou (2015) surmised that both math self-efficacy and math fear of failure would function as antecedents to primary students’ achievement goal orientation, which would in turn influence their math interest and math achievement. Their results showed that math self-efficacy enhanced both mastery-approach and performance-approach goal orientations as well as math interest, but not math achievement. Meanwhile, some researchers have focused primarily on the results of achievement goal orientations. For example, Peetsma and van der Veen (2013) found that early middle school students in the Netherlands who exhibited some level of performance-avoidance goal orientation had lower math self-efficacy, poorer wellbeing at school, and reduced development of a performance-approach goal orientation. In addition, for Taiwanese middle school students, both mastery- and performance-approach orientations were positively associated with math self-efficacy and math achievement of; in contrast, both mastery- and performance-avoidance orientations were negatively associated with both math self-efficacy and math achievement (Chiang & Lin, 2014).
In a powerful statement of the utility of achievement goal orientation as a theoretical framework, many research groups have investigated both antecedents and results of these orientations within the same person-centered contexts. A few relatively recent examples are included below to give a sense of the high value of this approach. Nelson and DeBacker (2008) found that adaptive achievement goal orientation for U.S. 6th, 7th and 9th grade science students arose from the social context of positive peer climate within the school and at least one friend who valued academics. Unfortunately, the converse was also true for the development of maladaptive achievement goal orientation. Note that science self-efficacy was positively associated with both mastery- and performance-approach orientations, positive peer climate and a friend valuing academics (Nelson & DeBacker, 2008). Turkish middle school science students who perceived their parents or teachers to hold mastery orientation goals tended to have higher mastery-approach learning goals, and to make use of more adaptive coping strategies (Kahraman & Sungur, 2013). On the other hand, students who perceived that their parents had performance orientation goals presented more complex results, with students who held higher science self-efficacy showing a performance-approach orientation but students who were fearful of upsetting others showing a performance-avoidance orientation (Kahraman & Sungur, 2013). While parents’ academic help, press and support negatively influenced academic outcomes (math self-efficacy, math mastery goal orientation and math achievement) of Slovenian 8th grader students, teachers’ mastery goal orientation, academic press, and support enhanced such academic outcomes (Puklek Levpušček & Zupančič, 2009). Maladaptive student behavior (class disruption, cheating) was more likely to ensue if students perceived their math teachers held a
performance-approach goal orientation; meanwhile, student perception of a mastery-approach orientation held by their math teachers resulted in enhanced mastery-approach orientation, math self-efficacy and math achievement among students (Peklaj, Kalin, Pečjak, Valenčič Zuljan, & Puklek Levpušček, 2012). Fadlelmula, Cakiroglu, and Sungur (2015), working with Turkish middle school students, identified a linkage between a perceived classroom-level mastery goal orientation and the use of adaptive learning strategies (most notably, elaboration), math self-efficacy, and math achievement. Luo, Lee, Ng and Ong (2014, p. 619) discussed students’ “incremental belief of math ability”; such students believed that their abilities were not fixed, but instead that they could learn and progress—a mastery orientation is apparently a natural outgrowth of this concept. Luo et al. (2014) noted the students with high incremental math beliefs held higher levels of math enjoyment and pride and lower levels of math boredom and anxiety; math achievement was enhanced by math pride and weakened by math anxiety.

**Epistemological Belief Theory**

In Schommer-Aikins’ (2004) epistemological belief theory, students’ ability beliefs and beliefs about the nature of scientific knowledge were differentiated. Her seminal work thus allowed for the development of a theoretical framework based on epistemology, wherein a student could conceivably hold a high science self-concept but epistemic beliefs about the nature of science which could, for example, identify scientific knowledge as held only by the elite. Such students would be, potentially, less likely to be invested in learning science. Notably, Schommer-Aikins (2004) set forth a research agenda based on her model. Schommer-Aikins, Duell, and Hutter (2005) examined the fit of the above theory with middle school math students, finding a linkage between
adaptive epistemological beliefs and math achievement. One of the original strands for Schommer-Aikins’ (2004) theory was drawn from the work of Perry (1970) who observed male undergraduates to arrive at the university with a relatively fixed view of knowledge, derived from authorities, but to develop by the time of graduation in their personal epistemologies of knowledge as a complex entity, derived from experimentation and reason. Schoenfeld (1983, 1985) noted that high school students’ perceptions about the nature of math problems influenced their problem solving processes; for example, those who failed to solve problems believed that math was a gift, solutions should come rapidly, and strategies should be provided by teachers.

Chen (see Chen, 2012; Chen & Pajares, 2010) has been particularly active in the further development of this theoretical framework. Chen and Pajares (2010) evaluated fixed entity and incremental ability beliefs of 6th grade U.S. science students, considering the influences of those ability beliefs upon four aspects of epistemology, and subsequently upon science self-efficacy, self-regulatory strategies and science achievement. Fixed entity self-beliefs had positive associations with naïve epistemological beliefs (i.e., authorities are the sole source of scientific knowledge, scientific knowledge is certain and unchangeable); in addition, students’ agreement with scientific knowledge as certain led to a negative influence on their science self-efficacy (Chen & Pajares, 2010). Meanwhile, students with more adaptive incremental ability beliefs had strongly positive associations with the belief that science is developed as concepts in particular contexts and with the belief that scientific knowledge is justified through the use of hypotheses and experiments; in addition, the epistemological belief of justification had a positive influence on science self-efficacy which in turn enhanced
science achievement (Chen & Pajares, 2010). Chen (2012) uncovered differentiated influences of U.S. middle and high school students’ epistemological profiles on their science self-efficacy and science achievement; in addition, he also noted differentiated antecedents for those epistemological profiles. Chen’s (2012) student profiles included thriving (e.g., believed that their own science ability could develop; believed that scientific knowledge was constantly evolving), fixed/sophisticated (e.g., believed their own science ability was of a fixed nature; held similar beliefs about the nature of science as the thriving group), growth/passive (e.g., modest self-belief in possibility of their own growth in science ability, strong belief that science knowledge resided in external authorities), and uncommitted (e.g., not clearly committed to a position on their own ability development or on the nature of science). Notably, students in the thriving profile (which would be considered the most adaptive epistemological/self-belief combination) had higher science self-efficacy, mastery-approach orientation and science achievement than any of the other three profile groups (Chen, 2012).

Several recent articles seem to validate an approach which pays attention to epistemological issues. In their comparison of epistemological beliefs about science among Taiwanese and Chinese high school students, Lin, Deng, Chai and Tsai (2013a) uncovered a higher degree of belief among Taiwanese students in the changing nature of scientific knowledge and that the development of scientific knowledge is culture-dependent. In spite of these adaptive epistemological beliefs, Taiwanese students reported higher levels of science anxiety than did their Chinese counterparts (Lin et al., 2013a). Mason, Boscolo, Tornatora, and Ronconi (2013), working with 5th, 8th and 11th grade Italian students, identified common threads across age groups to include the
following: the adaptive epistemological belief that science experiments help reveal new knowledge was related to both mastery-approach and performance-approach goal orientations, both mastery- and performance-approach goal orientations were related to science self-efficacy, mastery-approach goal orientation was related to science self-concept and, finally, science self-concept was related to science achievement. Taiwanese 10th grade students with epistemological views of science favoring constructivist learning environments pressed for even more opportunities to co-construct knowledge socially and to bridge with prior knowledge (Tsai, 2000), suggesting that student development in their epistemological views is possible (particularly for those who already show some bent in that direction). Turkish 9th grade boys, previously schooled in a traditional classroom environment, were able to develop in both their general and nature of science (specifically, physics) epistemological beliefs; however, growth under intentional, constructivist instruction occurred more slowly in science that in other subject areas (Ogan-Bekiroglu & Sengul-Turgut, 2011). The international group of van Griethuijsen et al. (2015) compared 10 to 14 year old students in the Netherlands and the United Kingdom with their counterparts in India, Lebanon, Malaysia and Turkey as to their views of the nature of science. Western Europeans students held more sophisticated views of the nature of science than did those from the sampled developing countries; van Griethuijsen et al. (2015) surmised that this was likely due to a combination of intentional education (i.e., constructivist) toward such views in Western Europe and a cultural fit of more simple views with other cultures (i.e., empiricist).
Social-Cognitive Theory

Bandura (1986, 1997) established a social cognitive theory, including an application to academic self-efficacy; the sources of such self-efficacy were defined as mastery experience, vicarious experience, social persuasion, and emotional arousal. The review of Usher and Pajares (2008) established the importance of mastery experiences over and above the other identified sources in the formation of academic self-efficacy; however, contextual factors such as academic domain, academic ability, gender, and ethnicity influenced the contributions of these sources. While mastery experience was the strongest overall source of academic self-efficacy for both genders, the second leading source of such self-efficacy among female U.S. middle school students was social persuasion but was vicarious experience among males (Usher & Pajares, 2006). Social persuasion was a stronger predictor of academic self-efficacy for African-American students than for Euro-American students (Usher & Pajares, 2006). Self-efficacy for academic achievement was related to both academic goals and academic achievement among U.S. high school students (Zimmerman, Bandura, & Martinez-Pons, 1992). Academic self-efficacy of Italian middle school students was a better predictor of their perceived occupational self-efficacy than were their school grades (Bandura, Barbaranelli, Caprara, & Pastorelli, 2001), implying that career trajectories may be strongly influenced by students’ beliefs about their academic self-efficacy.

Middle school females in the U.S. had higher science self-efficacy than did males; further, the most important source of science self-efficacy for both genders was mastery experience (Britner & Pajares, 2006). Perceived support by social others (parents, teachers, and friends) enhanced science self-efficacy of U.S. students (Rice et al., 2013).
Kiran and Sungur (2012) found no differences in science self-efficacy between Turkish middle school females and males; further, the only source of self-efficiency with a gender difference was emotional arousal (which favored females). Females did provide more support to one another in the context of Kiran and Sungur (2012).

Usher and Pajares (2009) tested the four hypothesized sources of math self-efficacy in a U. S. middle school context, finding good reproducibility across gender and ethnicity, and arguing that these sources should fit well for other domains of student learning. Usher’s (2009) qualitative study confirmed the importance of the sources of math self-efficacy among U. S. middle school students. Kitsantas, Cheema, and Ware (2011) identified a significant association between math self-efficacy and math achievement; they argued that social persuasion may have been a critical factor for some groups in the development of math self-efficacy (e.g., females were praised for their hard work by their parents, while parents of males expressed surprise that their students had done as well as they had).

In sum, my overarching theoretical framework for the consideration of science engagement as a meta-construct with cognitive, emotional and behavioral aspects was drawn from the comprehensive work of Fredricks et al. (2004), and directly supported by a number of subsequent researchers (e.g., Chen, 2005; Demanet & Van Houtte, 2014; Lam et al., 2014; Sinatra et al., 2015); however, that framework is also buttressed by the other related theoretical frameworks which have been described above. My contention is that this approach provides a unique lens through which to evaluate the understanding of students’ engagement in science, a lens which goes well beyond that afforded by any of the theoretical frameworks considered in an isolated context.
My research is therefore constructed upon the impressive foundations laid by expectancy/values theory (Wigfield & Eccles, 2000), achievement goal orientation theory (Dweck & Leggett, 1988), epistemic development theory (Schommer-Aikins, 2004), and social-cognitive theory (Bandura, 1986, 1997). Each of those theoretical frameworks supports critical aspects of the overarching theoretical framework of Fredricks et al. (2004), yet none of them in isolation provides the full context to consider all three strands (cognitive, emotional, and behavioral) of science engagement in the same student cohorts. Expectancy/value theory contributes a focus on the cognitive aspects of academic self-concept and self-efficacy, and a behavioral aspect in academic choices made as a result of expectations for success (Wigfield & Eccles, 2000). Achievement goal orientation theory has contributed to both cognitive (such as science self-efficacy, e.g., Nelson & DeBacker, 2008) and emotional aspects (such as math enjoyment, e.g., Luo et al., 2014). In the case of epistemological belief theory (Schommer-Aikins, 2004), a key contribution to this meta-construct has been the understanding that some students with high science self-concepts or science self-efficacy may hold views of the nature of science as knowledge restricted to the elite, and therefore fail to achieve as they otherwise might be expected (Chen, 2012). Besides the understanding of the critical role of mastery experience in the formation of science self-efficacy (e.g., Britner & Pajares, 2006), other researchers have also noted that social persuasion can be an exceptionally important factor for the formation of academic self-efficacy among female students (e.g., Usher & Pajares, 2006). Taken together, these results indicate that social-cognitive theory (Bandura, 1986, 1997) not only has obvious implications in the cognitive realm but also in both emotional and behavioral arenas as well.
All of the above theoretical considerations relate to ideas around a tripartite conception of science engagement in some way or another. The next pair of theories, stereotype threat (Inzlicht & Schmader, 2012) and equality of opportunity (Roemer, 2009), are focused on explaining individual differences in academic performance, and potentially in this dissertation, how those differences in student background may relate to science achievement. I do not intend either the consideration of stereotype threat or equality of opportunity to bolster my case for science engagement as a meta-construct consisting of cognitive, emotional, and behavioral aspects (Fredricks et al., 2004).

**Stereotype Threat**

Inzlicht and Schmader (2012), in their recent text-length review of stereotype threat, concluded that stereotype threat remains a major obstacle for selected student groups in a wide variety of educational contexts. Steele (1997) described stereotype threat as the “threat in the air” (p. 614), indicating that members of a minority group in an academic setting can be subject to the perception that they are expected to perform according to a commonly held negative viewpoint of their group’s academic capabilities. According to his review (Steele, 1997), both females and African-American students, under stereotype threat in academic contexts, have suffered reduced scores on standardized exams. Steele (1997) noted that stereotype threat could also result in a lack of identification with schooling and a loss of academic engagement, and argued for steps to enhance academic self-efficacy of potentially affected students (among other such efforts to reduce stereotype threat). Steele and Aronson (1995) indicated that diagnostic testing can cause elevated stereotype threat merely by asking students to identify their ethnicity and/or gender on test forms; thus, students may come to such situations with a
reasonable, pre-constructed sense of stereotype vulnerability. African-American college students, encouraged to think of their own intelligence as incremental (rather than fixed) were more engaged in their academics and had higher grade point averages; the authors attributed these changes to a mitigation of the ubiquitous stereotype threat faced by African-American students (Aronson, Fried, & Good, 2002). Nosek et al. (2009) concluded that national-level implicit gender stereotypes related to science were closely related to national-level science and math performance scores; they believed that these were mutually reinforcing factors. While stereotype threat harms (at least) those considered to be less capable, “stereotype lift” is a term used to describe a condition under which those normally imagined to be more capable are thought of as less capable (Johnson, Barnard-Brak, Saxon, & Johnson, 2012, p. 139). Under the math test conditions of these authors at the collegiate level, men responded positively to stereotype threat; in contrast, women responded negatively to stereotype threat and positively to stereotype lift (Johnson et al., 2012). Female high school physics students, exposed to explicit stereotype threat while completing physics problems, had lower scores than did their male counterparts; no gender difference was noted in a “nullified condition” for stereotype threat (Marchand & Taasoobshirazi, 2013, p. 3050).

Females taking collegiate-level biology outnumbered their male counterparts, but contributed less to class discussions and had lower examination scores (Eddy, Brownell & Wenderoth, 2014); the authors were concerned that stereotype threat may have played a role in these female responses. Bell, Spencer, Iserman, and Logel (2003) were able to enhance women’s professional exam scores (in engineering) of women to be equivalent with those of their male peers (all recent college graduates) simply by describing the
exam as non-diagnostic and not resulting in gender differences. Their obvious inference was that the women were every bit as well educated as the men, but that they faced stereotype threat in the normal testing environment (Bell et al., 2003). Beyond the adverse influence of stereotype threat noted on exam performance by the above authors, Deemer, Thoman, Chase, and Smith (2014) identified stereotype threat as a significant barrier to the science career choice intentions of collegiate women enrolled in science courses. Beasley and Fischer (2012) argued that stereotype threat can be responsible for decisions of minority students to leave science, technology, engineering, and math (STEM) majors at the collegiate level. Cheryan, Siy, Vichayapai, Drury, and Kim (2011) noted that female college students who interacted with non-stereotypical role models were more likely to believe that they could succeed in computer science than those who interacted with stereotypical role models (irrespective of the gender of the role model).

While math performance of collegiate women was equivalent to that of men on relatively easy examinations, even under stereotype threat, that same set of women performed more poorly than men on more difficult test instruments (Spencer, Steele, & Quinn, 1999). Inzlicht and Ben-Zeev (2003) identified a math performance deficit for collegiate women whose performance was private (to male counterparts) but had simply experienced the stereotype threat of taking the exam in their presence. Both male and female Latino college students suffered stereotype threat in a math performance context related to their ethnicity; Latinas experienced additional stereotype threat related to their gender (Gonzales, Blanton, & Williams, 2002).
Equality of Opportunity

Roemer (2009) did foundational work on the theoretical basis on economic equality of opportunity, concluding that persons should not suffer inequalities due to circumstantial differences while inequalities due to their individual decisions could indeed be acceptable. Unfortunately, in many contexts, the reverse (inequality of opportunity) is the order of the day or of the decade; for example, within Italy, the southern regions (which have a higher immigrant population) had a higher degree of opportunity inequality than northern regions (Checchi & Peragine, 2010). In three of six Latin American nations studied, 100% of the population facing severely limited educational opportunities were either indigenous or of African descent (Ferreira & Gignoux, 2011). These authors, and others, have applied Roemer’s (2009) theory to education, arguing that individuals, communities, and nations ought to have access to educational opportunities. Based on a measure of inequality of educational opportunity in science developed by the same authors (Ferreira & Gignoux, 2014), Asia (in general), and Australia, Canada, Columbia, Finland and Iceland (in particular) had low scores (positive) for this measure, while Austria, Bulgaria, France, Germany and Switzerland were highly unequal in their educational opportunities. Notably, the U.S. was just behind the above list with an unfavorable rating (Ferreira & Gignoux, 2014). Lee and Buxton (2008) called for specific reforms in science curricula in urban U.S. schools which often have high concentrations of minority, ESL, and low SES students; they considered this to be a national imperative for equity of learning opportunities. Salehi-Isfahani, Hassine, and Assaad (2014) identified significant inequalities in educational opportunities within the Middle Eastern and North African (MENA) nations involved in their study.
Low SES eighth grade U.S. science students showed science performance gains by tenth grade, and further gains by twelfth grade; however, high SES eighth grade students started with higher performance scores and gained more rapidly at both subsequent high school intervals (Lee, Smith, & Croninger, 1997). A similar trend was noted for math performance over SES groups and time in their study (Lee et al., 1997). Unsurprisingly, an inquiry-based science instruction intervention produced significant gains in science performance over a more traditional instructional approach (Wilson, Taylor, Kowalski, & Carlson, 2010); surprisingly, while the traditional approach resulted in a significant ethnic difference in performance, there were no performance differences related to ethnicity under the inquiry-based model. One could argue that the new instructional approach may have brought all students into a new learning context and raised the opportunity to learn for everyone. McConney and Perry (2010), working with PISA data for Australian students, concluded that the positive association between school-mean SES and science, math and reading achievement was consistent across student-level SES backgrounds. While Zhang and Campbell (2015) were unable to identify an opportunity gap in science achievement between students based on their families’ SES, school-level SES was consistently related to science achievement. Further, schools with higher school-level SES had access to higher quality teachers (Zhang & Campbell, 2015).

While Minor, Desimone, Phillips, and Spencer (2015) studied math opportunity to learn at the elementary level, their conceptualization of opportunity to learn as a factor in explaining achievement gaps between majority and minority groups is indeed useful. The lack of opportunity to learn math was shown to have impeded math performance of
rural U.S. high school students (Reeves, 2012); this opportunity was narrowed by both family SES and their friends’ academic interests. In response to the standard practice of routing students with low middle school math scores into “dead-end” math courses, some states (e.g., California and New York) have configured bridge courses to help low-performing, often low-SES students to get back on track in math (Gamoran, Porter, Smithson, & White, 1997, p. 325). Unfortunately, such courses have been only a partial success (Gamoran et al., 1997), leading one to wonder if perhaps earlier interventions may have been more effective.

Both stereotype threat (Inzlicht & Schmader, 2012) and equality of opportunity (Roemer, 2009) provide theoretical frameworks potentially explaining differences in science achievement among individual students due to their backgrounds. Minority and female students routinely produce lower science and math achievement results when they perceive a stereotype threat, whether that means identifying their status on the exam instrument (Steele & Aronson, 1995) or taking the exam in the presence of those perceived to be superior in the given subject matter (Inzlicht & Ben-Zeev, 2003). Some efforts to counter stereotype threat include description of academic abilities of minority students to those very students as incremental rather than fixed (Aronson et al., 2002), nullifying the stereotype threat for female students (Marchand & Taasoobshirazi, 2013), and telling female engineering students that an engineering exam does not result in gender differences (Bell et al., 2003). Particular national or regional contexts have been shown to result in unequal educational opportunities; for example, Italian regions with higher immigrant populations (Checchi & Peragine, 2010), indigenous people groups in three Latin American nations (Ferreira & Gignoux, 2011), or Western European nations
with extensive immigrant populations (e.g., Ferreira & Gignoux, 2014). Several U.S.-
based studies have also questioned whether lower SES students have been afforded the
same opportunity to learn as their counterparts from higher SES families (e.g., Lee et al.,
1997; Reeves, 2012). Thus, this pair of theoretical frameworks (stereotype threat and
equality of opportunity) may provide useful insights as to the bases for difference in
science achievement related to student background characteristics such as gender,
etnicity, immigration status, and family SES.

Influence of Student Background on Aspects of Science Engagement

Science self-efficacy.

Formation. Studies of the formation of science self-efficacy have developed from
the initial groundwork in both academic and math self-efficacy. Usher and Pajares
(2006) studied four primary sources of academic self-efficacy: mastery experience,
physiological state, social persuasions, and vicarious experience. Mastery experience
were the most important source in the formation of academic self-efficacy (Usher &
Pajares, 2006). A subsequent qualitative study (Usher, 2009) confirmed the role of
directly assessed science self-efficacy of U.S. middle school students; they found that
mastery experience was the only one of the above noted sources of academic self-
efficacy to be operative in the science-specific domain. Kiran and Sungur (2012) showed
that science self-efficacy of Turkish middle school students was related to mastery
experience and emotional/physiological reactions, but was not to vicarious experience.
The sources of science self-efficacy were confirmed by Chen and Usher (2013) as
mastery experience, vicarious experience, social persuasion, and
physiological/psychological state; mastery experience was most important in their work. The four sources acted in an additive way to enhance science self-efficacy; in addition, students who believed that their capacity to learn science could grow and develop tended to have higher science self-efficacy (Chen & Usher, 2013). Chen and Pajares (2010) noted that 6th grade U.S. science students who viewed their own science abilities as incremental (that is, having the possibility of improvement) showed adaptive motivational factors (e.g., also holding a view that science experiments can help discover new information led to enhanced science self-efficacy), while their counterparts with fixed views of their science abilities showed maladaptive motivational factors (e.g., also holding a view that absolute science truth exists led to a performance-avoidance goal orientation and reduced science self-efficacy).

Nelson and DeBacker (2008) observed that adaptive achievement goal orientation (mastery- and performance-approach) for U.S. 6th, 7th, and 9th grade science students arose from the social context of positive peer climate within the school and at least one friend who valued academics; science self-efficacy was also positively associated with these adaptive goal orientations. Rice et al. (2013) investigated the role of social support mechanisms in the development of positive science self-efficacy; their cross-sectional report of U.S. students from 5th grade through collegiate levels found students who noted higher levels of support from friends, parents and teachers to have higher science self-efficacy. Mason et al. (2013) identified the adaptive epistemological belief that science experiments help reveal new knowledge as related to science self-efficacy. “Math-science career self-efficacy” of college sophomores was related to math-science self-
beliefs inculcated in these young adults during middle school by their mothers (Bleeker & Jacobs, 2004, p. 97).

**Dimensions.** Dimensions of science self-efficacy have focused on assessing science literacy, notably, making use of scientific evidence, explaining observations in scientific ways, and identifying issues in scientific terms (OECD, 2009). The eight items used in the 2006 PISA survey (OECD, 2007a) to assess these dimensions and to infer science self-efficacy as a construct are shown in chapter three below (OECD, 2009). Other authors have partitioned science self-efficacy into skill components; for example, Lin, Tan, and Tsai (2013b) considered science self-efficacy to consist of the following four dimensions: conceptual understanding and higher order cognitive skills, practical work, everyday application and science communication. Lin et al. (2013b) uncovered some differences in these dimensions among Singaporean and Taiwanese eighth grade students in their validation study. Chemistry self-efficacy of Turkish high school students was shown to include both cognitive and laboratory skills components (Aydin & Uzuntiryaki, 2009). Due to logistical complications involved in an assessment across many nations, PISA 2006 did not include the assessment of laboratory skills invoked by Aydin and Uzuntiryaki (2009). Apart from that difference, the work Aydin and Uzuntiryaki (2009) and Lin et al. (2013b) otherwise affirmed the cognitive and applications-oriented approach taken by PISA 2006 (OECD, 2009).

**Functions.** Science self-efficacy has been associated with science achievement across 15 nations (Perera, 2014), and in Canada (Areepattamannil et al., 2011), Finland (Lavonen & Laaksonen, 2009), Germany (Scherer, 2013), Hong Kong (Lam & Lau, 2014; Sun et al., 2012), Taiwan (Wang, Wu, & Huang, 2007), and the U.S. (Lau &
Roeser, 2002). Turkish high school science students with high science self-efficacy tended to expend more effort when confronted with difficult problems as well as implementing adaptive metacognitive strategies (Sungur, 2007). Turkish researchers concluded that “the success of metacognitive physics instruction depends on physics self-efficacy” (Yerderlen-Damar & Peşman, 2013, p. 287).

**Student background.** Individual differences in science self-efficacy could potentially relate to gender, age, family SES, immigrant status, and ethnicity/cultural background. For girls in the middle school sample of Usher and Pajares (2006), mastery experience and social persuasion were the significant predictors of academic self-efficacy; meanwhile, for boys, mastery and vicarious experiences predicted academic self-efficacy. Turkish female students scored significantly higher in three of the four sources of academic self-efficacy: mastery experience, social persuasion, and physiological state (Arslan, 2013). Kiran and Sungur (2012) identified the development of science self-efficacy as more related to social persuasion among females than among males in their study. Britner and Pajares (2006) noted that girls had stronger science self-efficacy than did boys. Uitto (2014) assessed patterns of biology motivation and achievement of Finnish high school students; notably, she found no gender difference in biology self-efficacy. In contrast, boys had higher math, chemistry and physics self-efficacy (Uitto, 2014). Hong Kong students who had higher science self-efficacy tended to be male and from higher SES families (Sun et al., 2012). Science self-efficacy of both boys and girls in Taiwan declined sharply at the transition from elementary to middle school; during middle and high school, science self-efficacy favored boys (Hong & Lin, 2013). Both immigrant and non-immigrant students across Canada had positive
associations between science self-efficacy and science achievement (Areepattamannil & Kaur, 2013). Tang and Neber (2008) uncovered higher chemistry self-efficacy for U.S. students than for German or Chinese students; in addition, U.S. students had higher effort as well as more adaptive goal orientations than did Chinese students. Combinations of individual student characteristics may make them especially vulnerable to adverse perceptions about science opportunities and science self-efficacy; for example, Latino- and African-American males perceived themselves to be less included in science than high SES, Euro-American males, and females of any ethnicity or SES level (Perry, Link, Boelter, & Leukefeld, 2012). Ethnicity has influenced math self-efficacy (Stevens, Olivarez, Lan, & Talent-Runnels, 2004); while age (Caprara, Vecchione, Alessandri, Gerbino, & Barbaranelli, 2011) and immigrant status (Frank, Plunkett, & Otten, 2010) have been shown to influence academic self-efficacy.

Science self-concept.

Formation. Parents, peers, teachers, and the resulting frames of reference may influence the formation of science self-concept. Parents of tenth grade Malaysian students who implemented an authoritative rather than an authoritarian parenting style helped build a more profoundly positive academic self-concept (Ishak, Low, & Lau, 2012). Positive relationships with teachers and peers influenced science self-concept of Taiwanese 8th grade students; this relationship tended to be more significant for the high-achieving subset of the group than for the low-achieving subset (Jen, Lee, Chien, Hsu, & Chien, 2013).

Dimensions. A firm consensus on the dimensions of science self-concept appears not to have been reached at present. According to OECD (2009), dimensions of science
functions. The most important function of science self-concept seems to be an enhancement of science achievement. Such an effect has been noted in many places such as Canada (Areepattamannil et al., 2011; Areepattamannil, 2012b; Areepattamannil & Kaur, 2013), East Asian nations/regions (Shen, 2005; Yu, 2012), Finland (Lavonen & Laaksonen, 2009), Saudi Arabia (Tighezza, 2014), Singapore (Mohammadpour, 2013), Taiwan (Jen et al., 2013) and the U.S. (Lau & Roeser, 2002; Shen, 2005; Yu, 2012), even though Anagün (2011) found no relationship between science self-concept and science achievement for Turkish students and Bouhlila (2011) observed a negative relationship between these measures for students from a group of MENA nations. English students who chose to continue to study physics after it was no longer compulsory were apparently motivated by physics self-concept and home support; a de-motivating factor was pressure to study physics (Mujtaba & Reiss, 2014).

Student background. Individual differences in science self-concept have been shown to be related to gender, age, family SES, ethnicity/cultural group, and science
domain. Across fifty nations in PISA 2006, males had consistently higher science self-concepts than did females (Sikora & Pokropek, 2012). German middle school girls reported higher science self-concept in gender-segregated vs. co-educational physics classrooms; however, boys’ science self-concept was invariant across classroom type (Kessels & Hannover, 2008). Males had higher science self-concept in all domains except biology; apparently, biology, at least in this English context, was gender-neutral (Hardy, 2014). Fathers had little influence on science self-concept of their offspring, but mothers of 8th grade girls in the U.S. positively influenced science self-concept of their daughters through both encouragement and discussions (Bhanot & Jovanovic, 2009).

Meanwhile, as mothers’ encouragement and discussion of science with their sons increased, the science self-concept of those boys actually dropped. Kurtz-Costes, Rowley, Harris-Britt, & Woods (2008) concluded that normal developmental processes may drive students to more closely align with their gender grouping in terms of both science and math self-concept.

In general, academic (Caprara et al., 2011; Purdie & McCrindle, 2004) or science self-concept (Greenfield, 1996; Von Secker, 2004) has been shown to decline with age. One notable exception has been for academic self-concept of indigenous Australian students (Purdie & McCrindle, 2004).

Math, chemistry and physics self-concepts of German 11th grade students each successfully mediated the positive relationship between father’s socioeconomic status (SES) and domain-specific achievement (Steinmayr et al., 2012); meanwhile, mother’s SES was only mediated by chemistry self-concept for chemistry achievement. Von Secker (2004) noted that particular types of school-based science instructional strategies...
(science inquiry, hands-on learning) could protect students disadvantaged in science fields from otherwise lower science achievement, (e.g., those with low SES, female gender, minority status, and older age). Science self-concept of Turkish middle school students was related to their mothers’ educational level; furthermore, family involvement and the educational levels of both parents explained differences in science achievement (Senler & Sungur, 2009).

Science self-concept was lower for Hispanic-American females than for African- or Euro-American students or for Hispanic-American male students (Riegle-Crumb et al., 2011). Eighth grade students in the U.S. held higher science self-concepts than did their peers in China, Japan and Korea, in spite of pronounced deficits in science achievement compared with all three East Asian nations (Mullis, Martin, Gonzalez, & Chrostowski, 2004). Marsh et al. (2013) observed lower science self-concept for English-speaking 8th graders (Australia, England, Scotland and the U.S.) than for their Arabic-speaking counterparts (Egypt, Jordan, Oman and Saudi Arabia), in spite of pronounced differences in science and math achievement (favoring the U.S. students); they suggested that students form their self-concepts within their own frames of reference. Gordon Rouse and Austin (2002) found differences among African-, Hispanic-, and Euro-Americans in the formation of academic self-concept.

Hardy (2014) assessed science self-concept in five different science domains (biology, chemistry, inquiry, physics, and nature of science) across 7th through 11th grade in England, noting that science self-concept was strongly domain-dependent (e.g., nature of science showed the highest values and physics showed the lowest values). Jansen et al. (2014) differentiated among subject-specific science self-concepts of German 10th
grade students, finding that biology, chemistry and physics self-concepts fit science subject achievement better than generalized science self-concept fit generalized science achievement. Further, while females held biology self-concepts equivalent to those of males, their chemistry and physics self-concepts were significantly lower than males (Jansen et al., 2014).

**Enjoyment of science.**

*Formation.* Science enjoyment of Taiwanese eighth grade students was enhanced by positive relationships with peers and teachers (Jen et al., 2013). Hampden-Thompson and Bennett (2013) linked enjoyment of science with three different science instructional strategies: interactions, hands-on activities, and applications. High school biology students in the U.S. reported higher levels of science enjoyment when their teachers implemented hands-on learning activities (Shumow et al., 2013).

*Dimensions.* I was unable to identify specific discussion of dimensions of enjoyment of science in the literature.

*Functions.* A positive relationship between enjoyment of science and science achievement has been observed in Canada (Areepattamannil et al., 2011), Finland (Lavonen & Laaksonen, 2009), Hong Kong (Lam & Lau, 2014), Malaysia and Singapore (Ng et al., 2012), Saudi Arabia (Tighezza, 2014), and Taiwan (Jen et al., 2013; Lin, Hong, & Huang, 2012a; and Tsai & Yang, 2015). Science enjoyment was associated with science achievement of 2nd generation, but not 1st generation immigrants to Canada (Areepattamannil, 2012b). In contrast, enjoyment of science has been shown to be negatively related to science achievement in MENA nations (Bouhlila, 2011). Both higher effort and more adaptive goal orientations of U.S. compared with either German
or Chinese students were related to higher enjoyment of science (Tang & Neber, 2008). Across four culturally diverse nations (Columbia, Estonia, Sweden, and the U.S.), Ainley and Ainley (2011a) found enjoyment of science to best explain variations in general interest in science. Ainley and Ainley (2011b) identified an influence of enjoyment of science on both personal value of science and general interest in science among a subset of the nations involved in PISA 2006. Enjoyment of science also stimulated continued study of physics by English students after this subject was no longer required (Mujtaba & Reiss, 2014).

**Student background.** Stables (1990) asked British 13 and 14 year old students to indicate the level of their enjoyment and value of biology, chemistry and physics; boys ranked physics (but not biology or chemistry) higher in co-educational than in single-sex classrooms, while girls did not show a pronounced classroom-type difference in their rankings. While immigrant Canadian students exhibited a positive relationship between enjoyment of science and science achievement, non-immigrant students did not evidence this relationship (Areepattamannil & Kaur, 2013). Science enjoyment was lower for Hispanic-American females than for African- or Euro-American students or for Hispanic-American male students (Riegle-Crumb et al., 2011). English-speaking eighth grade students reported lower enjoyment of science than their Arabic-speaking peers even though the English-speakers had higher science achievement (Marsh et al., 2013).

**General interest in science.**

**Formation.** Most of the research related to the formation of general interest in science has focused on instructional strategies. Krapp (2002) concluded that general interest in science in a given student arose from situational interest in science, followed
by stabilized situational interest in science, and then by general interest in science. An urban university provided out-of-school inquiry science enrichment activities to a suite of resource-poor urban high schools; both students and teachers reported that this activity enhanced student interest in school science (Luehmann, 2009). Science learning environments which included more hands-on involvement and more interaction through technologies stimulated higher levels of student interest in science among 6th and 7th grade U.S. students (Swarat et al., 2012), suggesting that presentation format may well be more important than content in efforts to enhance this aspect of science engagement. Luce and Hsi’s (2015) qualitative study of photo-journals of nineteen diverse 6th grade science students in the U.S. revealed a wide range in the extent and types of science interests and curiosities they expressed; an instructional application of such a study might be to attempt to meet students where they are in their science interests. Friendship group support of study in STEM fields, coupled with individual science interest, promoted STEM career interest of U.S. high school students (Robnett & Leaper, 2012). Interest in science among Qatari middle school students was enhanced by particular types of science instruction, namely interactive classrooms and the use of models and applications (Areepattamannil, 2012a). Jocz et al. (2014) observed that science interest was derived from instructional methods which related learning to daily life and allowed for peer discussions.

**Dimensions.** I was unable to identify specific discussion of dimensions of general interest in science in the literature.

**Functions.** While science interest was positively associated with science achievement in Qatar (Areepattamannil, 2012a), this relationship was negative for
students in both Canada (Aarepattamannil et al., 2011) and Finland (Lavonen & Laaksonen, 2009), raising at least a concern about making enhanced science interest a major instructional emphasis.

**Student background.** According to the review of Krapp and Prenzel (2011), female interest in biology is similar to that of males; however, females have generally lower interest in other science disciplines than do males. According to Stake and Nickens (2005), adolescent females generally had less support for their interest in science than did their male counterparts; these authors reported on a successful summer science enrichment program to build peer relationships, and argued that extending this model could potentially increase participation of females in high school and college science courses and science-related careers. In urban middle schools in China, males had higher situational interest in biology lessons than did females; no gender influence was noted in this precursor to more sustained interest in science in rural middle schools (Liu & Neuhaus, 2014). Kerger, Martin, and Brunner (2011), working with 8th and 9th grade students in Luxembourg, found that both genders’ science interest was increased when science concepts were presented in gender-appropriate contexts, e.g., social and practical aspects for girls, technological and systematic aspects for boys. Buccheri, Gürber, and Brühwiler (2011) learned that a lack of general interest in science was a predisposing factor against follow through in science study by high school females in Switzerland, Finland, Australia, and Korea; they concluded that gender stereotyping across multiple fields of science played a significant role.

Science effort of Indian high school students was the single strongest predictor of both chemistry and physics achievement; science interest amplified this effect for boys
but not for girls (Larson et al., 2014). Potvin and Hasni (2014) noted a longitudinal decline in science interest from 5th through 11th grade for French-Canadian students, and suggested that looming college entrance examinations had an adverse impact on science interest. Lebanese students in fourth through eighth grade identified science in very narrow terms, apparently restricted to what was covered in their school science courses and what their ethnic/religious background would permit (Khishfe & Boujaoude, 2016); these authors argued that for Lebanese youth to maintain an interest in science, a broader conception of science would have to be developed.

**Instrumental motivation for science.**

**Formation.** Instrumental motivation of U.S. students declined across their middle and high school years; this was related to a decline in science self-concept, peer context, and lack of teacher encouragement towards science (George, 2006). Hampden-Thompson and Bennett (2013) chose to evaluate the relationships between instrumental motivation for science of U.K. students and four teaching and learning contexts for science (interactions, investigations, hands-on activities, and applications). Instrumental motivation for science was associated with the three of the teaching and learning contexts tested: interactions, hands-on activities, and applications.

**Dimensions.** I was unable to identify specific discussion of dimensions of instrumental motivation for science in the literature.

**Functions.** Instrumental motivation for science positively impacted science achievement of students across 15 nations (Perera, 2014), in Hong Kong (Sun et al., 2012), and in New Zealand (Acosta & Hsu, 2014a). Both East Asian and U.S. eighth grade students with higher instrumental motivation for college placement showed higher
science achievement (Yu, 2012). In response to a higher degree of instrumental motivation, English high school students were more likely to continue to study physics after it was no longer compulsory (Mujtaba & Reiss, 2014). A “utility-value intervention” through parents was effective in motivating their previously high-achieving daughters and low-achieving sons to take more science and math courses in high school, indicating that formation of instrumental motivation for science may be partially influenced by parental factors (Rozek, Hyde, Svoboda, Hulleman, & Harackiewicz, 2015, p. 195).

**Student background.** Norwegian high school students, especially females, chose to study science-related subjects from the context of instrumental motivation (Bøe, 2011). Australian middle school girls had unfavorable perceptions of their science classroom environments, resulting in an adverse impact on their instrumental motivation for science; Spearman and Watt (2013) believed that enhanced autonomy support could improve such perceptions and ensuing impacts. Farmer et al. (1999), in a longitudinal study, found that women who had held high instrumental motivation for science, thus taking more high school science courses, were much more likely to be engaged in science-related careers approximately a decade later. Buccheri et al. (2011) believed that an emphasis on the instrumental value of a science career could make a difference in career decision-making of female students. Marsh et al. (2013) measured lower instrumental motivation for science for English-speaking 8th grade students than for their Arabic-speaking counterparts, in spite of pronounced differences in science and math achievement (favoring the U.S. students). In the work of Kjærnsli and Lie (2011), students from Islamic and Latin American countries had much higher future motivation for science than
did students from other types of nations; instrumental motivation for science appeared to
be the strongest underlying variable in explaining this trend.

**Future-oriented science motivation.**

**Formation.** Lupart et al. (2004), working with 7th and 10th grade students in
Canada, noted that younger students had a more positive future attitude toward science
than did older students. Perceptual research with British students (about 10 years old)
and their parents addressed the contrasting issues of liking science and actually
considering it for a career; many of the perceptions described by both students and their
parents were narrowly construed as to the concepts of science and scientists, and thus
seemed likely to preclude active consideration of entry into such a career (DeWitt,
Archer, & Osborne, 2013). While DeWitt, Archer, and Osborne (2014) reported that
British middle school students enjoyed science, and held positive views about scientists,
this did not seem to translate into high numbers of these students actively considering a
future in science. Hampden-Thompson and Bennett (2013) observed that future
motivation for science was positively associated with teaching strategies involving
interactions, hands-on activities, and applications. Spanish high school students held
positive views toward sciences; however, they generally had very low levels of future
orientation towards science-related careers (Vázquez Alonso & Manassero Mas, 2009).

**Dimensions.** I was unable to identify specific discussion of dimensions of future-
oriented science motivation in the literature.

**Functions.** Both immigrant and non-immigrant students across Canada had
positive associations between future motivation for science and science achievement
(Areepattamannil & Kaur, 2013).
**Student background.** Science-oriented females (across fifty nations in PISA 2006) expressed a preference for future careers in areas related to biology, while males tended to be more interested in technical applications of science (Sikora & Pokropek, 2012). According to Lupart et al. (2004), girls were more motivated toward science-related careers in that science “gives me the opportunity to make the world a better place” rather than by the boys’ top choice of science “allows me to earn a great deal of money” (p. 36). Stereotype threat adversely influenced future motivation for science among female U.S. undergraduates in physics but not in chemistry contexts (Deemer et al., 2014).

**General value of science.**

**Formation.** Parents of Hong Kong students who reported holding high general value of science successfully influenced their sons and daughters to hold higher general value of science (Acosta & Hsu, 2014b).

**Dimensions.** I was unable to identify specific discussion of dimensions of general value of science in the literature.

**Functions.** In Hong Kong, students with higher general value of science had higher science achievement (Acosta & Hsu, 2014b; Lam & Lau, 2014).

**Student background.** While immigrant Canadian students exhibited a positive relationship between general value of science and science achievement, non-immigrant students did not evidence this relationship (Aarepattamannil & Kaur, 2013).

**Personal value of science.**

**Formation.** I was unable to identify explicit discussion of formation of personal value of science in the literature.
**Dimensions.** I was unable to identify specific discussion of dimensions of personal value of science in the literature.

**Functions.** Non-immigrant students in Canada showed no relationship between personal value of science and science achievement; in contrast, for immigrant students, this relationship was negative (Areepattamannil & Kaur, 2013). Personal value of science was related to science achievement for East Asian but not U.S. students (Yu, 2012). Viljaranta et al. (2009) noted that Finnish high school students who held a high personal value of science were more apt to expect to find themselves in careers which would take advantage of science training.

**Student background.** Middle school girls formed higher personal values of science after being exposed to the history of gender discrimination in the U.S. (Weisgram & Bigler, 2007). Female U.S. high school students, across four different ethnicities (Afro-, Asian-, Hispanic- and Euro-American) held higher personal science value than did males (Else-Quest et al., 2013).

**Science-related Activities.**

**Formation.** I was unable to identify explicit discussion of formation of science-related activities in the literature.

**Dimensions.** I was unable to identify specific discussion of dimensions of science-related activities in the literature.

**Functions.** Engagement in science-related activities has been shown to enhance science achievement in Hong Kong (Ho, 2010), Turkey (Kalendar & Berberoglu, 2009), and the U.S. (Sha, Schunn, & Bathgate, 2015; Tran, 2011). Ho (2010), working with Hong Kong students, found that parents’ reports of having encouraged science activities
at home with their children prior to age 10 had a positive relationship with science achievement. High school and college U.S. students who were involved in a full summer research program reported that early childhood experiences with science, fostered by family and friends, got them interested in science, and that extracurricular science-related activities sustained their interest in science (VanMeter-Adams et al., 2014). Gerber et al. (2001) described science-related activities outside of school as “enriched informal learning environments” (p. 539) and saw enhanced scientific reasoning ability as an outcome for 7th through 10th grade U.S. students who had such opportunities. Out-of-school science activities helped middle school U.S. girls from “non-dominant backgrounds” (p. 72) to build their future identities in science-related areas (Barton, Tan, & Rivet, 2013). Augmented reality learning games (which involved computer-assisted instruction and were developed by Bressler & Bodzin [2013]), have shown potential in building science interest among middle school students in the U.S.; notably, these researchers compared science engagement to the concept of flow (Csikzentmihalyi, 1988) as discussed above. Lin et al. (2012b, p. 945) referred to science-related activities as “engagement with leisure science learning”, and observed a closer connection for their Taiwanese students with this aspect of science engagement (as described by OECD, 2009) and science interest and enjoyment than with science self-efficacy and self-concept. Lin et al. (2012b) believed that this augured for an emphasis of science education on enjoyment and interest rather than competence.

**Student background.** I was unable to identify direct discussion of individual differences in science-related activities in the literature.
Influence of Science Engagement on Science Achievement

My discussion in this section addresses the potential roles of all nine aspects of science engagement (OECD, 2009) in influencing science achievement to at least some degree. While most of the reported associations between science engagement and science achievement have been positive, some have shown no relationship, and others have, in fact, identified negative relationships. Science self-efficacy has been positively associated with science achievement across 15 nations (Perera, 2014), and in Canada (Areepattamannil et al., 2011), Finland (Lavonen & Laaksonen, 2009), Germany (Scherer, 2013), Hong Kong (Lam & Lau, 2014; Sun et al., 2012), Taiwan (Wang et al., 2007), and the U.S. (Lau & Roeser, 2002). Science self-concept has enhanced science achievement in Canada (Areepattamannil et al., 2011; Areepattamannil, 2012b; Areepattamannil & Kaur, 2013), East Asian nations/regions (Shen, 2005; Yu, 2012), Finland (Lavonen & Laaksonen, 2009), Saudi Arabia (Tighezza, 2014), Singapore (Mohammadpour, 2013), Taiwan (Jen et al., 2013), and the U.S. (Lau & Roeser, 2002; Shen, 2005; Yu, 2012). In contrast, Anagün (2011) found no relationship between science self-concept and science achievement for Turkish students, while Bouhlila (2011) observed a negative relationship between these measures for students from a group of MENA nations. While general interest in science was positively associated with science achievement in Qatar (Areepattamannil, 2012a), this relationship was negative for students in both Canada (Areepattamannil et al., 2011) and Finland (Lavonen & Laaksonen, 2009). Instrumental motivation for science positively impacted science achievement of students across 15 nations (Perera, 2014), in Hong Kong (Sun et al., 2012), and in New Zealand (Acosta & Hsu, 2014a). Both immigrant and non-immigrant
students across Canada had positive associations between future motivation for science and science achievement (Areepattamannil & Kaur, 2013). In Hong Kong, students with higher general value of science had higher science achievement (Acosta & Hsu, 2014b; Lam & Lau, 2014). Non-immigrant students in Canada showed no relationship between personal value of science and science achievement; in contrast, for immigrant students, this relationship was negative (Areepattamannil & Kaur, 2013). A positive relationship between enjoyment of science and science achievement has been observed in Canada (Areepattamannil et al., 2011), Finland (Lavonen & Laaksonen, 2009), Hong Kong (Lam & Lau, 2014), Malaysia and Singapore (Ng et al., 2012), Saudi Arabia (Tighezza, 2014), and Taiwan (Jen et al., 2013; Lin et al., 2012a; Tsai & Yang, 2015). Science enjoyment was associated with science achievement of 2nd generation, but not 1st generation immigrants to Canada (Areepattamannil, 2012b). In contrast, enjoyment of science has been shown to be negatively related to science achievement in MENA nations (Bouhlila, 2011). Engagement in science-related activities has been shown to enhance science achievement in Hong Kong (Ho, 2010), Turkey (Kalander & Berberoglu, 2009), and the U.S. (Sha et al., 2015; Tran, 2011).

In summary, the preponderance of research evidence has shown positive associations between the various studied aspects of science engagement and science achievement. Notable exceptions include mixed findings for general interest of science (Areepattamannil, 2012a; Areepattamannil et al., 2011; Lavonen & Laaksonen, 2009) and personal value of science (Areepattamannil & Kaur, 2013), and some occurrences of non- or negative associations between science engagement and science achievement for
particular groups for specific aspects of science engagement (Anagün, 2011; Areepattamannil, 2012b; Bouhlila, 2011).

**Influence of Student Background on Science Achievement**

**Gender.** Female gender was associated with lower science achievement across 31 nations (Fuchs & Wößmann, 2007) and across 15 nations (Perera, 2014). Gender did not influence science achievement of Turkish students (Dincer & Uysal, 2010). Bacharach, Baumeister, and Furr (2003) noted that the gender gap in science achievement widened over the course of secondary education in the U.S. Gender differences in science achievement may be partially explained by differences in spatial ability which favor males (Ganley, Vasilyeva, & Dulaney, 2014); these authors called for interventions which would enhance the development of spatial ability among females. An extensive meta-analysis of gender differences in science achievement showed that high school senior males had a “small but stable” advantage over females, and were over-represented at the upper echelon of science achievement by a 2:1 ratio (Reilly, Neumann, & Andrews, 2015, p. 1). Voyer and Voyer (2014), in their meta-analysis of school grades by gender, learned that across grade levels (K-16) and subject matter (science, math, and language), females had consistently higher grades in classroom settings; when attempting to mesh their consistent finding with similarly consistent findings of a female disadvantage in science achievement (see above), Voyer and Voyer (2014) included stereotype threat as one of several plausible explanations.

**Age.** Increasing age beyond a 15-year-old baseline was related with lower science achievement of students from 31 nations (Fuchs & Wößmann, 2007). Across three different science disciplines (environmental, physical, and biological science), U.S.
students were observed to progress rapidly in achievement in their early secondary years but to gain more slowly in achievement later on (Ma & Wilkins, 2002).

**Family SES.** Parental SES is a critical factor influencing science achievement, having been documented in numerous cases around the world; a few examples are cited here: 31 nations (Fuchs & Wößmann, 2007), several MENA nations (Bouhlila, 2011), Croatia (Gregurović & Kuti, 2010), Ireland (Gilleece, Cosgrove, & Sofroniou, 2010), Spain (Gil-Flores, 2011), Taiwan (Chen, Lin, Wang, Lin, & Kao, 2012; Tsai & Yang, 2015), Turkey (Dincer & Uysal, 2010; Kalendar & Berberoglu, 2009), the U.K. (Gorard & See, 2009), and the U.S. (Muller, Stage, & Kinzie, 2001; Sousa, Park, & Armor, 2012). Educational status of a student’s father proved to be most closely associated with science achievement in Turkey (Anil, 2009). In spite of the above compelling global evidence, Marks (2014) argued that academic achievement by year 3 of a student’s school career was more important in determining their future achievement than either their family’s SES status or their demographic standing; further, he indicated that academic achievement at that tender age was tied to ability rather than to environment.

**Immigration status and ethnicity.** Somewhat surprisingly, relatively few published articles seemed to be available which directly tied ethnicity to science achievement; on the other hand, a steady stream of research has addressed the influence of immigration status on science achievement. Given that my research included an assessment of the influence of immigration status (but not ethnicity) as a potential student
background characteristic affecting science achievement, I have chosen to include the brief discussion of ethnicity as part of this section on immigration status.

Lower science achievement was noted for students with immigrant status across 31 nations (Fuchs & Wößmann, 2007), and across 15 nations (Perera, 2014). Immigrant Korean students were considered by fellow students and teachers to be less capable in advanced placement biology in a U.S. high school classroom due to their imperfect command of English, their reluctance to engage in class discussions, and their apparent lack of understanding of school culture (Ryu, 2015). Native-born Canadian students, especially males, out-performed immigrant students on a science literacy exam, in spite lower classroom grades and less time-on-task outside of the classroom (Adamuti-Trache & Sweet, 2013). Asian-Canadian students preferentially entered science and math courses in high school in the province of British Columbia (Adamuti-Trache & Sweet, 2014). Second-generation Turkish immigrant students in three European nations (Austria, Germany, and Switzerland) had fewer academic resources at home and at school than did their native peers; notably, their resource deficit at home was closely related to their lower average (science, math, and reading) achievement results (Song, 2011). Meunier (2011) identified a deficit in science achievement for first and second generation immigrant high school students when compared with native Swiss students; the author believed this was related to “lower endowments” (read as aptitude/training) of the immigrants combined with “lower returns” (read as participation in substandard schools) (p. 16). Spanish regions with higher proportions of immigrant high school populations scored significantly lower on the science achievement portion of PISA 2006 (Cordero Ferrera, Crespo Cebada, Pedraja Chaparro, & Santín Gonzáles, 2011).
A national-level U.S. study indicated that the significant ethnic (specifically between African- and Euro-American) gap in science achievement, which existed at the outset of secondary education, continued to widen during students’ high school careers (Bacharach et al., 2003). Profound differences between ethnic groups (Asian-, Euro-, Hispanic-, and African-American) and between genders within ethnic groups in both initial science achievement and in rate of science achievement growth over their high school years were also noted (Muller et al., 2001). Students’ religious backgrounds affected their willingness to engage with classroom conversations about science topics; Hanley, Bennett, and Ratcliffe (2014) suggested that science teachers may need to develop a sensitive and appropriate approach to such topics in order to be effective. Else-Quest et al. (2013) compared tenth grade students from African-, Asian-, Hispanic-, and Euro-American ethnic groups for science and math attitudes and achievement, finding that the Asian-American students exhibited stronger achievement in both subjects. Strikingly, multiple regression analysis showed that self-concept, task value and expectancy for success was strongly associated with both science and math achievement for Asian-American students but not for other student groups (Else-Quest et al., 2013). Their finding suggests that this suite of attitudinal factors may be culturally derived, yet potentially amenable to interventions.

**Language spoken at home.** Students who spoke a language other than the exam language at home had lower science achievement results across 15 nations (Perera, 2014), across a range of MENA nations (Bouhlila, 2011), and in Canada (Areepattamannil & Kaur, 2013), Ireland (Gilleece et al., 2010), and Taiwan (Tsai & Yang, 2015).
Influence of School Characteristics on Aspects of Science Engagement

A paucity of research is apparently available on the influence of school context on aspects of science engagement; in contrast, school climate has been shown to impact many aspects of science engagement (see below).

School context. In co-educational high schools, Australian females were more likely to enroll in life science courses and less likely to sign up for physical sciences classes than their male counterparts (Sikora, 2014). However, future intentions expressed by students in single-gendered schools were only modestly different from what would be expected based on the above trends; that is, females were less likely, but males more likely to express interest in pursuing life science careers (Sikora, 2014).

School climate. Osborne, Simon, & Collins (2003), in their review of two decades of literature on science attitudes among students, concluded that the most important formative factor was classroom environment and thus argued that appropriate teaching strategies would go far to improve student engagement in science. Andermann, Andrzejewski, and Allen (2011), based on an ideal teacher profile of mastery goal orientation, academic press, and teacher support, observed high school science classrooms, concluding that teachers who well-managed their classrooms, created rapport with their students, and supported content understanding were most likely to produce positive motivational and learning outcomes.

Muis and Duffy (2013) implemented an instructional framework in a collegiate statistics class designed to promote epistemic thinking among their students; results included a higher level of statistics self-efficacy and final course grades compared with the control group. Students who maintained their interest in science from elementary
school into middle school reported that teachers who gave them opportunity to express their ideas, taught in a positive way, and constructed a welcoming classroom environment were key supportive factors (Logan & Skamp, 2008). Schools in the Czech Republic, Finland, Germany, and Norway had a much more pronounced influence on students’ interest in science through their instructors and curricula than did the students’ own families (Basl, 2011). Teachers making use of “personal every day and future relevance” were able to make modest gains toward science interest among Canadian high school male students who originally held instrumental views about their science courses (Niewsandt & Shanahan, 2008, p. 3). Norwegian science teacher quality (an emphasis on student understanding, challenge, and building relationships) enhanced instrumental motivation for science of high school students and indirectly influenced science achievement (Christopherson, Elstad, & Turmo, 2010). Korean middle school students who reported that their teachers helped them relate science to their daily lives, work problems on their own, or design experiments were more likely to hold a future interest in science as a career (House, 2009). DeWitt et al. (2014) argued that science teachers need to make science more engaging and families need to work at persuading their offspring of the importance of science for a future career. Bottia, Stearns, Mickelson, Moller, and Parker (2015) concluded that a key strategy to enhance future intent of female high school students to pursue science as a college major and subsequent career was by making courses like physics relevant to the students’ daily lives through specifically planned instructional strategies. Instructional environments in German and Swiss high school physics classrooms which involved “deep-reasoning teacher questions and feedback” resulted in a higher level of enjoyment of science (Jurik, Gröschner, & Seidel,
Israeli middle school culture was credited over and above any family factors in inculcating continuing motivation for science-related activities among students (Vedder-Weiss & Fortus, 2011).

**Influence of School Effects on Science Achievement**

**School context.** Enhanced science achievement was more related to a suite of institutional features (e.g., school autonomy in personnel decisions, teacher control over teaching methods, encouragement of parental involvement) than to school resources per se in a study of 39 nations (Wößmann, 2003). High schools in Hong Kong differed sharply in science achievement; however, this was almost entirely explained by differences in the science scores of their students upon entry to such high schools (Lam & Lau, 2014). Small but significant differences in science achievement between rural and non-rural schools in Australia favored non-rural schools; however, a deficit in rural school-level resources did not exist and so could not account for the achievement difference (Webster & Fisher, 2000). Science achievement of Turkish students in rural schools was lower than that of their counterparts in city schools in both PISA 2006 and PISA 2009 (Topçu, Arikant, & Erbilgin, 2015).

**School size.** Larger school size positively affected science achievement of non-immigrant (but not immigrant) students in Canada (Areepattamannil & Kaur, 2013). Large school enrollments led to enhanced science achievement in an Indian context (Areepattamannil, 2014). Larger schools in Spain had slightly lower math achievement scores (Martín, Martínez-Arias, Marchesi, & Pérez, 2008). Werblow and Duesbery (2009) found that students in very small (<674 students) or very large (>2592 students)
high schools had the largest gains in math achievement. Larger school size and more adequate school resources improved math achievement (Schreiber, 2002).

School ownership type. Increasing competition from private schools had a positive impact on academic achievement in public schools (Wößmann, 2001, 2003). Using multiple methods across nine nations in PISA 2000 (which assessed science, math and reading achievement), Vandenberghe and Robin (2004) showed no systematic benefits for private schooling over public schooling. Two of their studied nations (Belgium and Brazil) did indeed produce a positive private school effect in all three achievement areas; Vandenberghe and Robin (2004, p. 505) suggested that “. . . the better education received in private schools could be explained by religious values, such as hard work, effort, obedience, discipline, and dedication to a task, for both students and teachers.” Private schools in the developing countries of Columbia, the Dominican Republic, the Philippines, Tanzania, and Thailand generally resulted in greater academic achievement of students than did public schools, even when differences in intake populations were taken into account (Jimenez, Lockheed, & Paqueo, 1991). Kingdon (1996) noted that 14-year-old urban Indian students had sharply higher math achievement scores when they were able to attend fully-private schools as compared with either public or private schools which were government supported. Some international research thus appears to indicate a positive influence of private schools over public schools in terms of academic achievement.

Cordero Ferrera, Crespo Cebada, & Santín González (2010) found no differences in science achievement between private and public schools; however, they indicated that since better students were matriculated into private schools, such schools were actually
less efficient than were private schools. School ownership type did not influence science achievement in Spain for PISA 2006 (Cordero Ferrera et al., 2011). Mancebón, Calero, Choi & Ximénez-de-Embún (2012) concluded that public high schools in Spain were more efficient (in terms of costs of obtaining equivalent PISA 2006 outcomes) than were private Spanish high schools which were receiving government support. In the Spanish context, some privately-managed, but government-supported high schools have resulted in better academic achievement than public high schools (Crespo-Cebada, Pedraja-Chaparro, & Santin, 2014). Taken together, the above research on school ownership type in Spain provided little support for an advantage in academic achievement for private schools, and seemed to indicate that such schools may actually be less efficient that public schools.

*Proportion girls in a school.* Boys’ academic achievement was enhanced by an increasing proportion of girls in a school, and this enhancement was related to a general elevation of the school’s study orientation (Van Houtte, 2004). The proportion of girls in Turkish high schools did not influence science achievement (Dincer & Uysal, 2010).

*School-level SES.* Like family SES, school SES is an important explanatory factor for science achievement; examples of this relationship include: 15 nations (Perera, 2014), 17 collated studies (Sellström & Bremberg, 2006), Australia (McConney & Perry, 2010), China (Zhang & Campbell, 2015), Ireland (Gilleece et al., 2010), Turkey (Acar, 2009; Dincer & Uysal, 2010), and the U.S. (Borman & Dowling, 2010). School-level SES was the only statistically significant influence on science performance for Irish students in PISA 2006; the authors raised a national-level school equity question based on this finding (Gilleece et al., 2010). Based on their intensive review of PISA 2009
data, de Mendizabal and Calero Martinez (2013) called for a national policy of “maintenance of equity” at the school-level due to the tendency of science (and math and reading) achievement to be tied to school-level SES measures (p. 563). Unsurprisingly, Marks (2006, p. 21), who chose to analyze multilevel data from 30 nations tested in PISA 2000 by multiple regression techniques rather than by using HLM, concluded that “differences in student performance between and within schools cannot be accounted for by socioeconomic background.” (p. 21). Marks (2006) did acknowledge that high status parents with greater social capital may have been able to place their children into higher status tracked schools or programs, and thus influence the educational outcomes for their offspring.

**Teacher certification.** The literature presents a mixed picture of the influence of teacher certification on science achievement. An increase in the proportion of teachers certified enhanced science achievement in PISA 2000 across 31 countries (Fuchs & Wößmann, 2007); however, teacher certification did not result in enhanced science achievement scores for high school seniors in U.S. private schools (Sharkey & Goldhaber, 2008). High school science students, whose teachers held emergency certification in science, earned statistically similar science achievement scores to those students whose teachers held standard science certification (Goldhaber & Brewer, 2000). Darling-Hammond, Berry, and Thoreson (2001) challenged Goldhaber and Brewer’s (2000) conclusions, indicating in their analysis that most science teachers who held emergency certification had similar background and training as those who held standard certification, and thus argued that the certification system should be strengthened rather than weakened. Middle school students taught by teachers with secondary school science
certification substantially outscored those taught by uncertified teachers; note that many states did not have a separate middle school certification arrangement (Neild, Farley-Ripple, & Byrnes, 2009). Higher free or reduced lunch percentages and higher minority percentages in Missouri schools were associated with lower science achievement scores; however, such schools were able to mitigate lower achievement by increasing numbers of certified teachers and teachers with master’s degrees (Hogrebe & Tate, 2010). Substantial differences exist among instructional practices employed by alternatively certified science teachers; those with some educational experience tend to practice “standards-based instruction” to a greater degree (Scribner & Akiba, 2010). Alternatively certified science teachers, using substandard materials (and potentially, misaligned teaching strategies) had below average student science achievement on state exams in Texas (Linek et al., 2009). Kane, Rockoff, and Staiger (2008), working with six years of incoming teacher cohorts varying in certification credentials, found that differences among individual teachers in their effectiveness were evident within their first two years in residence, persistent, and more powerful than effects of initial certification status. While Teach for American volunteers were more effective in terms of student academic achievement than traditionally trained teachers in North Carolina, other alternatively trained teachers were less effective (Henry et al., 2014). As noted above, the role of teacher certification in producing enhanced academic achievement is not entirely clear.

Student-teacher ratio. Smaller class sizes resulted in improved science achievement across 31 countries evaluated in PISA 2000 (Fuchs & Wößmann, 2007). As student-teacher ratios climbed in Turkey, science achievement declined (Dincer & Uysal,
2010). Provision of smaller class sizes during elementary years has been shown to improve achievement in science and math; moreover, longer term provision of small class sizes has reduced the achievement gap between low- and high-performing middle school students (Konstantopoulos & Chung, 2009). From a suite of nine diverse countries studied, only the U.S. showed a positive impact for reduced class size on math achievement (Pong & Pallas, 2001).

**Teacher shortage.** A shortage of teachers adversely influenced science achievement of U.S. students in both PISA 2006 and 2009 relative to the nine other largest developed OECD countries (Sousa et al., 2012). Teacher shortages adversely influenced science achievement of immigrant (but not non-immigrant) students in Canada (Areepattamannil & Kaur, 2013).

**Educational resources.** Quality of a school’s educational resources positively influenced science achievement in India (Areepattamannil, 2014). Norwegian high schools which were located near waterfalls, and thus had access to locally generated hydro-power revenue for funding, had higher overall academic achievement (Hægeland, Raaum, & Salvanes, 2012). Häkkinen, Kirjavainen, and Uusitalo (2003) identified no school-level effect of decreased spending on teaching resources, during a 1990s recession in Finland, on student performance across subject domains. Wei, Clifton, and Roberts (2012) found, surprisingly, that school physical resources did not influence math achievement across Canadian provinces.

**School climate.** Overall school climate (consisting of positive teacher, parent and student relationships within the school environment) was the most important school-level factor associated with science performance of eighth grade students in Taiwan (Tsai &
Yang, 2015). Higher levels of local budget control resulted in improved science achievement across 31 countries evaluated in PISA 2000 (Fuchs & Wößmann, 2007). Control of school budgets by principals has also been shown to improve students’ math achievement in Uruguay in PISA 2009 and PISA 2012 (Santín and Sicilia, 2015).

**Ability grouping.** Ability grouping negatively impacted science achievement of U.S. students in both PISA 2006 and 2009 relative to the nine other largest developed OECD countries (Sousa et al., 2012). In school contexts with relatively few immigrants, placement of first-generation, Mexican-origin students in ESL classes proved to be detrimental to their overall academic progress (Callahan, Wilkinson, & Muller, 2008). In England, ability grouping has been shown to adversely impact science achievement, in large measure due to the loss of opportunity for learning due to misplacement of students based on nonacademic grounds such as behavior (Wilkinson & Penney, 2014). Dincer and Uysal (2010) found no impact of ability grouping on science achievement within Turkish high schools. Using a quasi-experimental design of “tiered instruction” for science instruction, Richards and Omdal (2007) found the low-ability group to benefit most from separate instruction; meanwhile, the high-ability group saw no change in science achievement with specialized instruction. Ability grouping failed to influence science or math achievement of English and Welch students across their 9th to 11th grade years in high school (Ireson, Hallam, & Hurley, 2005). Ability grouping may need to be more internally flexible; that is, the grouped classes may still include sufficient heterogeneity such that instructors need to differentiate their instruction within ability grouped classes (Ireson et al., 2005). Ability grouping had no perceivable influence on math performance; perhaps because de facto ability grouping (isolating low-achieving
students in separate classes) was occurring in nearly all schools which claimed not to employ ability grouping (Betts & Shkolnik, 2000).

**Science promotion activities.** Perera (2014) showed science promotion activities (such as science fairs and school-based clubs) to enhance science achievement of students in 15 countries in PISA 2006.

**Parental involvement.** Hong Kong parents positively influenced the general value of science and science achievement of their children; they did so by sharing their own elevated general value of science with their offspring at home (Acosta & Hsu, 2014b). Across 15 nations, Perera (2014) uncovered a positive influence of parents’ general value of science on science achievement of their children (as measured by PISA 2006); further, the strength of this influence was independent of family SES, indicating that low SES parents’ attitude was just as impactful on science achievement as was that of higher SES parents. Maternal acceptance, as perceived by students, improved grade point averages of male seventh grade students in Mississippi (Khan, Haynes, Armstrong, & Rohner, 2010). The degree to which fathers were involved in their children’s education had a significantly positive relationship with overall academic achievement, according to the meta-analysis of Jeynes (2015). This relationship held true across the range of ethnic groups in his study. While parental involvement was directly linked to science achievement at the elementary age level, its linkage to science achievement was indirect (through task value) at the middle school level (Senler & Sungur, 2009). Early parental support, as perceived by students, was unrelated to growth in science achievement for either gender (Ing, 2014). Johnson and Hull (2014) noted that school-based parental involvement with their children in the third, fifth and eighth grades failed
to positively influence either initial science achievement or growth in science achievement. Mji and Mbinda (2005) found high parental involvement with their twelfth grade science students in South Africa to be related to low science achievement; in this extraordinary case, parents had less education than did their children, and that may have explained both their involvement and their inability to provide a positive academic influence.

**Teaching strategies.** An array of teaching strategies has been shown to enhance science achievement; unfortunately, other teaching strategies have actually had negative influences on this important outcome. Perceived teacher acceptance enhanced grade point averages of seventh grade male (but not female) students in Mississippi (Khan et al., 2010). Pickens and Eick (2009) found more highly motivated science students to respond well to the incorporation of enthusiasm in classroom presentations, the development of a low-threat classroom environment, and connections of students’ realms to science fields; on the other hand, less motivated students responded positively to strategies which enhanced their self-confidence, encouraged dialogue between students, involved practical applications, and utilized hands-on inquiry methods. Student-centered instructional contexts (such as those with group experiments on a recurrent basis) were positively associated with enhanced science achievement of U.S. middle school students (Odom, Stoddard, & LaNasa, 2007). The progression in learning from science facts to the relationships among science concepts was markedly more rapid for Finnish compared with either German or Swiss high school students, potentially explaining their higher performance on science achievement assessments (Geller et al., 2014). Geller et al. (2014) believed that the primary reason for this progression was due to the instructional
style of Finnish teachers, which emphasized applications of scientific knowledge.
Classroom environments which supported autonomy of eighth grade Turkish science
students also enhanced their science achievement (Kingir, Tas, Gok, & Vural, 2013).
Instructional approaches which emphasized independent thinking and understanding by
students were associated with student satisfaction and science achievement; in contrast,
when students perceived that instruction was fast-paced, focused on correct answers, and
only accessible to the best students, their science achievement was reduced (Nolen,
2003). Teachers who fostered learning through life examples, experiments and exercises
had positive impacts on science achievement of Turkish students (Kalendar &
Berberoglu, 2009).

While instruction involving a focus on models and applications was positively
associated with science performance for students in 15 nations involved in PISA 2006,
both hands-on and science investigations instructional methods proved to have negative
associations with science achievement (Perera, 2014). Science teaching methods
involving student investigations had a negative impact on science achievement of both
immigrant and non-immigrant students in Canada (Areepattamannil & Kaur, 2013).
 Teachers who struggled with the implementation of the inquiry-based science units had
lower student performance gains; these teachers would presumably benefit from
professional development in inquiry learning strategies/implementation (Liu, Lee, & Lin,
2010). Rivkin, Hanushek, and Kain (2005) argued that Texas public schools should
emphasize improving teacher quality over reducing class size, based on the costs
involved and the academic achievement responses to these parameters in their study. At
the collegiate level, a meta-analysis of over 200 studies concluded that the inclusion of
active learning (of any type to any extent) within a standard class session (e.g., not laboratory or recitation) revealed a profound improvement in letter grade outcomes compared with traditional lecture, including a sharp decline in the percentage of failing grades (Freeman et al., 2014).

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Chapter Three: Methodology

From its first involvement with international large scale assessment in 2000, OECD has administered a PISA literacy instrument to 15-year-olds in both OECD member nations and cooperating non-member nations every three years. While each triennial administration of PISA has included assessment items related to reading, math, and science achievement, each has focused on one of these three key areas of literacy. Thus, the 2000 instrument was reading-focused (Adams & Wu, 2002), the 2003 instrument was math-focused (OECD, 2005), and the 2006 instrument was science-focused (OECD, 2009). The next round of PISA to be science-focused will be the 2015 administration (OECD, 2014a). In addition to an assessment focused more strongly on a particular literacy, each administration of PISA has also included a suite of variables thought to be potentially related to that literacy. Among these variables, PISA 2006 included nine aspects of science engagement, as well as several measures of individual students’ backgrounds along with school context and climate. Information on aspects of science engagement and student background were drawn from the student questionnaire (OECD, 2007e), while information on school context and climate measures were drawn from the school questionnaire (OECD, 2007d) as completed by principals (or in some cases, were aggregated from student-level data).

The inclusion of nine aspects of science engagement in PISA 2006 (OECD, 2009) provided science researchers with unique opportunities to relate a macrostructure of science engagement to science achievement (Fensham, 2009). These research opportunities have extended across nations (e.g., Woods-McConney et al., 2014), across ranges of individual student differences (Areepattamannil, 2012b; Areepattamannil &
Kaur, 2013; Sikora & Pokropek, 2012), and across a variety of school factors for the examination of the role of school effects (e.g., Basl, 2011).

My research focused on U.S. students not only because PISA data has shown that science literacy is relatively stagnant in the U.S. (OECD, 2007b, 2010b, 2014b), but also because the U.S. science educational community appears to need to make a more determined response to this problem (Bieber & Martens, 2011). A fresh look at the potential relationships between aspects of science engagement and science achievement, with an appropriate control over student- and school-level measures, could provide insights on ways to make progress in science literacy in the U.S. (Bieber & Martens, 2011).

While researchers have approached datasets such as PISA 2006 from a variety of different methodological approaches, the most statistically appropriate approach is to make use of multilevel modeling because of the hierarchical structure of data (students nested within schools). Marks (2006) used multiple regression techniques to analyze a 30-nation sample from PISA 2000; unsurprisingly, his results were quite different from others looking a similar research questions. Among other researchers, Sun et al. (2012) argued that multilevel modeling techniques should have been applied in the analysis of such hierarchically structured datasets. Thus I have chosen to employ multilevel modeling techniques (Raudenbush & Bryk, 2002) in this research.

Sample

Data on 15-year-old U.S. students were acquired from the 2006 PISA dataset (OECD, 2007a). Multi-stage stratified random sampling was used to sample the U.S. 15-year-old student population (OECD, 2009). Schools were sampled first from a
comprehensive national list of all eligible schools; the systematic sampling probability was proportional to the size of a given school. Once schools were selected for inclusion, students were selected from the eligible list (based on age); a random sample of the target cluster size (approximately 35 students) was selected for testing. If a selected school had less than 35 students of the targeted age, all students in that age range were selected. Thus, the initial U.S. sample contained 5555 students from 166 schools.

Missing data on outcome measures at level-one (aspects of science engagement and science achievement) was handled by listwise deletion (Raudenbush, Bryk, & Congdon, 2011). Due to the large number of students sampled (over 5000), this listwise deletion did not cause abnormal data reduction. On the other hand, 34 of 166 chosen schools (20.5%) could not be included in the final study due to missing school-level data, because multilevel modeling techniques do not permit missing data at level-two (Raudenbush et al., 2011). If school-level data is lost, the corresponding student-level data from that given school cannot be used in multilevel analysis, even if students may have completed the assessments and questionnaires. According to OECD (2009, p. 281), “(t)he [U.S] National Centre provided a detailed analysis of school non-response bias, which indicated no evidence of substantial bias resulting from school non-response.” Thus, the final U.S. sample included 4456 students in 132 schools.

Finally, Liou and Hung (2015) suggested reporting criteria for science education researchers involving sampling weighting factors in large scale international assessments. The PISA dataset included both student- and school-level sampling weight factors (OECD, 2007a), and they were included in my analysis.
**Outcome Measures**

Nine aspects of science engagement were considered in the first part of this two-part study. Those aspects of science engagement (science self-efficacy, science self-concept, enjoyment of science, general interest in science, instrumental motivation for science, future-oriented science motivation, general value of science, personal value of science, and science-related activities) were defined in chapter one; literature related to their formation, dimensions, functions, and individual differences was reviewed in chapter two. In the first part of this study, each aspect of science engagement served as an outcome (i.e., dependent) variable. For each aspect of science engagement, several items were included as a scale on the PISA student questionnaire (OECD, 2007e). For all nine aspects of science engagement, PISA researchers implemented item response theory (IRT) to derive final student measures (sometimes referred to as composite variables). Under PISA 2006 implementation of IRT, “a calibration sample of 500 cases from each of the OECD datasets was used to estimate item parameters. These item parameter estimates were then used to estimate weighted likelihood estimates” for each of the resultant aspects of science engagement (OECD, 2009, p. 353). Appendix A presents items that describe these aspects of science engagement. In data analysis, items were inverted for scaling so that higher values consistently indicated more positive aspects of science engagement. Note that no negatively worded items were included the sets of items used to derive each aspect of science engagement (see Appendix A).

In the second part of this study, science achievement (at the student level) was the outcome variable, while each aspect of science engagement served as a key independent variable. The definition for scientific literacy utilized by PISA (OECD, 2007c, p. 35)
refers to an individual’s “scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues [e.g., when individuals read about a health-related issue, can they separate scientific from non-scientific aspects of the text, and can they apply knowledge and justify personal decisions?], understanding of the characteristic features of science as a form of human knowledge and inquiry [e.g., do individuals know the difference between evidence-based explanations and personal opinions?], and awareness of how science and technology shape our material, intellectual, and cultural environments [e.g., can individuals recognize and explain the role of technologies as they influence a nation’s economy, social organization, and culture or are individuals aware of environmental changes and the effects of those changes on economic and social stability?”.

This definition was operationalized as science achievement based on a combined literacy scale including three subscales: using scientific evidence, identifying scientific issues, and explaining phenomena scientifically (OECD, 2007c). For purposes of analysis, five plausible values of science achievement for each student were estimated by PISA based on a random selection of items from all three subscales; these plausible value estimates were used in my subsequent analytical steps.

**Student-level Variables**

Based on the review of research literature (e.g., Ma et al., 2008), six student-level variables, considered to be exogenous to the outcome variables, were selected from those available in the PISA dataset (OECD, 2007a). Those variables included gender (dummy coded with 1 = males and 0 = females), age (continuous with two decimal places beyond
the 15-year-old base testing level), father’s SES and mother’s SES (standardized index based on parental occupation using procedures in International Labor Organization [1990] and Ganzeboom, De Graaf, & Treiman [1992]), immigration background (dummy coded based on where students and each of their parents had been born with 1 = native [at least one parent born in the U.S.] and 0 = immigrant [either they or their parents were born outside the U.S.]), and language spoken at home (dummy coded with 1 = English language spoken at home and 0 = any other language spoken at home). According to Ma et al. (2008), these variables provided a good representation of student and family background.

**School-level Variables**

Based on the review of research literature (e.g., Ma et al., 2008), school-level variables were either selected from those directly available through the dataset (OECD, 2007a) as acquired from the principals in the school-level questionnaire (OECD, 2007d) or aggregated from the corresponding student-level data within a school. School context variables included school size (the total enrollment in the school), school type (dummy coded with 1 = public schools and 0 = other types of schools), proportion of girls enrolled at school (calculated from the number of girls in a school and total enrollment), school-mean father’s SES and school-mean mother’s SES (aggregated from SES of students within a school), proportion of teachers certified (calculated as the number of fully certified teachers divided by the total number of teachers), student-teacher ratio (calculated as total school enrollment to total number of teachers), teacher shortage (PISA index based on principals’ responses to four items suggesting that the school’s capacity was hindered by a lack of qualified teachers in English, math, science or in other
subjects with higher values indicating a more extensive teacher shortage), and quality of educational resources (PISA index based on principals’ responses to seven items about shortage or inadequacy of educational resources including science laboratory equipment, textbooks, computers, connectivity, software, library materials, and audiovisual resources with higher values indicating more adequate educational resources after these responses were inverted).

Meanwhile, school climate variables included school responsibility for resource allocation (PISA index based on six items assessing the relative influence of principal and teachers compared with central educational authorities such as governing bodies), school responsibility for curriculum and assessment (PISA index based on four items assessing the relative influence of principal and teachers with central educational authorities), ability grouping (dummy with 1 = schools with ability grouping either as separate classes or within classes and 0 = schools without any ability grouping), school activities to promote the learning of science (count of “yes” to whether each of the five potential school activities were occurring at their school including science clubs, science fairs, science competitions, science research projects, or science field trips), parent influence (count of “yes” to four items about whether parent groups exert a direct influence on decisions about staffing, budgeting, instructional content, or assessment practices), teacher influence (count of “yes” to four items about whether teacher groups exert a direct influence on decisions about staffing, budgeting, instructional content, or assessment practices), school-mean science teaching—focus on models or applications (see Appendix B), school-mean science teaching—hands-on activities (see Appendix B), school-mean science teaching—interaction (see Appendix B), and school-mean science
teaching—student investigations (see Appendix B). According to Ma et al. (2008), these variables provided a good overall representation of school context and school climate.

**Statistical Procedures**

Means and standard deviations for all outcome, student background, and school factors were run using SPSS, Version 22. Note that since no missing data is permitted at level-two in multilevel modeling (Raudenbush & Bryk, 2002), and since any missing schools (level-two in this study) would thereby remove any associated level-one information (that is, student background) from the analyzed dataset, means and standard deviations were calculated for the reduced dataset as used for multilevel modeling (rather than from the full dataset). In order to test for possible relationships among aspects of science engagement, bivariate correlations were run using SPSS.

Multilevel modeling was done using Hierarchical Linear Models software (HLM7; Raudenbush et al., 2011) per the methods of Raudenbush and Bryk (2002) and Ma et al. (2008). In order to address my first two questions, the null model was run for each of the nine outcome variables (i.e., aspects of science engagement) with no student- or school-level variables entered into the model; this approach allowed for the estimation of the grand mean of each of the outcome variables, adjusted for the sampling errors (at both the student- and school-levels), and also served to provide an estimate of variance components at both the student- and school-levels (i.e., partition of variance).

**Null Models with Aspects of Science Engagement as Outcome Variables**

In the case of Equation 3.1, science self-efficacy ($E_{ij}$) was modeled with no student- or school-level variables entered into the model. Thus, according to this model, science self-efficacy for student $i$ in school $j$ was related to the intercept ($\beta_0$, a measure of
the average science self-efficacy for school $j$), student-level error unique to a student ($r_{ij}$), and school-level error unique to a school ($u_{0j}$). The average school-level science self-efficacy was represented by ($\gamma_{00}$). In a similar fashion, null models (not shown) were also run for each of the other eight aspects of science engagement: science self-concept, enjoyment of science, general interest in science, instrumental motivation for science, future motivation for science, general value of science, personal value of science, and science-related activities.

$$E_{ij} = \beta_{0j} + r_{ij}$$

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

$$or \ E_{ij} = \gamma_{00} + u_{0j} + r_{ij}$$

**Parsimonious Models with Aspects of Science Engagement as Outcome Variables**

Next all six student-level variables were entered, as grand-mean centered, into the level-one model for each of the nine successive aspects of science engagement. The intent of the level-one model was to build a parsimonious individual (student) model to test for individual differences in science engagement. In order to achieve a parsimonious level-one model, student-level variables with the largest $p$ values were progressively eliminated one by one until only those significant at the probability level of $p < .05$ remained in the level-one model. Once a parsimonious level-one model had been developed, all nineteen school-level variables (both context and climate) were entered, as grand-mean centered, into the level-two model to test for school effects on science engagement. This process allowed for the impartial elimination of the least significant school-level variables, irrespective of whether those variables were school context or school climate variables. Once again, non-significant school-level variables were
progressively eliminated one by one, starting with the variable with the largest $p$ value, until only those with $p$ values <.05 remained in the level-two model. In this way, parsimonious full models were developed for each aspect of science engagement; each model included only the remaining significant student- and school-level variables. Proportion of variance accounted for by the full model was calculated according to the methods of Raudenbush and Bryk (2002) and Ma et al. (2008). Specific details of those calculations were as shown below.

Equations 3.2 and 3.3 show the process of parsimonious model development for one example (science self-efficacy or $E_{ij}$) of the nine aspects of science engagement as outcome variables. Four parameters in Equations 3.2 and 3.3 ($\beta_{0j}$, $r_{ij}$, $u_{0j}$, and $\gamma_{00}$) were as described above for Equation 3.1. Additional parameters were as follows:

$\beta_{nj} = \text{coefficient for the } n\text{th level-one variable in the level-one model}$

$\gamma_{n0} = \text{coefficient for the } n\text{th level-one variable in the mixed model}$

$\gamma_{0n} = \text{coefficient for the } n\text{th level-two variable in the level-two and mixed model}$

Equation 3.2 shows the parsimonious level-one model with science self-efficacy as the outcome variable, developed as described above.

$$E_{ij} = \beta_{0j} + \beta_{1j}\text{Gender}_{ij} + \beta_{2j}\text{Age}_{ij} + \beta_{3j}\text{Father\_SES}_{ij} + \beta_{4j}\text{Language}_{ij} + r_{ij}$$

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

$$\beta_{1j} = \gamma_{10}$$

$$\beta_{2j} = \gamma_{20}$$

$$\beta_{3j} = \gamma_{30}$$

$$\beta_{4j} = \gamma_{40}.$$

Or $$E_{ij} = \gamma_{00} + \gamma_{10}\text{Gender}_{ij} + \gamma_{20}\text{Age}_{ij} + \gamma_{30}\text{Father\_SES}_{ij} + \gamma_{40}\text{Language}_{ij} + u_{0j} + r_{ij}$$
Equation 3.3 shows the parsimonious model for science self-efficacy for both level-one and level-two; the process by which this model was derived was described above.

\[
E_{ij} = \beta_{0j} + \beta_{1j}Gender_{ij} + \beta_{2j}Age_{ij} + \beta_{3j}Father_{SES_{ij}} + \beta_{4j}Language_{ij} + r_{ij} \\
\beta_{0j} = \gamma_{00} + \gamma_{01}Hands-on\_Activities_{ij} + u_{0j} \\
\beta_{1j} = \gamma_{10} \\
\beta_{2j} = \gamma_{20} \\
\beta_{3j} = \gamma_{30} \\
\beta_{4j} = \gamma_{40}.
\]

Or \( E_{ij} = \gamma_{00} + \gamma_{01}Hands-on\_Activities_{ij} + \gamma_{10}Gender_{ij} + \gamma_{20}Age_{ij} + \gamma_{30}Father_{SES_{ij}} + \gamma_{40}Language_{ij} + u_{0j} + r_{ij} \)

In the second part of the data analysis, in order to address my latter three questions, science achievement became the outcome variable for a series of nine models—one for each aspect of science engagement. Methods were as above, with the important difference that the nine aspects of science engagement were entered into nine successive level-one models, one per model, and remained in the parsimonious full models (or not) depending on whether or not each given aspect of science engagement was significant. Specifically, the null model for science achievement was run without any level-one (aspect of science engagement or individual student characteristics) or level-two (school context and climate) variables in order to allow for the estimation of the grand mean of science achievement, adjusted for the sampling errors (at both the student- and school-levels), and also to provide an estimate of variance components at both the student- and school-levels (i.e., partition of variance).
Null Model for Science Achievement

Equation 3.4 provides the null model for science achievement \((A_{ij})\), with no level-one (i.e., no student characteristics, no aspects of science engagement) and no level-two (i.e., no school context or climate measures) variables included in the model. Thus, according to this model, science achievement for student \(i\) in school \(j\) was related to the intercept \(\beta_{0j}\), a measure of the average science achievement for school \(j\), student-level error unique to each student \(r_{ij}\), and school-level error unique to each school \(u_{0j}\). The (grand) average school-level science achievement was represented by \(\gamma_{00}\).

\[
A_{ij} = \beta_{0j} + r_{ij}
\]

\[
\beta_{0j} = \gamma_{00} + u_{0j}
\]

or

\[
A_{ij} = \gamma_{00} + u_{0j} + r_{ij}
\]  

(3.4)

Next the first aspect of science engagement to be modeled (e.g., science self-efficacy), along with all six student-level variables were entered, as grand-mean centered, into the level-one model with science achievement as the outcome variable. Thus, seven student-level variables were entered into the level-one model for this first round of modeling for science achievement. The intent of the level-one model was to build a parsimonious individual (student) model to test the effects of science engagement on and individual differences in science achievement. Starting with the student-level variable with the largest \(p\) value, student-level variables were progressively eliminated one by one until only those significant at the probability level of \(p < .05\) remained in the level-one model. Importantly, the aspect of science engagement under consideration only remained in the level-one model if it met the same inclusion criterion as the other student characteristics. Once a parsimonious level-one model had been developed, all nineteen
school-level variables (both context and climate) were entered, as grand-mean centered, into the level-two model. This process allowed for the impartial elimination of the least significant school-level variables, irrespective of whether those variables were school context or school climate variables. Once again, non-significant school-level variables were progressively eliminated one by one, starting with that with the largest $p$ value, until only those with $p$ values $< .05$ remained in the level-two model. In this way, a parsimonious full model was developed for science achievement to test school effects on science achievement. This modeling process was repeated a total of nine times, once for each aspect of science engagement. Proportion of variance accounted for by the parsimonious model for each of the nine science achievement models was calculated according to the methods of Raudenbush and Bryk (2002) and Ma et al. (2008). Specific details of those calculations were as shown below. A tenth parsimonious science achievement model was developed; this model included none of the nine aspects of science engagement. Level-one and level-two modeling included the same student-level and school-level characteristics, respectively, and implemented the same procedures as did the nine science achievement models which did include an aspect of science engagement. The purpose for including this additional model was as a reference point for comparison for the proportion of variance accounted for by the other nine science achievement models. Finally, a series of null models was run, one for each of the nine aspects of science engagement.
Parsimonious Models for Science Achievement, Including Aspects of Science Engagement as Independent, Student-level Variables

Equations 3.5 and 3.6 below show the process of parsimonious model development for science achievement for one example (science self-efficacy) of inclusion of a single aspect of science engagement as level-one (student) variable. Four parameters in Equations 3.5 and 3.6 ($\beta_{0j}$, $r_{ij}$, $u_{0j}$, and $\gamma_{00}$) were as described above for Equation 3.4. Additional parameters were as follows:

$\beta_{nj} =$ coefficient for the $n$th level-one variable in the level-one model

$\gamma_{n0} =$ coefficient for the $n$th level-one variable in the mixed model

$\gamma_{0n} =$ coefficient for the $n$th level-two variable in the level-two and mixed model

Equation 3.5 shows the parsimonious level-one model for science achievement, with no level-two variables included; developmental procedures for this model were as described above.

$$A_{ij} = \beta_{0j} + \beta_{1j}Self-efficacy_{ij} + \beta_{2j}Father\_SES_{ij} + \beta_{3j}Mother\_SES_{ij} + \beta_{4j}Language_{ij} + r_{ij}$$

$$\beta_{0j} = \gamma_{00} + u_{0j}$$

$$\beta_{1j} = \gamma_{10}$$

$$\beta_{2j} = \gamma_{20}$$

$$\beta_{3j} = \gamma_{30}$$

$$\beta_{4j} = \gamma_{40}.$$  

Or

$$A_{ij} = \gamma_{00} + \gamma_{10}Self-efficacy_{ij} + \gamma_{20}Father\_SES_{ij} + \gamma_{30}Mother\_SES_{ij} + \gamma_{40}Language_{ij} + \gamma_{00} + r_{ij}$$
Equation 3.6 was the parsimonious model for science self-efficacy for both level-one (student background) and level-two (school context and school climate); like Equation 3.5, the developmental steps for this model were as described above.

\[ A_y = \beta_0 + \beta_1 \text{Self-efficacy}_{ij} + \beta_2 \text{Father SES}_{ij} + \beta_3 \text{Mother SES}_{ij} + \beta_4 \text{Language}_{ij} + r_{ij} \]

\[ \beta_0 = \gamma_{00} + \gamma_{01} \text{Size}_j + \gamma_{02} \text{School Father SES}_j + \gamma_{03} \text{Curriculum Assessment Responsibility}_j + \gamma_{04} \text{Student Investigations}_j + u_{0j} \]  

\[ \beta_{1j} = \gamma_{10} \]

\[ \beta_{2j} = \gamma_{20} \]

\[ \beta_{3j} = \gamma_{30} \]

\[ \beta_{4j} = \gamma_{40} . \]

Or \[ A_y = \gamma_{00} + \gamma_{01} \text{Size}_j + \gamma_{02} \text{School Father SES}_j + \gamma_{03} \text{Curriculum Assessment Responsibility}_j + \gamma_{04} \text{Student Investigations}_j + \gamma_{10} \text{Self-efficacy}_{ij} \]

\[ + \gamma_{20} \text{Father SES}_y + \gamma_{30} \text{Mother SES}_y + \gamma_{40} \text{Language}_y + u_{0j} + r_{ij} \]

Eight individual parsimonious models for the remaining science achievement models which each included one of eight remaining aspects of science engagement as outcome variables are shown in chapter four. In addition, a parsimonious model for science achievement was developed without any of the nine aspects of science achievement, but including level-one and level-two variables which met the appropriate \( p < .05 \) test for inclusion. This model is also shown is chapter four, and was run in order to provide for an appropriate comparison for the proportion of level-one (student) and level-two (school) variance accounted for by models which included an aspect of science engagement.
Proportion of Variance Explained

I calculated proportion of variance explained at level-one (student-level) and level-two (school-level) by using the general formula as shown below in Equation 3.7 and as drawn from Raudenbush and Bryk (2002). Specifically, the proportion of student-level variance explained, derived from any given parsimonious model, was calculated by using the appropriate variance component $\hat{\sigma}^2$ from that model as well as from its corresponding null model. Similarly, proportion of school-level variance explained for any given parsimonious model was determined by making use of the appropriate variance components from the parsimonious model and its corresponding null model.

$$\frac{(\hat{\sigma}^2_{null} - \hat{\sigma}^2_{final})}{\hat{\sigma}^2_{final}}$$

(3.7)

Effect Size

Given the large number of students and schools involved in this multilevel study, a high level of statistical power was available. Further, my approach (assessing potential influences of the nine aspects of science engagement on science achievement one such aspect per model, rather than testing all or several in the same model as some others have done [e.g., Areepattamannil, 2012b]), begs for a comparison of effect size across models. Hence, I made use of Cohen’s $d$ to estimate effect size. Cohen’s $d$ was calculated for each significant response variable in each parsimonious model by dividing the coefficient by its corresponding standard deviation (SD) of the outcome. For example, in the case of PISA science achievement on a measurement scale of mean = 500 and SD = 100, each significant coefficient was divided by 100 to obtain its corresponding effect size. Effect
sizes of 0.20 to 0.49 are considered small, 0.50 to 0.79 are considered medium, and those of 0.80 or greater are considered to be large (Cohen, 1988).
Chapter Four: Results

This chapter is organized in three parts: i) a brief introduction, consisting of presentations of descriptive statistics for all variables (Table 4.1) and bivariate correlations among the nine studied aspects of science engagement (Table 4.2), ii) multilevel model analyses for each successive aspect of science engagement treated as an outcome variable with student-level and school-level variables as level-one and level-two variables, respectively (Tables 4.3 through 4.11), and iii) multilevel model analyses with science achievement as the outcome variable with no aspects of science engagement included (Table 4.12) and then with each successive aspect of science engagement treated as a level-one variable (alongside student-level variables) and each school-level variable included as a level-two variable (Tables 4.13 through 4.21), and finally a summary table (Table 4.22) which compiled the effect sizes calculated for each nine aspects of science engagement from Tables 4.13 through 4.21. Note that $p < .05$ was utilized throughout this chapter for consistency, even though some $p$ values were $< .01$ or $.001$.

There are quite a few standardized variables or indices in Table 4.1, all of which are standardized based on the overall OECD sample (i.e., set by OECD with a global mean of 0.00 and standard deviation of 1.00; see OECD, 2009). Therefore, the reference for any discussion of these standardized variables is the international average (i.e., on the global scale). Means for the nine aspects of science engagement center around zero and their standard deviations center around 1.00 (Table 4.1); this is to be expected for standardized variables such as these. The five plausible values of science are presented here only as a reminder of the derivation of science achievement discussed in the methods above; the resultant variable (that is, science achievement) is also a standardized
measure, so the observed results are in line with that expectation. Among student-level variables, males were slightly more numerous than females in my sample (Table 4.1). Since PISA was designed to assess 15-year-old students (note that the specific sampling frame was from 15 years, 3 months to 16 years, 2 months of age), an average age of 15.82 for this U.S. sample is reasonable (Table 4.1). Neither mean father’s SES nor mean mother’s SES was particularly high in this sample; in addition, pronounced variability was observed around both of those means. Mean mother’s SES was similar to mean father’s SES, perhaps surprising to some observers. Approximately 15% of this sample was of an immigrant background, while 11% of the tested group acknowledged speaking a language other than English at home (Table 4.1).

I have chosen to carefully distinguish throughout this dissertation between school context and school climate variables; this paragraph focuses on school context measures. The standard deviation for school size approached the mean for school size, indicating substantial variability in this measure (Table 4.1). Unsurprisingly, the proportion of girls enrolled (0.49) matched the student-level gender variable (which used female coded as 1). The importance of this school-level variable was to assess whether or not gender composition in a school influenced any of the aspects of science engagement or science achievement. Some 94% of teachers were certified (Table 4.1), perhaps indicating that the likelihood of identifying associations between this variable and my outcomes of interest was modest. Nearly 90% of sampled schools were fully public in their ownership (Table 4.1). Student-teacher ratio averaged 15.47, while teacher shortage (index) averaged -0.03 (Table 4.1), seemingly indicating that these schools, on average, were well-staffed with teachers. Quality of educational resources averaged 0.30 (values
progressively greater than zero were more favorable); however, variability in this measure was particularly high (Table 4.1). While school-mean father’s SES and school-mean mother’s SES were understandable similar in value to the corresponding student-level measures, their variability was much lower, since these measures were based on means rather than individual students (Table 4.1).

This paragraph addresses school climate variables. Both school responsibility for resource allocation and school responsibility for curriculum and assessment show very high mean local decision-making authority within sampled U.S. schools, and somewhat lower variability than anticipated (Table 4.1). A very high proportion of schools in this study (86%) indicated that they were using some ability grouping in their classrooms; meanwhile, approximately half (48%) of schools provided intentional, school-level activities to promote science learning (Table 4.1). While parent influence was rated by principals as relatively modest on average (0.67 on a 4-point scale), those same principals rated teacher influence as much more substantial (2.23 on the same scale; Table 4.1). The student questionnaire (OECD, 2007e) included items designed to evaluate the types of science teaching students were experiencing; I aggregated their responses to the school-level and treated the following four measures as school climate variables: i) school-mean science teaching—focus on application or models, ii) school-mean science teaching—hands-on activities, iii) school-mean science teaching—interaction among students, and iv) school-mean science teaching—investigations. Admittedly, this provided me with the perspective of students on what sort of science instruction they were experiencing, rather than the principals’ intention of the type of science instruction which should be delivered. Note that while students reported positive average values for
all four types of science instruction, hands-on activities may have been more extensive than interaction (Table 4.1). I ran bivariate correlations among science teaching approaches (not reported in any table) and found them all significant ($p < .05$). The strength of those correlations varied markedly nonetheless. Focus on applications or models and interactions were somewhat closely related (0.69), as were interactions and investigations (0.62); however, focus on applications or models and hands-on activities (0.49) and focus on applications and models and investigations (0.43) were moderately related, while hands-on activities and interactions (0.31) and hands-on activities and investigations (0.25) were less closely related. Given these bivariate correlation results and the markedly different questions asked of students on the questionnaire to elicit this information (see Appendix B), I believe that these four measures of science instruction merit separate consideration.

Table 4.2 includes all possible bivariate correlations among the nine aspects of science engagement considered in this research. Recall that OECD researchers (OECD, 2009) set up these aspects in four pairs, with science-related activities as an unpaired aspect of science engagement. Those pairs (discussed and differentiated in chapter one) were as follows: i) science self-efficacy and science self-concept, ii) enjoyment of science and general interest in learning science, iii) instrumental motivation for science and future-oriented science motivation, and iv) general value of science and personal value of science. One would thus not be surprised if bivariate correlations among such pairs of variables were higher than for other comparisons. Indeed, while all bivariate correlations among the nine aspects of science engagement proved to be significant, the three numerically largest values shown in Table 4.2 were for the above pairings: i)
general value of science with personal value of science, 0.70, ii) instrumental motivation for science with future-oriented science motivation, 0.63, and enjoyment of science with general interest in learning science, also 0.63. Notably, the fourth pairing (science self-efficacy and science self-concept), which has received attention in the literature as to whether or not these measures (as academic self-efficacy vs. academic self-concept) actually differ substantially (e.g., Bong & Skaalvik, 2003), had a bivariate correlation of only 0.52. Given that approximately 4432 students were included in each of the aspects of science engagement, significant correlations are to be expected. However, a close review of the rest of the bivariate correlations in Table 4.2 (beside the four anticipated pairings noted above), along with the sets of specific questionnaire items in Appendix A, supported my contention that each of these nine aspects of science engagement is reasonably independent of the other measures on theoretical grounds.

**Aspects of Science Engagement as Outcome Variables**

**Science self-efficacy.** Based on the null model for science self-efficacy, the grand average was 0.22 ($p < .05$); the positive value indicates that U.S. students held science self-efficacies significantly above the OECD standardized mean of 0 (OECD, 2009). Variance components of the null model were 1.20 for students and 0.03 for schools ($p < .05$ at the school-level). The proportion of variance in the null model attributable to students was 97.90% while the proportion of variance attributable to schools was 2.10%. Thus, student-level variance accounted for a very high proportion of the variance in science self-efficacy relative to schools.

The student-level variables gender, age, father’s SES, and language spoken at home all significantly influenced science self-efficacy, as did school-mean for science
teaching—hands-on activities (Table 4.3). Females and older students had lower science self-efficacy; meanwhile, higher father’s SES and English language spoken at home both promoted science self-efficacy. While all four of the above student-level variables significantly influenced science self-efficacy, the effect sizes for these variables were quite modest. The school-level variable (school climate) which influenced science self-efficacy was school-mean science teaching—hands-on activities; the effect size in this case was more substantial (0.26), although still small by generally accepted standards (see chapter three). I note that the multilevel model explained 86% of the variance at the school-level and 7% of the variance at the student-level, both acceptable performances.

**Science self-concept.** Based on the null model for science self-concept, the grand average was 0.20 ($p < .05$); the positive value indicates that U.S. students held science self-concepts significantly above the OECD standardized mean of 0 (OECD, 2009). Variance components of the null model were 1.05 for students and 0.04 for schools ($p < .05$ at the school-level). The proportion of variance in the null model attributable to students was 95.94% while the proportion of variance attributable to schools was 4.06%. Thus, student-level variance accounted for a very high proportion of the variance in science self-concept relative to schools.

The student-level variables gender and father’s SES significantly impacted science self-concept, as did the school-level variables proportion of girls enrolled and school-mean for science—teaching, focus on applications or models (Table 4.4). While females had lower science self-concept than males, father’s SES promoted science self-concept; however, the effect size for both of these student level variables was quite small. The school context variable proportion of girls enrolled and the school climate measure
focus on applications or models both positively influenced science self-concept; the
effect sizes of both of these variables were in the range generally described as small.
That a higher proportion of girls enrolled could enhance science self-concept, while
females averaged lower on this measure than did males may seem anomalous; however, a
good explanation for these results appears to be available (which will be provided in my
discussion). This model explained 67% of the school-level variance and 7% of the
student-level variance, both reasonable results.

**Enjoyment of science.** Based on the null model for enjoyment of science, the
grand average was -0.03 ($p = 0.52$); this value indicates that U.S. students held values of
enjoyment of science similar to the OECD standardized mean of 0 (OECD, 2009).
Variance components of the null model were 0.96 for students and 0.04 for schools ($p <
.05$ at the school-level). The proportion of variance in the null model attributable to
students was 96.19% while the proportion of variance attributable to schools was 3.81%.
Thus, student-level variance accounted for a very high proportion of the variance in
enjoyment of science relative to schools.

The student-level variables gender and father’s SES significantly influenced
enjoyment of science, as did school-mean science teaching—focus on applications or
models (Table 4.5). Female gender was associated with lower average enjoyment of
science, while higher father’s SES had a positive influence on this aspect of science
engagement. However, the effect size for both of these variables was less than 0.10. The
school climate measure of school-mean science teaching—focus on applications or
models positively influenced enjoyment of science, with a small (0.32) effect size.
Proportion of variance explained by this multilevel model at the school-level (61%) and
General interest in learning science. Based on the null model for general interest in learning science, the grand average was 0.00 ($p = .98$); this value indicates that U.S. students held values of general interest in learning science very similar to the OECD standardized mean of 0 (OECD, 2009). Variance components of the null model were 1.10 for students and 0.02 for schools ($p < .05$ at the school-level). The proportion of variance in the null model attributable to students was 98.58% while the proportion of variance attributable to schools was 1.42%. Thus, student-level variance accounted for a very high proportion of the variance in general interest in learning science relative to schools.

Student-level variables age and immigration background, along with school-level variables teacher shortage, science promotion, and school-mean science teaching—hands-on activities, all significantly influenced general interest in learning science (Table 4.6). General interest in learning science was lower for older students within this cohort; meanwhile, native students scored lower than immigrant students (on average) for this measure (Table 4.6). I must concede that neither of these student-level measures had appreciable $d$ values. The school context variable teacher shortage had a negative influence on general interest in learning science, as did the school climate variable school activities to promote science. Both measures had small effect sizes. The school climate measure school-mean science teaching—hands-on activities was positively associated with general interest in learning science, and showed an effect size of somewhat greater
value than did the other two school-level measures. Model performance was sound, with 68% of school-level variance and 3% of student-level variance explained.

**Instrumental motivation for science.** Based on the null model for instrumental motivation for science, the grand average was 0.31 ($p < .05$); the positive value indicates that U.S. students held values of instrumental motivation for science significantly above the OECD standardized mean of 0 (OECD, 2009). Variance components of the null model were 0.82 for students and 0.01 for schools ($p < .05$ at the school-level). The proportion of variance in the null model attributable to students was 98.49% while the proportion of variance attributable to schools was 1.51%. Thus, student-level variance accounted for a very high proportion of the variance in instrumental motivation for science relative to schools.

The student-level variables father’s SES and immigration background, along with the school-level variable school-mean for science teaching—focus on applications or models, significantly influenced instrumental motivation for science (Table 4.7). Father’s SES positively influenced instrumental motivation for science; meanwhile, native students averaged lower instrumental motivation for science than did immigrant students. Note that the effect sizes for both of these student-level variables were very small. School-mean science teaching—focus on applications or models was associated with higher instrumental motivation for science; the effect size was small (0.24). While the proportion of variations explained at the school-level remained reasonably high (60%), the corresponding proportion at the student-level was very low (rounded to 0%).

**Future-oriented science motivation.** Based on the null model for future-oriented science motivation, the grand average was 0.19 ($p < .05$); the positive value
indicates that U.S. students held future-oriented science motivation significantly above the OECD standardized mean of 0 (OECD, 2009). Variance components of the null model were 0.92 for students and 0.00 for schools (the significance was $p < .05$ at the school-level). The proportion of variance in the null model attributable to students was 99.88% while the proportion of variance attributable to schools was 0.12%. Thus, student-level variance accounted for a very high proportion of the variance in future-oriented science motivation relative to schools.

At the student-level, two variables (gender and immigration background) significantly influenced future-oriented science motivation (Table 4.8). At the school-level, seven variables (school size, proportion of girls enrolled, school-mean father’s SES, ability grouping, school activities to promote science learning, parent influence, and school mean for science teaching—investigations) impacted future-oriented science motivation. Females and native students had lower average future-oriented science motivation; however, effect sizes were very small. Three school context variables, namely, school size (negative), proportion of girls enrolled (positive), and school-mean father’s SES (positive), influenced future-oriented science motivation. All three school context effect sizes were small. All four school climate variables (ability grouping, school activities to promote science learning, parent influence, and school mean for science teaching—investigations) were also positively associated with future-oriented science motivation; effect sizes were again small. An extraordinarily high level of 92% of the school-level variance was accounted for by this model, while only 2% of the student-level variance was accounted for by this model.
**General value of science.** Based on the null model for general value of science, the grand average was 0.16 ($p < .05$); the positive value indicates that U.S. students held general values of science significantly above the OECD standardized mean of 0 (OECD, 2009). Variance components of the null model were 1.04 for students and 0.05 for schools (the significance was $p < .05$ at the school-level). The proportion of variance in the null model attributable to students was 95.29% while the proportion of variance attributable to schools was 4.71%. Thus, student-level variance accounted for a very high proportion of the variance in general value of science relative to schools.

The student-level variables gender and father’s SES, along with the school-level variables school-mean for science teaching—focus on applications or models and school-mean for science teaching—interaction, all significantly influenced general value of science (Table 4.9). While female gender resulted in lower average general value of science, as father’s SES increased, so did average general value of science. The researcher noted that the effect sizes for both variables were quite small. Both of the significant school-level variables were from the school climate category, and were specifically related to science teaching. While school-mean for science teaching—focus on applications or models was positively associated with general value of science, school-mean for science teaching—interaction was negatively associated with this aspect of science engagement. Effect size for science teaching with a focus on applications or models approached medium (0.48), while the effect size for science teaching with
interaction was small (0.39). Model performance was sound, at both the school-level (73% of variance explained) and at the student-level (9% of variance explained).

**Personal value of science.** Based on the null model for personal value of science, the grand average was 0.32 ($p < .05$); the positive value indicates that U.S. students held personal values of science significantly above the OECD standardized mean of 0 (OECD, 2009). Variance components of the null model were 0.99 for students and 0.05 for schools (the significance was $p < .05$ at the school-level). The proportion of variance in the null model attributable to students was 95.21% while the proportion of variance attributable to schools was 4.79%. Thus, student-level variance accounted for a very high proportion of the variance in personal value of science relative to schools.

At the student-level, both gender and age significantly influenced personal value of science; meanwhile, at the school-level, both student-teacher ratio and school-mean for science teaching—focus on applications or models did likewise (Table 4.10). Females and older students showed lower personal value for science; effect sizes were very small. The school context variable student-teacher ratio had an inverse relationship with personal value of science; its effect size was small (0.19). On the other hand, the relationship between school-mean for science teaching—focus on applications or models and personal value of science was positive; while the associated effect size was small (0.39), the larger effect size value gave an indication of a more pronounced influence. Model performance was sound at the school-level, accounting for 72% of variance, but accounted for only 1% of the variance at the student-level.

**Science-related activities.** Based on the null model for science-related activities, the grand average was -0.11 ($p < .05$); the negative value indicates that U.S. students had
a level of participation in science-related activities significantly below the OECD standardized mean of 0 (OECD, 2009). Variance components of the null model were 0.95 for students and 0.02 for schools ($p < .05$ at the school-level). The proportion of variance in the null model attributable to students was 98.01% while the proportion of variance attributable to schools was 1.99%. Thus, student-level variance accounted for a very high proportion of the variance in science-related activities relative to schools.

Student-level variables which significantly influenced science-related activities were gender, father’s SES, and language spoken at home; school-level variables which showed such relationships were school size, student-teacher ratio, and school mean for science teaching—interaction (Table 4.11). While females and those who spoke English at home had lower average science-related activities, father’s SES was associated with an increase in this aspect of science engagement. All three significant student-level variables had quite small effect sizes (under 0.10). Both school size (a school context measure) and school mean for science teaching—interaction (a school climate measure) were positively associated with science-related activities; meanwhile, student-teacher ratio (another school context measure) was inversely related to this measure. All three significant school-level variables had effect sizes in the small category. While this model accounted for a relatively high percentage of the student-level variance (8%), the proportion of the school-level variance accounted for by this model (36%) was much lower than that of the multilevel models developed for the eight other aspects of science engagement.
Science Achievement as the Outcome Variable

As preface to this section, the researcher noted that the intercept coefficient in Tables 4.12 through 4.21 had practical meaning: the grand average science achievement score for the U.S. sample. Given that those values are marginally above 500 (the OECD mean science achievement), this serves as a reminder of the average standing of U.S. 15-year-olds in science achievement in comparison with their global counterparts once science engagement is adjusted.

Based on the null model for science achievement, the grand average was 505.55 ($p < .05$); this value indicates that the science achievement levels of U.S. students were slightly though significantly above the OECD standardized mean of 500 (OECD, 2009). Variance components of the null model were 7590.17 for students and 1664.08 for schools ($p < .05$ at the school-level). The proportion of variance in the null model attributable to students was 82.02% while the proportion of variance attributable to schools was 17.98%. Thus, student-level variance accounted for a high proportion of the variance in science achievement relative to schools. However, the percentage of science achievement attributable to schools was considerably higher than the percentage of any of the nine aspects of science engagement attributable to schools.

Multilevel model without any aspects of science engagement. No aspect of science engagement was included in this multilevel model (Table 4.12); this allowed for comparison with each of the nine successive multilevel models below, each of which did include a single aspect of science engagement. At the student-level, father’s SES, mother’s SES, and language spoken at home were all positively related to science achievement, however, only mother’s SES had an effect size over 0.20. At the school-
level, two school context variables were significantly related to science achievement: school size (negative relationship) and school-mean father’s SES (positive relationship). Three school climate variables emerged with significant influences on science achievement: school responsibility for curriculum and assessment (positive), school-mean science teaching—hands-on activities (also positive), and school-mean science teaching—investigations (negative). Effect sizes for all five significant school-level variables were small. Proportion of variance explained by the model was 78% at the school-level and 8% at the student-level.

**Multilevel model including science self-efficacy.** Science self-efficacy was positively related to science achievement even after control over significant student characteristics (individual differences) and school characteristics (school effects) (Table 4.13), with a large effect size of 0.98 (see chapter three). Other student-level variables which were significantly (and positively) associated with science achievement were father’s SES, mother’s SES, and English language spoken at home. While effect sizes for father’s SES and language spoken at home were very small, the effect size for mother’s SES was small (0.34). Two school context variables influenced science achievement, albeit in different directions. As school size increased, average science achievement declined; in contrast, as school-mean father’s SES went up, average science achievement increased. In addition, two school climate variables influenced science achievement; as was the case for school context, the directionality of those influences was inverse. While school responsibility for curriculum and assessment evidenced a positive association with science achievement, school-mean for science teaching—investigations was negatively related to science achievement. Effect sizes of all four
significant school-level variables fell in the small range (0.24 to 0.32). Proportion of variance accounted for by this multilevel model was strong at the school-level (80%) and remarkably high at the student-level (23%). Since the multilevel model which included no aspects of science engagement explained only 8% of the student-level variance (Table 4.12), this result was particularly impressive, indicating the highly important contribution of science self-efficacy to the explanation of variance in science achievement (over and above significant student background and school characteristics).

**Multilevel model including science self-concept.** Science self-concept was positively and significantly related to science achievement even after control over significant student and school characteristics, with a large effect size (1.07; Table 4.14). Three student-level variables (father’s SES, mother’s SES, and language spoken at home) were also positively related to science achievement; effect sizes were small for all three, although mother’s SES approached the medium category (0.40). Two school context variables (school size and school-mean father’s SES) were significant; while larger schools, on average had lower science achievement, higher school-mean father’s SES resulted in higher science achievement. One school climate measure (school-mean science teaching—investigations) was negatively associated with science achievement. All three significant school variables had effect sizes in the small range (0.25 to 0.38). Proportion of variance explained at the school-level was 75% (sound); the level explained at the student-level, like that for science self-efficacy above, was remarkably high (20%). Since the multilevel model which included no aspects of science engagement explained
only 8% of the student-level variance (Table 4.12), this result was particularly impressive.

**Multilevel model including enjoyment of science.** Enjoyment of science was significantly (and positively) related to science achievement even after control over significant student and school characteristics, with an effect size approaching medium (0.49; Table 4.15). Three student-level variables were also positively tied to science achievement: father’s SES, mother’s SES, and language spoken at home. Effect sizes were diverse for these variables; father’s SES was very small (0.10), language spoken at home was approaching small (0.19), and mother’s SES was small (0.38) but somewhat higher than the other two. Two school context variables were associated with science achievement: school size (larger schools averaged lower scores) and school-mean father’s SES (higher school-mean was related to higher scores). Two school climate variables were also associated with science achievement: school mean for science teaching—hands-on activities and school mean for science teaching—investigations. These two instructional approaches had inverse relationships with science achievement; that is, hands-on activities were positively associated with science achievement while investigations were negatively associated with science achievement. While three of the significant school variables had small effect sizes (0.22 to 0.29), the effect size for school mean for science teaching—investigations was 0.44, approaching a medium designation. Proportion of variance accounted for by the model was again sound at the school-level (81%) and quite high (18%) at the student-level. Since the multilevel model which
included no aspects of science engagement explained only 8% of the student-level variance (Table 4.12), this result was particularly impressive.

**Multilevel model including general interest in learning science.** General interest in learning science was significantly related to science achievement even after control over significant student and school characteristics, with a medium effect size (0.56; Table 4.16). The student-level variables father’s SES, mother’s SES, and immigration background were also positively related to science achievement; however, their effect sizes differed substantially. The effect size for father’s SES was very small (0.14), while that for mother’s SES was small (0.34), and effect size for immigration background was medium (0.60). At the school-level, two variables significantly influenced science achievement in each of the two classes of variables (school context and school climate); notably, each pair was directionally different. In the case of school context, increasing school size was associated with reduced science achievement, while increased school-mean father’s SES resulted in enhanced science achievement. In the case of school climate, higher levels of school-mean science teaching—hands on activities was positively tied to science achievement; meanwhile, greater school-mean science teaching—investigations resulted in reduced science achievement. Effect sizes were small for all four school-level variables; however, the effect size for school-mean science teaching—investigations was numerically greater (0.38) than the other three (0.21 to 0.27). This multilevel model explained 78% of the school-level variance and 12% of the student-level variance. Since the multilevel model which included no aspects of science engagement explained only 8% of the student-level variance (Table 4.12), this result indicated somewhat better model performance at the student-level.
Multilevel model including instrumental motivation for science. Instrumental motivation for science significantly impacted science achievement, even after control over significant student and school characteristics, with a medium effect size (0.58; Table 4.17). Father’s SES, mother’s SES, and language spoken at home, all three student-level variables, also enhanced science achievement, with very small (0.14), small (0.38), and small (0.19) effect sizes, respectively. Among school-level variables, two school context measures affected science achievement: school size and school-mean father’s SES. As school size increased, science achievement declined; the inverse was the case for school-mean father’s SES. One school context variable was significant: school-mean science teaching—investigations. This science teaching approach had a negative influence on science achievement. All three school-level variables had effect sizes in the small range. Proportion of variance explained was again good, with 69% explained at the school-level and 13% at the student-level. Since the multilevel model which included no aspects of science engagement explained only 8% of the student-level variance (Table 4.12), this result indicated a somewhat important contribution of instrumental motivation for science to the explanation of variance in science achievement.

Multilevel model including future-oriented science motivation. While future-oriented science motivation was significantly related to science achievement even after control over significant student and school characteristics, its effect size was very small (0.16; Table 4.18). Among student-level variables, father’s SES, mother’s SES, and language spoken at home all enhanced science achievement, albeit with a range of effect sizes (0.23, 0.42, and 0.16, respectively). At the school-level, three variables (school size and school-mean father’s SES [both school context measures], and school-mean science
teaching—investigations [a school climate measure] affected science achievement. While increasing school size negatively impacted science achievement, greater school-mean father’s SES enhanced science achievement. As school-mean science teaching—investigations increased, science achievement declined. Effect sizes for all three school-level variables were small. Proportion of variance explained by this multilevel model was 67% at the school-level and 15% at the student-level. Since the multilevel model which included no aspects of science engagement explained only 8% of the student-level variance (Table 4.12), this result was impressive.

**Multilevel model including general value of science.** General value of science had a significant positive influence on science achievement, even after control over significant student and school characteristics, with a large effect size (1.38; Table 4.19). The student-level variables father’s SES and language spoken at home were also positively related to science achievement, but with differences in their effect sizes (0.39 for father’s SES, but 0.18 for language spoken at home). Four school-level variables were significantly tied to science achievement: two each from the school context and school climate categories. Among school context variables, school size showed a negative relationship with science achievement, while school-mean father’s SES had a positive relationship with science achievement. Among school climate variables, two school-mean science teaching measures proved significant, although with opposite influences: hands-on activities enhanced science achievement, while investigations were related to lower science achievement. All four school-level variables had effect sizes in the small range. Proportion of variance explained was 78% at the school-level and 10% at the student-level. Since the multilevel model which included no aspects of science
engagement explained only 8% of the student-level variance (Table 4.12), this result indicated a somewhat important contribution of general value of science to the explanation of variance in science achievement.

**Multilevel model including personal value of science.** Personal value of science enhanced science achievement even after control over significant student and school characteristics, with a large effect size (1.51; Table 4.20). Father’s SES, mother’s SES, and language spoken at home (all three student-level variables) also positively influenced science achievement; all three had small effect sizes. At the school-level, the school context variables school size (negatively) and school-mean father’s SES (positively) both influenced science achievement, albeit in opposite directions. The school climate variables school-mean science teaching—hands-on activities (positively) and school-mean science teaching—investigations (negatively) also impacted science achievement, but again in opposite directions. Effect sizes for all four school-level variables were small (or essentially so), but ranged from 0.19 to 0.41. Proportion of variance explained by this multilevel model was 78% at the school-level and 15% at the student-level. Since the multilevel model which included no aspects of science engagement explained only 8% of the student-level variance (Table 4.12, this result was impressive.

**Multilevel model including science-related activities.** Science-related activities positively influenced science achievement even after control over significant student and school characteristics, with a medium effect size (0.61; Table 4.21). Among student-level variables, father’s SES, mother’s SES, and language spoken at home also enhanced science achievement. While the effect size for father’s SES was very small (0.14), effect
sizes for both mother’s SES and language spoken at home were small. Among the suite of studied school context variables, both school size (negative impact) and school-mean father’s SES (positive influence) were significantly tied to science achievement. Among the group of school climate variables, two school-mean for science teaching measures proved to be significant: hands-on activities and investigations. While the science teaching measure hands-on activities positively influenced science achievement, investigations had a negative impact. All four significant school-level variables had small effect sizes. The proportion of variance explained by the model was 77% at the school-level and 12% at the student-level. Since the multilevel model which included no aspects of science engagement explained only 8% of the student-level variance (Table 4.12), this result indicated a somewhat important contribution of science-relative activities to the explanation of variance in science achievement.

**Effect sizes for nine aspects of science engagement with science achievement as the outcome variable.** A series of multilevel models was tested, each of which included a single aspect of science engagement as a potential model variable at the student level. As noted in the presentation of Tables 4.13 through 4.21 above, each individual aspect of science engagement was indeed included in the tested multilevel model at the tested level of significance ($p < .05$) even after control over significant student and school characteristics. However, effect sizes for these aspects of science engagement varied widely, and to some extent, systematically (Table 4.22). Large effect sizes were noted for the paired-but-different aspects of science engagement of general value of science and personal value of size; a similar pattern was noted for science self-efficacy and science self-concept. In a similar way, enjoyment of science and general
interest in learning science, another pairing of aspects of science engagement, had quite similar effect sizes, both near 0.50. This pattern was not followed for instrumental motivation for science (medium effect size) and future-oriented science motivation (very small effect size). Science-related activities, an unpaired aspect of science engagement, showed a medium effect size.
Table 4.1

Descriptive Statistics of Outcome, Student-Level, and School-Level Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outcome variable</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science self-efficacy</td>
<td>0.22</td>
<td>1.16</td>
</tr>
<tr>
<td>Science self-concept</td>
<td>0.21</td>
<td>1.04</td>
</tr>
<tr>
<td>Enjoyment of science</td>
<td>-0.05</td>
<td>1.01</td>
</tr>
<tr>
<td>General interest in learning science</td>
<td>0.00</td>
<td>1.08</td>
</tr>
<tr>
<td>Instrumental motivation for science</td>
<td>0.29</td>
<td>0.93</td>
</tr>
<tr>
<td>Future-oriented science motivation</td>
<td>0.21</td>
<td>0.96</td>
</tr>
<tr>
<td>General value of science</td>
<td>0.16</td>
<td>1.09</td>
</tr>
<tr>
<td>Personal value of science</td>
<td>0.29</td>
<td>1.05</td>
</tr>
<tr>
<td>Science-related activities</td>
<td>-0.10</td>
<td>1.00</td>
</tr>
<tr>
<td>Plausible value in science--one</td>
<td>492.12</td>
<td>103.81</td>
</tr>
<tr>
<td>Plausible value in science--two</td>
<td>492.35</td>
<td>104.17</td>
</tr>
<tr>
<td>Plausible value in science--three</td>
<td>492.38</td>
<td>103.82</td>
</tr>
<tr>
<td>Plausible value in science--four</td>
<td>492.36</td>
<td>104.19</td>
</tr>
<tr>
<td>Plausible value in science--five</td>
<td>492.18</td>
<td>104.21</td>
</tr>
<tr>
<td><strong>Student-level variable</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender (1 = female, 0 = male)</td>
<td>0.49</td>
<td>0.50</td>
</tr>
<tr>
<td>Age</td>
<td>15.82</td>
<td>0.30</td>
</tr>
<tr>
<td>Father's socioeconomic status (SES)</td>
<td>46.41</td>
<td>18.28</td>
</tr>
<tr>
<td>Mother's SES</td>
<td>47.93</td>
<td>15.72</td>
</tr>
<tr>
<td>Immigration background (1 = native; 0 = immigrant)</td>
<td>0.85</td>
<td>0.36</td>
</tr>
<tr>
<td>Language spoken at home (1 = English; 0 = other)</td>
<td>0.89</td>
<td>0.31</td>
</tr>
</tbody>
</table>
Table 4.1 (continued)

School-level variable, school context

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean 1</th>
<th>Mean 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>School size</td>
<td>1346.07</td>
<td>938.80</td>
</tr>
<tr>
<td>Proportion of girls enrolled</td>
<td>0.49</td>
<td>0.09</td>
</tr>
<tr>
<td>Proportion of teachers certified</td>
<td>0.94</td>
<td>0.16</td>
</tr>
<tr>
<td>School ownership (1 = public; 0 = private or mixed)</td>
<td>0.89</td>
<td>0.31</td>
</tr>
<tr>
<td>Student-teacher ratio</td>
<td>15.47</td>
<td>4.71</td>
</tr>
<tr>
<td>Teacher shortage</td>
<td>-0.03</td>
<td>0.92</td>
</tr>
<tr>
<td>Quality of educational resources</td>
<td>0.30</td>
<td>0.97</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>45.67</td>
<td>7.72</td>
</tr>
<tr>
<td>School-mean mother's SES</td>
<td>47.65</td>
<td>5.67</td>
</tr>
</tbody>
</table>

School-level variable, school climate

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean 1</th>
<th>Mean 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>School responsibility for resource allocation</td>
<td>0.70</td>
<td>0.65</td>
</tr>
<tr>
<td>School responsibility for curriculum and assessment</td>
<td>0.51</td>
<td>0.80</td>
</tr>
<tr>
<td>Ability grouping (1 = some grouping; 0 = no grouping)</td>
<td>0.86</td>
<td>0.35</td>
</tr>
<tr>
<td>School activities to promote science learning</td>
<td>0.48</td>
<td>0.94</td>
</tr>
<tr>
<td>Parent influence</td>
<td>0.67</td>
<td>1.00</td>
</tr>
<tr>
<td>Teacher influence</td>
<td>2.23</td>
<td>1.19</td>
</tr>
<tr>
<td>School-mean science teaching--focus on applications or models</td>
<td>0.41</td>
<td>0.24</td>
</tr>
<tr>
<td>School-mean science teaching--hands-on activities</td>
<td>0.67</td>
<td>0.24</td>
</tr>
<tr>
<td>School-mean science teaching--interaction</td>
<td>0.30</td>
<td>0.23</td>
</tr>
<tr>
<td>School-mean science teaching--investigations</td>
<td>0.49</td>
<td>0.32</td>
</tr>
</tbody>
</table>

*Note.* Separate descriptive information for each of the five plausible values does not mean that they are used in an isolated manner for data analysis. The Hierarchical Linear Modeling (HLM) software has the capability to combine plausible values properly for multilevel data analysis.
Table 4.2

*Bivariate Correlations among Nine Aspects of Science Engagement*

<table>
<thead>
<tr>
<th>Correlate</th>
<th>Variable</th>
<th>SSE</th>
<th>SSC</th>
<th>JOY</th>
<th>INT</th>
<th>INS</th>
<th>FUT</th>
<th>GEN</th>
<th>PER</th>
<th>ACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSE</td>
<td>1.00</td>
<td></td>
<td>0.52*</td>
<td>0.43*</td>
<td>0.41*</td>
<td>0.31*</td>
<td>0.32*</td>
<td>0.42*</td>
<td>0.46*</td>
<td>0.37*</td>
</tr>
<tr>
<td>SSC</td>
<td>1.00</td>
<td>0.59*</td>
<td>0.46*</td>
<td>0.48*</td>
<td>0.51*</td>
<td>0.37*</td>
<td>0.50*</td>
<td>0.43*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JOY</td>
<td>1.00</td>
<td>0.63*</td>
<td>0.54*</td>
<td>0.61*</td>
<td>0.43*</td>
<td>0.60*</td>
<td>0.58*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INT</td>
<td>1.00</td>
<td>0.49*</td>
<td>0.53*</td>
<td>0.39*</td>
<td>0.54*</td>
<td>0.51*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INS</td>
<td>1.00</td>
<td>0.63*</td>
<td>0.39*</td>
<td>0.59*</td>
<td>0.40*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FUT</td>
<td>1.00</td>
<td>0.30*</td>
<td>0.56*</td>
<td>0.49*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GEN</td>
<td>1.00</td>
<td>0.70*</td>
<td>0.34*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PER</td>
<td>1.00</td>
<td>0.48*</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>ACT</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Aspects of science engagement are denoted above as follows: SSE, science self-efficacy; SSC, science self-concept; JOY, enjoyment of science; INT, general interest in learning science; INS, instrumental motivation for science; FUT, future-oriented science motivation; GEN, general value of science; PER, personal value of science; and ACT, science-related activities.
Table 4.3

Statistical Results for Multilevel Model of Student-Level and School-Level Effects on Science Self-Efficacy

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>(d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (self-efficacy)</td>
<td>0.27*</td>
<td>0.02</td>
<td>10.79</td>
<td></td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.29*</td>
<td>0.05</td>
<td>-5.94</td>
<td>0.10</td>
</tr>
<tr>
<td>Age</td>
<td>-0.15*</td>
<td>0.07</td>
<td>-2.07</td>
<td>0.04</td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.01*</td>
<td>0.00</td>
<td>6.41</td>
<td>0.11</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>0.38*</td>
<td>0.07</td>
<td>5.30</td>
<td>0.09</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hands-on activities</td>
<td>0.39*</td>
<td>0.13</td>
<td>3.01</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Random effects

<table>
<thead>
<tr>
<th>Variance</th>
<th>df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>0.00</td>
<td>130</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>1.12</td>
<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.86</td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.07</td>
</tr>
</tbody>
</table>

Note. Gender was coded as 1 = female, 0 = male; language refers to language spoken at home, coded as 1 = English, 0 = other; and hands-on activities refer to school-mean for science teaching—hands-on activities.

\*\(p < .05\)
Table 4.4

Statistical Results for Multilevel Model of Student-Level and School-Level Effects on Science Self-Concept

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (self-concept)</td>
<td>0.21*</td>
<td>0.04</td>
<td>5.12</td>
<td></td>
</tr>
</tbody>
</table>

Student-level variables

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>-0.40*</td>
<td>0.05</td>
<td>-7.26</td>
<td>0.12</td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.01*</td>
<td>0.00</td>
<td>3.75</td>
<td>0.06</td>
</tr>
</tbody>
</table>

School-level variables

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of girls enrolled</td>
<td>0.73*</td>
<td>0.20</td>
<td>3.69</td>
<td>0.32</td>
</tr>
<tr>
<td>Focus on applications</td>
<td>0.58*</td>
<td>0.16</td>
<td>3.72</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Random effects

<table>
<thead>
<tr>
<th></th>
<th>Variance</th>
<th>df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>0.01*</td>
<td>129</td>
<td>198.98</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>1.12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.67</td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.07</td>
</tr>
</tbody>
</table>

Note. Gender was coded as 1 = female, 0 = male; and focus on applications refers to school-mean for science teaching—focus on applications or models.

*p < .05
Table 4.5

*Statistical Results for Multilevel Model of Student-Level and School-Level Effects on Enjoyment of Science*

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (enjoyment)</td>
<td>0.00</td>
<td>0.04</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td><strong>Student-level variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.12*</td>
<td>0.06</td>
<td>-2.23</td>
<td>0.04</td>
</tr>
<tr>
<td>Father’s SES</td>
<td>0.01*</td>
<td>0.00</td>
<td>3.52</td>
<td>0.06</td>
</tr>
<tr>
<td><strong>School-level variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus on applications</td>
<td>0.43*</td>
<td>0.12</td>
<td>3.72</td>
<td>0.32</td>
</tr>
</tbody>
</table>

| Random effects                 |             |     |         |    |
| **Variance**                   |             |     |         |    |
| Between-school variability     | 0.01*       | 130 | 198.93  |    |
| Within-school variability      | 0.93        |     |         |    |

| Proportion of variance explained|             |     |         |    |
| School level (between schools)  | .61         |     |         |    |
| Student level (between students)| .03         |     |         |    |

*Note.* Gender was coded as 1 = female, 0 = male; and focus on applications refers to school-mean for science teaching—focus on applications or models.

*p < .05*
### Table 4.6

**Statistical Results for Multilevel Model of Student-Level and School-Level Effects on General Interest in Learning Science**

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>(d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (interest)</td>
<td>0.01</td>
<td>0.02</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td><strong>Student-level variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-0.20*</td>
<td>0.08</td>
<td>-2.36</td>
<td>0.04</td>
</tr>
<tr>
<td>Immigration background</td>
<td>-0.28*</td>
<td>0.06</td>
<td>-4.71</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>School-level variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher shortage</td>
<td>-0.06*</td>
<td>0.03</td>
<td>-2.39</td>
<td>0.21</td>
</tr>
<tr>
<td>Science promotion</td>
<td>-0.06*</td>
<td>0.02</td>
<td>-3.25</td>
<td>0.29</td>
</tr>
<tr>
<td>Hands-on activities</td>
<td>0.39*</td>
<td>0.09</td>
<td>4.32</td>
<td>0.38</td>
</tr>
</tbody>
</table>

**Random effects**

<table>
<thead>
<tr>
<th></th>
<th>Variance</th>
<th>Df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>0.01*</td>
<td>128</td>
<td>159.61</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>1.07</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Proportion of variance explained**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.68</td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.03</td>
</tr>
</tbody>
</table>

*Note.* Immigration background was coded as 1 = native, 0 = immigrant; science promotion refers to school activities to promote science learning; and hands-on activities refers to school mean for science teaching—hands-on activities.

\(*p < .05\)
Table 4.7

Statistical Results for Multilevel Model of Student-Level and School-Level Effects on Instrumental Motivation in Science

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (instrumental)</td>
<td>0.33*</td>
<td>0.03</td>
<td>12.10</td>
<td></td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.00*</td>
<td>0.00</td>
<td>2.07</td>
<td>0.04</td>
</tr>
<tr>
<td>Immigration background</td>
<td>-0.15*</td>
<td>0.07</td>
<td>-2.26</td>
<td>0.04</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus on applications</td>
<td>0.33*</td>
<td>0.12</td>
<td>2.74</td>
<td>0.24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Random effects</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>0.00</td>
<td>130</td>
<td>154.99</td>
<td></td>
</tr>
<tr>
<td>Within-school variability</td>
<td>0.83</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Immigration background was coded as 1 = native, 0 = immigrant; and focus on applications refers to school mean for science teaching—focus on applications or models.

*p < .05
Table 4.8

**Statistical Results for Multilevel Model of Student-Level and School-Level Effects on Future-oriented Motivation in Science**

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (future)</td>
<td>0.21*</td>
<td>0.02</td>
<td>14.18</td>
<td></td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.18*</td>
<td>0.06</td>
<td>-3.01</td>
<td>0.05</td>
</tr>
<tr>
<td>Immigration background</td>
<td>-0.19*</td>
<td>0.04</td>
<td>-4.64</td>
<td>0.07</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>-0.00*</td>
<td>0.00</td>
<td>-2.53</td>
<td>0.23</td>
</tr>
<tr>
<td>Proportion of girls enrolled</td>
<td>0.37*</td>
<td>0.16</td>
<td>2.32</td>
<td>0.21</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>0.01*</td>
<td>0.00</td>
<td>3.29</td>
<td>0.30</td>
</tr>
<tr>
<td>Ability grouping</td>
<td>0.19*</td>
<td>0.05</td>
<td>4.00</td>
<td>0.36</td>
</tr>
<tr>
<td>Science promotion</td>
<td>0.04*</td>
<td>0.01</td>
<td>2.69</td>
<td>0.24</td>
</tr>
<tr>
<td>Parent influence</td>
<td>0.03*</td>
<td>0.01</td>
<td>2.05</td>
<td>0.18</td>
</tr>
<tr>
<td>Investigations</td>
<td>0.19*</td>
<td>0.06</td>
<td>2.94</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Random effects

<table>
<thead>
<tr>
<th></th>
<th>Variance</th>
<th>Df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>0.00</td>
<td>124</td>
<td>107.40</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>0.90</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.92</td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.02</td>
</tr>
</tbody>
</table>

*Note.* Gender was coded as female = 1, male = 0; immigration background was coded as 1 = native, 0 = immigrant; ability grouping was coded as 1 = some grouping, 0 = no grouping; science promotion refers to school activities to promote science learning; and investigations refers to school mean for science teaching—investigations.

*p < .05
Table 4.9

Statistical Results for Multilevel Model of Student-Level and School-Level Effects on General Value of Science

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (general value)</td>
<td>0.21*</td>
<td>0.03</td>
<td>7.90</td>
<td></td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.20*</td>
<td>0.06</td>
<td>-3.51</td>
<td>0.06</td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.01*</td>
<td>0.00</td>
<td>6.89</td>
<td>0.12</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus on applications</td>
<td>0.91*</td>
<td>0.17</td>
<td>5.50</td>
<td>0.48</td>
</tr>
<tr>
<td>Interaction</td>
<td>-0.67*</td>
<td>0.15</td>
<td>-4.38</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Random effects

<table>
<thead>
<tr>
<th></th>
<th>Variance</th>
<th>df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability( intercept)</td>
<td>0.01*</td>
<td>129</td>
<td>191.04</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>0.90</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.73</td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.09</td>
</tr>
</tbody>
</table>

Note. Gender was coded as 1 = female, 0 = male; focus on applications refers to school mean for science teaching—focus on applications or models, and interaction refers to school mean for science teaching—interaction.

*p < .05
Table 4.10

*Statistical Results for Multilevel Model of Student-Level and School-Level Effects on Personal Value of Science*

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (personal value)</td>
<td>0.29*</td>
<td>0.03</td>
<td>11.01</td>
<td></td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.15*</td>
<td>0.05</td>
<td>-3.02</td>
<td>0.09</td>
</tr>
<tr>
<td>Age</td>
<td>-0.16*</td>
<td>0.08</td>
<td>-2.07</td>
<td>0.03</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student-teacher ratio</td>
<td>-0.01*</td>
<td>0.01</td>
<td>-2.70</td>
<td>0.19</td>
</tr>
<tr>
<td>Focus on applications</td>
<td>0.64*</td>
<td>0.15</td>
<td>4.47</td>
<td>0.39</td>
</tr>
</tbody>
</table>

| Random effects                           |             |     |         |      |
| Variance                                 |             |     |         |      |
| Between-school variability (intercept)   | 0.01*       | 129 | 214.45  |      |
| Within-school variability                | 0.98        |     |         |      |

Proportion of variance explained

| School level (between schools)            | .72         |     |         |      |
| Student level (between students)         | .01         |     |         |      |

*Note.* Gender was coded as 1 = female, 0 = male; and focus on applications refers to school mean for science teaching—focus on applications or models.

*p < .05
Table 4.11

Statistical Results for Multilevel Model of Student-Level and School-Level Effects on Science-related Activities

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intercept (activities)</strong></td>
<td>-0.09*</td>
<td>0.02</td>
<td>-4.21</td>
<td></td>
</tr>
<tr>
<td><strong>Student-level variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.27*</td>
<td>0.05</td>
<td>-4.94</td>
<td>0.09</td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.01*</td>
<td>0.00</td>
<td>4.02</td>
<td>0.07</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>-0.35*</td>
<td>0.08</td>
<td>4.59</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>School-level variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>0.00*</td>
<td>0.00</td>
<td>3.05</td>
<td>0.27</td>
</tr>
<tr>
<td>Student-teacher ratio</td>
<td>-0.02*</td>
<td>0.01</td>
<td>-2.41</td>
<td>0.21</td>
</tr>
<tr>
<td>Interaction</td>
<td>0.39*</td>
<td>0.16</td>
<td>2.48</td>
<td>0.22</td>
</tr>
</tbody>
</table>

**Random effects**

| Variance (intercept)            | 0.01*       | 128 | 186.82  |    |
| Within-school variability       | 0.87        |     |         |    |

Proportion of variance explained

| School level (between schools)  | .36         |     |         |    |
| Student level (between students)| .08         |     |         |    |

*Note.* Gender was coded as 1 = female, 0 = male; language spoken at home was coded as 1 = English, 0 = other; and interaction refers to school mean for science teaching—interaction.

*p < .05
Table 4.12

*Statistical Results for Multilevel Model of Student-Level and School-Level Effects on Science Achievement, No Aspects of Science Engagement Included*

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (achievement)</td>
<td>505.82*</td>
<td>3.03</td>
<td>166.83</td>
<td></td>
</tr>
<tr>
<td><strong>Student-level variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.66*</td>
<td>0.18</td>
<td>3.74</td>
<td>0.19</td>
</tr>
<tr>
<td>Mother's SES</td>
<td>0.54*</td>
<td>0.25</td>
<td>2.12</td>
<td>0.27</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>30.49*</td>
<td>9.31</td>
<td>3.27</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>School-level variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>-0.01*</td>
<td>0.00</td>
<td>-2.83</td>
<td>0.25</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>1.57*</td>
<td>0.66</td>
<td>2.38</td>
<td>0.21</td>
</tr>
<tr>
<td>Curriculum and assessment</td>
<td>9.21*</td>
<td>4.54</td>
<td>2.03</td>
<td>0.21</td>
</tr>
<tr>
<td>Hands-on activities</td>
<td>39.74*</td>
<td>15.03</td>
<td>2.64</td>
<td>0.24</td>
</tr>
<tr>
<td>Investigations</td>
<td>-53.46*</td>
<td>12.98</td>
<td>-4.12</td>
<td>0.37</td>
</tr>
</tbody>
</table>

**Random effects**

<table>
<thead>
<tr>
<th></th>
<th>Variance</th>
<th>df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>363.07*</td>
<td>126</td>
<td>314.82</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>6995.46</td>
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</tr>
</tbody>
</table>

Proportion of variance explained

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.78</td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.08</td>
</tr>
</tbody>
</table>

*Note.* Language spoken at home was coded as 1 = English, 0 = other; curriculum and assessment refers to school responsibility for curriculum and assessment; hands-on activities refers to school mean for science teaching—hands-on activities; and investigations refers to school mean for science teaching—investigations.

*p < .05*
Table 4.13

*Statistical Results for Multilevel Model of Science Self-efficacy, Student-Level and School-Level Effects on Science Achievement*

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (achievement)</td>
<td>503.85*</td>
<td>2.87</td>
<td>175.74</td>
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</tr>
<tr>
<td>Science self-efficacy</td>
<td>33.43*</td>
<td>2.33</td>
<td>14.34</td>
<td>0.98</td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.39*</td>
<td>0.19</td>
<td>2.10</td>
<td>0.09</td>
</tr>
<tr>
<td>Mother's SES</td>
<td>0.50*</td>
<td>0.23</td>
<td>2.20</td>
<td>0.34</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>18.65*</td>
<td>7.61</td>
<td>2.45</td>
<td>0.16</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>-0.01*</td>
<td>0.00</td>
<td>-2.90</td>
<td>0.26</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>2.01*</td>
<td>0.55</td>
<td>3.66</td>
<td>0.32</td>
</tr>
<tr>
<td>Curriculum and assessment</td>
<td>8.84*</td>
<td>4.41</td>
<td>2.01</td>
<td>0.24</td>
</tr>
<tr>
<td>Investigations</td>
<td>-42.26*</td>
<td>12.95</td>
<td>-3.26</td>
<td>0.29</td>
</tr>
</tbody>
</table>

| Random effects                                 |             |       |         |      |
| Variance (intercept)                           | 336.41*     | 127   | 332.98  |      |
| Within-school variability                      | 5838.66     |       |         |      |

| Proportion of variance explained               |             |       |         |      |
| School level (between schools)                 | .80         |       |         |      |
| Student level (between students)               | .23         |       |         |      |

*Note. Language spoken at home was coded as 1 = English, 0 = other; curriculum and assessment refers to school responsibility for curriculum and assessment, and investigations refers to school mean for science teaching—investigations.*

*p < .05
Table 4.14

Statistical Results for Multilevel Model of Science Self-concept, Student-Level and School-Level Effects on Science Achievement

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
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<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (achievement)</td>
<td>505.81*</td>
<td>3.29</td>
<td>153.51</td>
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<tr>
<td>Science self-concept</td>
<td>29.59*</td>
<td>2.60</td>
<td>11.37</td>
<td>1.07</td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.56*</td>
<td>0.18</td>
<td>3.07</td>
<td>0.19</td>
</tr>
<tr>
<td>Mother's SES</td>
<td>0.56*</td>
<td>0.21</td>
<td>2.62</td>
<td>0.40</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>27.11*</td>
<td>7.85</td>
<td>3.46</td>
<td>0.20</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>-0.01*</td>
<td>0.00</td>
<td>-2.81</td>
<td>0.25</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>2.05*</td>
<td>0.55</td>
<td>3.70</td>
<td>0.33</td>
</tr>
<tr>
<td>Investigations</td>
<td>-53.93*</td>
<td>12.38</td>
<td>-4.36</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Random effects

<table>
<thead>
<tr>
<th>Variance</th>
<th>df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>414.72*</td>
<td>128</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>6038.94</td>
<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.75</td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.20</td>
</tr>
</tbody>
</table>

Note. Language spoken at home was coded as 1 = English, 0 = other; and investigations refers to school mean for science teaching—investigations.

*p < .05
Table 4.15

Statistical Results for Multilevel Model of Enjoyment of Science, Student-Level and School-Level Effects on Science Achievement

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (achievement)</td>
<td>505.10*</td>
<td>3.05</td>
<td>165.35</td>
<td></td>
</tr>
<tr>
<td>Enjoyment of science</td>
<td>29.07*</td>
<td>2.67</td>
<td>10.87</td>
<td>0.49</td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.52*</td>
<td>0.19</td>
<td>2.69</td>
<td>0.10</td>
</tr>
<tr>
<td>Mother's SES</td>
<td>0.50*</td>
<td>0.22</td>
<td>2.24</td>
<td>0.38</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>31.12*</td>
<td>8.83</td>
<td>3.52</td>
<td>0.19</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>-0.01*</td>
<td>0.00</td>
<td>-3.28</td>
<td>0.29</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>1.63*</td>
<td>0.57</td>
<td>2.88</td>
<td>0.26</td>
</tr>
<tr>
<td>Hands-on activities</td>
<td>34.32*</td>
<td>13.89</td>
<td>2.47</td>
<td>0.22</td>
</tr>
<tr>
<td>Investigations</td>
<td>-56.54*</td>
<td>11.28</td>
<td>-5.01</td>
<td>0.44</td>
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</table>

Random effects

<table>
<thead>
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<th>Variance</th>
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<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>332.75*</td>
<td>127</td>
<td>311.13</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>6255.99</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

<table>
<thead>
<tr>
<th></th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.81</td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.18</td>
</tr>
</tbody>
</table>

Note. Language spoken at home was coded as 1 = English, 0 = other; hands-on activities refers to school mean for science teaching—hands-on activities, and investigations refers to school mean for science teaching—investigations.

*p < .05
Table 4.16

Statistical Results for Multilevel Model of General Interest in Learning Science Self-efficacy, Student-Level and School-Level Effects on Science Achievement

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (achievement)</td>
<td>505.92*</td>
<td>3.13</td>
<td>161.79</td>
<td></td>
</tr>
<tr>
<td>General interest in learning science</td>
<td>18.56*</td>
<td>2.45</td>
<td>7.57</td>
<td>0.56</td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.60*</td>
<td>0.20</td>
<td>3.03</td>
<td>0.14</td>
</tr>
<tr>
<td>Mother's SES</td>
<td>0.57*</td>
<td>0.24</td>
<td>2.39</td>
<td>0.34</td>
</tr>
<tr>
<td>Immigration background</td>
<td>31.81*</td>
<td>7.79</td>
<td>4.08</td>
<td>0.60</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>-0.01*</td>
<td>0.00</td>
<td>-2.99</td>
<td>0.27</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>1.88*</td>
<td>0.64</td>
<td>2.92</td>
<td>0.26</td>
</tr>
<tr>
<td>Hands-on activities</td>
<td>36.86*</td>
<td>15.85</td>
<td>2.32</td>
<td>0.21</td>
</tr>
<tr>
<td>Investigations</td>
<td>-53.65*</td>
<td>12.50</td>
<td>-4.29</td>
<td>0.38</td>
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</tbody>
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Random effects

<table>
<thead>
<tr>
<th></th>
<th>Variance</th>
<th>df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>359.05*</td>
<td>127</td>
<td>319.52</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>6642.49</td>
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<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.78</td>
<td></td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.12</td>
<td></td>
</tr>
</tbody>
</table>

Note. Immigration background was coded as 1 = native, 0 = immigrant; hands-on activities refers to school mean for science teaching—hands-on activities, and investigations refers to school mean for science teaching—investigations.

*p < .05
Table 4.17

Statistical Results for Multilevel Model of Instrumental Motivation for Science, Student-Level and School-Level Effects on Science Achievement

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (achievement)</td>
<td>505.64*</td>
<td>3.48</td>
<td>145.37</td>
<td></td>
</tr>
<tr>
<td>Instrumental motivation for science</td>
<td>19.35*</td>
<td>2.56</td>
<td>7.56</td>
<td>0.58</td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.63*</td>
<td>0.20</td>
<td>3.09</td>
<td>0.14</td>
</tr>
<tr>
<td>Mother's SES</td>
<td>0.59*</td>
<td>0.22</td>
<td>2.70</td>
<td>0.38</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>31.13*</td>
<td>8.28</td>
<td>3.76</td>
<td>0.19</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
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<td>0.01</td>
<td>-2.44</td>
<td>0.22</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>2.35*</td>
<td>0.61</td>
<td>3.84</td>
<td>0.34</td>
</tr>
<tr>
<td>Investigations</td>
<td>-43.12*</td>
<td>16.55</td>
<td>-2.61</td>
<td>0.23</td>
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</table>

Random effects

<table>
<thead>
<tr>
<th></th>
<th>Variance</th>
<th>df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>517.63*</td>
<td>128</td>
<td>402.29</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>6587.79</td>
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<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>School level (between schools)</td>
<td>.69</td>
</tr>
<tr>
<td>Student level (between students)</td>
<td>.13</td>
</tr>
</tbody>
</table>

*Note.* Language spoken at home was coded as 1 = English, 0 = other; and investigations refers to school mean for science teaching—investigations.

*p < .05
<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (achievement)</td>
<td>505.56*</td>
<td>3.56</td>
<td>141.86</td>
<td></td>
</tr>
<tr>
<td>Future-oriented science motivation</td>
<td>22.44*</td>
<td>3.33</td>
<td>6.73</td>
<td>0.16</td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.64*</td>
<td>0.17</td>
<td>3.86</td>
<td>0.23</td>
</tr>
<tr>
<td>Mother's SES</td>
<td>0.58*</td>
<td>0.22</td>
<td>2.61</td>
<td>0.42</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>32.11*</td>
<td>8.93</td>
<td>3.59</td>
<td>0.16</td>
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<td>School-level variables</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>-0.01*</td>
<td>0.01</td>
<td>-2.53</td>
<td>0.22</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>2.20*</td>
<td>0.58</td>
<td>3.79</td>
<td>0.34</td>
</tr>
<tr>
<td>Investigations</td>
<td>-44.30*</td>
<td>16.24</td>
<td>-2.73</td>
<td>0.24</td>
</tr>
</tbody>
</table>

| Random effects                           |             |     |         |    |
| Between-school variability (intercept)   | 551.55*     | 128 | 425.66  |    |
| Within-school variability                | 6437.40     |     |         |    |

Proportion of variance explained

| School level (between schools)            | .67         |     |         |    |
| Student level (between students)         | .15         |     |         |    |

*Note.* Language spoken at home was coded as 1 = English, 0 = other; and investigations refers to school mean for science teaching—investigations.

*p < .05
Table 4.19

Statistical Results for Multilevel Model of General Value of Science, Student-Level and School-Level Effects on Science Achievement

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interception (achievement)</td>
<td>508.64*</td>
<td>2.62</td>
<td>193.96</td>
<td></td>
</tr>
<tr>
<td>General value of science</td>
<td>22.20*</td>
<td>2.11</td>
<td>10.51</td>
<td>1.38</td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father’s SES</td>
<td>0.65*</td>
<td>0.18</td>
<td>3.68</td>
<td>0.39</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>38.43*</td>
<td>7.56</td>
<td>5.08</td>
<td>0.18</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>-0.01*</td>
<td>0.00</td>
<td>-3.30</td>
<td>0.29</td>
</tr>
<tr>
<td>School-mean father’s SES</td>
<td>1.94*</td>
<td>0.60</td>
<td>3.21</td>
<td>0.28</td>
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<tr>
<td>Hands-on activities</td>
<td>31.87*</td>
<td>14.75</td>
<td>2.16</td>
<td>0.19</td>
</tr>
<tr>
<td>Investigations</td>
<td>-52.41*</td>
<td>12.23</td>
<td>-4.28</td>
<td>0.38</td>
</tr>
</tbody>
</table>

| Random effects                    |             |     |         |     |
| Variance                          | 361.01*     | 127 | 347.35  |     |
| Within-school variability         | 6795.99     |     |         |     |

Proportion of variance explained

| School level (between schools)    | .78         |
| Student level (between students) | .10         |

*Note. Language spoken at home was coded as 1 = English, 0 = other; hands-on activities refers to school mean for science teaching—hands-on activities, and investigations refers to school mean for science teaching—investigations.

*p < .05
Table 4.20

*Statistical Results for Multilevel Model of Personal Value of Science, Student-Level and School-Level Effects on Science Achievement*

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (achievement)</td>
<td>505.23*</td>
<td>3.23</td>
<td>156.25</td>
<td></td>
</tr>
<tr>
<td>Personal value of science</td>
<td>24.34*</td>
<td>2.31</td>
<td>10.56</td>
<td>1.51</td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.63*</td>
<td>0.18</td>
<td>3.60</td>
<td>0.20</td>
</tr>
<tr>
<td>Mother's SES</td>
<td>0.52*</td>
<td>0.25</td>
<td>2.09</td>
<td>0.29</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>30.35*</td>
<td>8.76</td>
<td>3.46</td>
<td>0.20</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>-0.01*</td>
<td>0.00</td>
<td>-2.83</td>
<td>0.25</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>1.86*</td>
<td>0.62</td>
<td>3.01</td>
<td>0.27</td>
</tr>
<tr>
<td>Hands-on activities</td>
<td>28.88*</td>
<td>13.71</td>
<td>2.11</td>
<td>0.19</td>
</tr>
<tr>
<td>Investigations</td>
<td>-57.53*</td>
<td>12.51</td>
<td>-4.60</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Random effects

<table>
<thead>
<tr>
<th>Between-school variability (intercept)</th>
<th>Variance</th>
<th>df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>366.92*</td>
<td>127</td>
<td>330.20</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>6466.59</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

| School level (between schools)            | .78         |
| Student level (between students)         | .15         |

*Note.* Language spoken at home was coded as 1 = English, 0 = other; hands-on activities refers to school mean for science teaching—hands-on activities, and investigations refers to school mean for science teaching—investigations.

*p < .05
Table 4.21

Statistical Results for Multilevel Model of Science-related Activities, Student-Level and School-Level Effects on Science Achievement

<table>
<thead>
<tr>
<th>Item</th>
<th>Coefficient</th>
<th>SE</th>
<th>t-ratio</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (achievement)</td>
<td>506.11*</td>
<td>3.20</td>
<td>157.95</td>
<td></td>
</tr>
<tr>
<td>Science-related activities</td>
<td>21.26*</td>
<td>2.41</td>
<td>8.81</td>
<td>0.61</td>
</tr>
<tr>
<td>Student-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father's SES</td>
<td>0.55*</td>
<td>0.20</td>
<td>2.81</td>
<td>0.14</td>
</tr>
<tr>
<td>Mother's SES</td>
<td>0.52*</td>
<td>0.25</td>
<td>2.07</td>
<td>0.28</td>
</tr>
<tr>
<td>Language spoken at home</td>
<td>36.09*</td>
<td>8.71</td>
<td>4.14</td>
<td>0.26</td>
</tr>
<tr>
<td>School-level variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School size</td>
<td>-0.01*</td>
<td>0.00</td>
<td>-3.22</td>
<td>0.29</td>
</tr>
<tr>
<td>School-mean father's SES</td>
<td>1.87*</td>
<td>0.63</td>
<td>2.98</td>
<td>0.26</td>
</tr>
<tr>
<td>Hands-on activities</td>
<td>34.62*</td>
<td>15.37</td>
<td>2.25</td>
<td>0.20</td>
</tr>
<tr>
<td>Investigations</td>
<td>-55.40*</td>
<td>12.69</td>
<td>-4.37</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Random effects

<table>
<thead>
<tr>
<th>Variance</th>
<th>df</th>
<th>Chi-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-school variability (intercept)</td>
<td>381.48*</td>
<td>127</td>
</tr>
<tr>
<td>Within-school variability</td>
<td>6642.04</td>
<td></td>
</tr>
</tbody>
</table>

Proportion of variance explained

| School level (between schools)     | .77   |
| Student level (between students)  | .12   |

Note. Language spoken at home was coded as 1 = English, 0 = other; hands-on activities refers to school mean for science teaching—hands-on activities, and investigations refers to school mean for science teaching—investigations.

* p < .05
Table 4.22

Compilation of Effect Sizes for Nine Aspects of Science Engagement in Multilevel Models with Science Achievement as the Outcome Variable

<table>
<thead>
<tr>
<th>Aspect</th>
<th>$d$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science self-efficacy</td>
<td>0.98</td>
</tr>
<tr>
<td>Science self-concept</td>
<td>1.07</td>
</tr>
<tr>
<td>Enjoyment of science</td>
<td>0.49</td>
</tr>
<tr>
<td>General interest in learning science</td>
<td>0.56</td>
</tr>
<tr>
<td>Instrumental motivation for science</td>
<td>0.58</td>
</tr>
<tr>
<td>Future-oriented science motivation</td>
<td>0.16</td>
</tr>
<tr>
<td>General value of science</td>
<td>1.38</td>
</tr>
<tr>
<td>Personal value of science</td>
<td>1.51</td>
</tr>
<tr>
<td>Science-related activities</td>
<td>0.61</td>
</tr>
</tbody>
</table>

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Chapter Five: Discussion

This chapter consists of four major sections: i) a summary of results, ii) the relationship of those results to the literature, iii) two key policy implications of this research, and iv) five limitations of the study in relation to future research. Conclusions follow those four major sections. Note that the summary of the results begins with a treatment of the nine aspects of science engagement as outcome variables (as influenced by student background and school characteristics) before moving into a discussion of science achievement as the outcome variable (as influenced independently by each aspect of science engagement, along with student background and school characteristics). My discussion of the relationship of the results to published literature will follow the same order as above; that is, firstly of science engagement per se and then of science achievement as outcome variables. Note that the ensuing section (policy implications of this research) represents my attempt to draw together the two prior sections (my research results in the context of prior research) in order to draw inferences for U.S. educators and policy-makers to consider based on that confluence of collated information. Finally, I address some limitations of this research, which naturally suggest some possible avenues of further research to improve upon the desired outcome variables of science engagement and science achievement among U.S. students.

Summary of Results

Aspects of science engagement as outcome variables. Paired-but-different aspects of science engagement (science self-efficacy with science self-aspect; enjoyment of science with general interest in learning science; instrumental motivation for science with future-oriented science motivation; and general value of science with personal value
of science) showed anticipated bivariate correlations (Table 4.2); however, those
correlations were not excessively high, nor were any other bivariate correlations among
aspects of science engagement. The relative independence among aspects of science
engagement was also buttressed by the above review of the literature (see chapters one
and two), along with the questionnaire items related to aspects of science engagement
(see Appendix A). Based on the above statistical, literature, and conceptual bases,
considered the treatment of aspects of science engagement as separate outcome variables,
and later, as separate student-level variables potentially influencing science achievement,
to be appropriate.

**Student background.** While two of the six student background characteristics
(gender and father’s SES) frequently produced significant influences on aspects of
science engagement, neither had transcendent effects. In cases in which gender
differences were significant for seven of the nine aspects of science engagement (gender
was not a significant factor for general interest in learning science or instrumental
motivation for science), females consistently had lower average results than did males.
Remarkably, while mother’s SES failed to influence any of the nine aspects of science
engagement, father’s SES had a positive influence on six of them (exceptions were
general interest in learning science, future-oriented science motivation, and personal
value of science). Age, immigration background, and language spoken at home
influenced a smaller number of aspects of science engagement; however, those influences
differed across the nine aspects of science engagement. Older students tended to have
weaker science self-efficacy, general interest in learning science, and personal value of
science. Students with an immigrant background (immigrants themselves, or at least one
parent an immigrant) had higher average levels of general interest in learning science, instrumental motivation for science, and future-oriented science motivation than did native students. Meanwhile, language spoken at home had inverse influences on two aspects of science engagement: speaking English at home was associated with higher levels of science self-efficacy, while speaking other languages at home was tied to higher science-related activities.

**School context.** Among school context variables, no single variable significantly influenced more than two of the nine aspects of science engagement. While school size negatively impacted future-oriented science motivation, but positively influenced science-related activities, proportion of girls enrolled was associated with enhanced science self-concept and future-oriented science motivation. School-mean father’s SES was tied only to future-oriented science motivation (in a positive manner). Student-teacher ratio was negatively related to both personal value of science and science-related activities; that is, as student-teacher ratio increased, both of these aspects of science engagement decreased. Meanwhile, teacher shortage (in the key subject areas of science, math, and English) negatively influenced general interest in learning science.

**School climate.** Among school climate variables, school-mean science teaching measures most frequently affected aspects of science engagement; in fact, each of the nine aspects of science engagement was positively affected by one of the four different strategies of science teaching (as observed by students). Focus on applications or models was the school-mean science teaching approach which positively impacted the most aspects of science engagement: science self-concept, enjoyment of science, instrumental motivation for science, general value of science, and personal value of science. Hands-on
activities, meanwhile, enhanced two additional aspects of science engagement: science self-efficacy and general interest in learning science. Finally, investigations (future-oriented science motivation) and interactions (science-related activities) each influenced one aspect of science engagement in a positive way. The science teaching approach involving interactions had a negative influence on general value of science. Both ability grouping and parent influence positively impacted future-oriented science motivation; while science promotion was also associated with enhanced future-oriented science motivation, this school climate measure negatively impacted general interest in science (these apparently counter-intuitive results are discussed below).

Since the proportion of variance in the null models for aspects of science engagement as outcome variables ranged from 95.21 to 99.88% at the student level, but only 0.12 to 4.79% at the school level (information collated from individual aspects of science engagement in chapter four), the vast majority of variance in the nine aspects of science engagement was found at the student level. Meanwhile, my multilevel models for these aspects of science engagement as outcome variables which included student background and school characteristics (that is, parsimonious models) only explained 0 to 9% of the student-level variance, but 35 to 92% of the school-level variance (Tables 4.3 through 4.11). Thus, the performance of these particular models in explaining student-level variance could have been considerably stronger; this is addressed as a research limitation below. In addition, even though school-level variance was consistently small, it was statistically significant in terms of many aspects of science engagement. This would seem to be amenable to intervention and has encouraged me to offer a policy recommendation (see below) regarding investment of U.S. science educators in school-
level efforts to enhance aspects of science engagement, particularly focused on two science teaching strategies.

**Science achievement as the outcome variable, aspects of science engagement included in multilevel models.** Ten parsimonious multilevel models were developed, nine of which included a single aspect of science engagement as a potential level-one variable and one which did not include any of the aspects of science engagement as the baseline model. Since all ten of these multilevel models were using the same outcome variable (i.e., science achievement), and a matching set of both student background and school characteristics, it is unsurprising that the patterns of the responses were similar across the ten multilevel models. Importantly, all nine aspects of science engagement were retained in the multilevel models of interest (by meeting the significance level of $p < .05$), and more importantly, nearly all showed medium or large effect sizes. Note that the tenth multilevel model (which did not include an aspect of science engagement) was primarily included in order to obtain a baseline proportion of student-level variance for this set of multilevel models.

**Aspects of science engagement.** As noted above, all individual aspects of science engagement were included in the parsimonious multilevel models in which they were potentially included, and nearly all effect sizes were in the medium to large range (future-oriented science motivation [0.16] was the lone exception, assuming medium effect size status is granted to enjoyment of science [0.49]). Notably, the influence of all nine aspects of science engagement on science achievement was positive.

**Student background.** Student-level variables were used mainly as control variables of individual differences to refine the effects of science engagement.
Nonetheless, very similar patterns of student background impacts on science achievement were noted when the nine individual aspects of science engagement were included in multilevel models. Father’s SES positively influenced science achievement in the context of each of the nine aspects of science engagement; meanwhile, both mother’s SES and language spoken at home showed positive influences in eight of nine cases (exceptions were general value of science and general interest in learning science, respectively). Immigration background enhanced science achievement in one case: in the multilevel model including general interest in learning science.

**School context.** Similar to student-level variables, school-level variables (whether school context or school climate) were used mainly as control variables of school effects to refine the effects of science engagement. As school size increased, science achievement declined; this was the case for all nine multilevel models which included an aspect of science engagement. School-mean father’s SES had a very consistent, positive influence on science achievement across all nine multilevel models including a single aspect of science engagement. No other school context variables influenced science achievement in this U.S. sample.

**School climate.** School responsibility for curriculum and assessment enhanced science achievement only when science self-efficacy was included in the model. Meanwhile, two school-mean science teaching measures appeared frequently in the nine multilevel models including single aspects of science engagement: investigations (all nine) and hands-on activities (five). Notably the influence of school-mean science teaching—investigations was negative in each of the nine multilevel models. On the other hand, school-mean science teaching—hands on activities enhanced science
achievement for five multilevel models: enjoyment of science, general interest in learning science, general value of science, personal value of science, and science-related activities.

**Relationship of Results to Published Literature**

This section will begin with some brief comments about the relationships of my observations with the theoretical frameworks discussed in chapter two above. Indeed, understanding the theoretical underpinnings of these results could enhance their interpretations, improve subsequent policy analysis, and highlight any limitations in the research. Secondly, only significant results will be discussed, starting with each aspect of science engagement as an outcome variable, and then moving to science achievement as a single outcome variable, but with the successive inclusion of each aspect of science engagement in the multilevel model.

**Theoretical frameworks.** The overarching theoretical framework considered in this dissertation was the tripartite school engagement theory of Fredricks et al. (2004), which described school engagement as a meta-construct, consisting of cognitive, emotional, and behavioral aspects. In the context of this work, the nine aspects of science engagement covered the spectrum of cognition, emotion, and behavior; indeed all nine aspects independently and positively and in many cases also strongly influenced science achievement. Other views of science engagement have considered only behavioral and emotional factors (e.g., Green et al., 2012; Skinner et al., 2009) or merely behavioral measures (Chang et al., 2007; Singh et al., 2002) as constituting engagement. Given my results with science self-efficacy (see below) and science self-concept (also see below), the theoretical frameworks relating to the development of these particular aspects of
science engagement (Bandura, 1986, 1997; and Wigfield & Eccles, 2000, respectively) might be of special interest. While stereotype threat was addressed in chapter two as a possible unseen hindrance to science achievement (Inzlicht & Schmader, 2012), the only minority student background measure which adversely influenced science achievement (speaking a language other than English at home) seemed to have an alternate explanation (briefly, the science literacy nature of the science achievement measure). However, please see the limitations section below for a concern about the lack of racial/ethnic identification in this PISA-based study. On the other hand, whether one looks at the lack of opportunity theory of Roemer (2009) as a student background or a school characteristic, there was considerable evidence that this theoretical framework was operative. For example, six of the nine aspects of science engagement were enhanced by increasing father’s SES. In the case of science achievement, in the context of aspects of science engagement, father’s SES (all nine aspects), mother’s SES (eight aspects), and school-mean father’s SES (all nine aspects) as a student’s background or a student’s school became more prosperous, one tended to perform at higher levels on this science achievement assessment. Another way to view this: lower income students, or students in lower income schools, under-performed in science achievement relative to other students and schools.

**Aspects of science engagement as outcome variables.** To my knowledge, no research has been conducted which addresses these nine aspects of science engagement as outcome variables for U.S. students; thus, my research makes unique contributions to the literature in terms of understanding how those aspects of science engagement can be enhanced, particularly among students in this nation. In some cases, strong literature
support was available, particularly from studies done in other nations, for strategies to enhance specific aspects of science engagement. Such literature support is, of course, an asset to the U.S. science education community in its quest to implement my policy recommendations below. However, in many cases, the current research appears to be novel, indeed ground-breaking, and thus little or no literature support is available. In such cases, I have relied primarily upon my own results to attempt to provide U.S. science educators with assistance on implementation of the key outcomes of this work.

As a prelude to what comes below, I note that certain science teaching strategies (namely, focus on applications or models and hands-on activities) were shown to enhance many of these aspects of science engagement in my work, and are thus identified as key focal points for the U.S. science education community, even if the international literature base does not always provide direct support for such inferences.

**Science self-efficacy.** Females had lower science self-efficacy in my study (Table 4.3); previous research results have been somewhat mixed. Britner and Pajares (2006) found U.S. girls to have higher science self-efficacy than boys; meanwhile, Sun et al. (2012) observed Hong Kong males to have higher science self-efficacy than females. In a more highly differentiated study, Uitto (2014) noted no gender effects for biology self-efficacy, but that males were favored for self-efficacy in the science disciplines of chemistry and physics. My observation of a decline in science self-efficacy with age (Table 4.3) was similar to the report of Hong & Lin (2013) from Taiwan. Higher father’s SES was associated with higher science self-efficacy in my work; this was also the case for Sun et al. (2012) in Hong Kong (although their measure was the more general family SES). While I was unable to locate any prior reports of an advantage for English
language spoken at home as a corroborating explanation for my positive results with science self-efficacy, this researcher believes that the situational context of the PISA assessment with science literacy as the focus (OECD, 2007c) could have contributed.

While schools’ instructional climates have been credited with more persuasive influence on students’ science engagement than their own families (Basl, 2011; Vedder-Weiss & Fortus, 2011), identifying specific instructional strategies connected with enhancement of specific aspects of science engagement in the literature has proved to be difficult. For example, Andermann et al. (2011) described an ideal teacher profile likely to produce positive engagement and achievement outcomes. Nevertheless, my observation that science teaching—hands-on activities positively influenced science self-efficacy does have a reasonable connection with the published literature, in the context of the formation of science self-efficacy. I note that several authors (e.g., Britner & Pajares, 2006; Chen & Usher, 2013; Kiran & Sungur, 2012) have identified mastery experience as the primary source of science self-efficacy. Thus, I believe that science teaching strategies which emphasize hands-on activities may give students an opportunity especially well-suited to develop their own science self-efficacy.

**Science self-concept.** My results showed a disadvantage for females in science self-concept (Table 4.4); this was generally the case in previously published research (e.g., across fifty nations, Sikora & Pokropek, 2012). Gender-segregated classrooms did enhance physics self-concept of German females (Kessels & Hannover, 2008); meanwhile, biology self-concept of English females was equivalent to that of English males (Hardy, 2014). Thus, the general rule seems to be that females have lower science self-concept than males except in particular contexts (i.e., gender-segregation) and
particular science disciplines (biology). Both Bong and Skaalvik (2003) and Marsh et al. (2013), albeit in very different contexts, argued that frame of reference is a critical formative basis for academic or science self-concept; given that German females developed higher physics self-efficacies when in physics class with only females, while physics self-efficacy of German males was unaffected by gender composition of their physics classes (Kessels & Hannover, 2008), one could argue that females benefit from feminine frames of reference. Father’s SES enhanced science self-concept in my work; in a similar, but more differentiated way, Steinmayr et al. (2012) identified positive relationships between both chemistry and physics self-concept and father’s SES.

The current dissertation uncovered a strong, positive relationship between science self-concept and the proportion of girls enrolled in a school, in spite of the disadvantage for females in science self-concept. I have already discussed above the work of Kessels and Hannover (2008) in gender-segregated vs. gender-mixed classrooms; perhaps, their result might generalize from the classroom to the school level. I was unable to identity research specifically related to the influence of proportion of girls enrolled on science self-concept; Van Houtte (2004) did find that males’ academic achievement rose as the proportion of girls rose, while Dincer and Uysal (2010) did not observe a science achievement response for either gender with varying proportion of girls in their Turkish study. Science teaching—focus on applications or models significantly influenced science self-concept in my research; while identifying articles which specifically link this science teaching strategy with this aspect of science engagement has proved difficult, science educators have clearly advocated relevant science instruction (e.g., Niewsandt & Shanahan, 2008; Bottia et al., 2015) to enhance science engagement in a general way.
Given the conceptual basis of science self-concept in the context of this study (a student’s belief that he can learn, understand, and perform at a high level in science disciplines; see chapter one), implementing science teaching strategies which help students see how science applies to their lives or fits coherent models, would seem to provide a likely match between this intended outcome and this chosen instructional strategy. I note especially that the statistically significant influence of the science teaching strategy which focused on applications or models enhanced science self-concept over and above the influences of student background (individual differences) and in the presence of other significant school characteristics (school effects); thus, efforts by teachers and schools to emphasize this science teaching strategy are highly likely to positively impact science self-concept.

**Enjoyment of science.** I observed lower levels of enjoyment of science for females in my work (Table 4.5); Riegle-Crumb et al. (2011) noted a similar pattern for Hispanic-American females in their work. Literature support for my result showing father’s SES to enhance enjoyment of science was apparently not available. Hampden-Thompson and Bennett (2013), as did I, linked science teaching—focus on application or models with enjoyment of science; their context was with U.K. students.

**General interest in learning science.** Like Potvin and Hasni (2014), who reported on a decline in science interest with age for French-Canadian students, age inversely impacted general interest in learning science in my research (Table 4.6). While I was unable to locate literature support for my observation that native students had lower general interest in learning science, this result appears not to be anomalous, as I had similar findings for both instrumental motivation for science and future-oriented science
motivation. Thus, immigrant students appear to have higher investment in particular aspects of science engagement, perhaps related to a perception that science study may afford them entry to science-related careers.

Teacher shortage, as reported by school principals and measuring an inadequacy of instructional personnel across the key subject areas of English, math, and science, was inversely related to general interest in learning science in my work; direct research support for this finding appears to be unavailable. Teacher shortages have been documented to adversely influence science achievement of U.S. students (e.g., Sousa et al., 2012), and has been particularly problematic for immigrant students in Canada (Areepattamannil & Kaur, 2013). School activities to promote science learning negatively impacted general interest in science in my work; given that Perera (2014) found this school climate variable to be associated with science achievement across fifteen nations, my results are somewhat surprising. Perhaps the techniques by which science is promoted in U.S. schools are less engaging to U.S. students than whatever science promotion methods are utilized elsewhere. It is also possible that schools where students are not interested in science are promoting science activities as a remedy. Science teaching strategies which included hands-on activities significantly enhanced general interest in learning science in my work; others have previously reported a similar relationship (Jocz et al., 2014; Swarat et al., 2012).

**Instrumental motivation for science.** Father’s SES positively influenced students’ instrumental motivation for science (Table 4.7); literature support for this observation seems not to be available. As mentioned above, immigrant students had higher instrumental motivation for science than did native students; a possible tie to the
work of Kjærnsli and Lie (2011) may exist—these authors noted that students from Islamic and Latin American nations held higher levels of instrumental motivation for science than did U.S. students. Perhaps a significant proportion of immigrant students within the U.S. originated from cultures with inherently higher levels of instrumental motivation for science. It is also possible that immigrant students see science as an opportunity for upward mobility in social status and thus have higher instrumental motivation for science. Science teaching which focused on applications or models significantly influenced instrumental motivation for science in my work, as well as that of Hampden-Thompson and Bennett (2013) in the U.K.

**Future-oriented science motivation.** Females had lower future-oriented science motivation in my research (Table 4.8). While directly related research seems to be unavailable, some qualitative inferences may be drawn. Females seem to hold a higher future-oriented science motivation related to biology, while males tend to tie their future-oriented science motivation to more technical science fields (Sikora & Pokropek, 2012). As was the case for both general interest in learning science and instrumental motivation for science, immigrant students held higher future-oriented science motivation than native students. Areepattamannil & Kaur (2013) compared immigrant and native students, as to the relationship between future-oriented science motivation and science achievement (no difference); unfortunately, they did not report on possible differences among these student groups in future-oriented science motivation per se.

Seven different school characteristics significantly influenced future-oriented motivation of U.S. students (Table 4.8). My literature review, unfortunately, does not include direct supporting evidence for any of these seven school characteristics. School
size negatively influenced future-oriented science motivation, while proportion of girls enrolled, school-mean father’s SES, ability grouping, science promotion, parent influence, and science teaching (investigations) all had positive influences. While research is available on the association of school size with science achievement, I was unable to identify such research tying school size to future-oriented science motivation. Conceivably, a frame of reference argument (similar to that which was advanced in the case of science self-concept, but without references tied to future-oriented science motivation) could explain why increasing the proportion of girls in a school might enhance this measure in the context of low future-oriented science motivation among females. Perhaps the inequality of opportunity theoretical framework of Roemer (2009) might explain why students along the continuum of school-mean father’s SES would carry differentiated levels of future-oriented science motivation. Ability grouping has shown profoundly mixed results in the context of science achievement; perhaps, this could be construed as a frame of reference scenario, under which grouped students are more likely to see a future for themselves in science when not in classes with “stronger” science students. Science promotion was a positive factor for this aspect of science engagement; meanwhile, this school climate factor negatively influenced general interest in science. A possible interpretation of this seeming dissonance could be that schools may have used school science activities in a pro-active manner to promote future motivation for science, while other schools may have implemented such activities in a reactive manner to treat a lack of general interest in learning science. Parent influence has been shown to have a range of relationships with science achievement (e.g., Johnson & Hull, 2014; Mji & Mbinda, 2005; Senler & Sungur, 2009), but I was unable to identify
research support for my findings with respect to future-oriented science motivation. The science teaching strategy which invoked investigations enhanced future-oriented science motivation in my work was the only one of four studied teaching strategies to fail to show a relationship with this aspect of science engagement in the U.K. (Hampden-Thompson & Bennett, 2013).

**General value of science.** Females in my work held lower general value of science (Table 4.9); I did not identify corroborating literature. Father’s SES enhanced general value of science; parents in Hong Kong who held a high general value of science themselves successfully communicated their high general value of science to their offspring (Acosta & Hsu, 2014b).

Two science teaching strategies were related to general value of science: focus on applications or models (positively) and interactions (negatively). No direct research evidence appears to be available to support these findings; however, House (2009) indicated that making science relevant could help Korean students perceive a higher value for science. Since Hampden-Thompson and Bennett (2013) found science teaching with interactions to positively influence other aspects of science engagement, it is unclear why interactions were a negative factor in my case (note that Hampden-Thompson & Bennett [2013] did not test this particular relationship). Since science teaching with interactions emphasizes interactions among students (see Appendix B), giving students opportunities to express and discuss their own ideas about science topics (rather than teachers explaining science topics to students), I speculate that schools with significant numbers of students who hold low general value of science may find those students to be holding sway in classroom discussions about the general value of science.
**Personal value of science.** Females in my study had lower personal value of science (Table 4.10); this directly contrasted with the report of Else-Quest et al. (2013), who observed a consistent female advantage across four different ethnicities (Afro-, Asian-, Hispanic- and Euro-American). Older U.S. students in my study had lower personal value of science; no directly corroborating evidence seems to be available. Student-teacher ratio had an unsurprisingly negative influence on personal value of science (that is, increases in student-teacher ratio resulted in lower personal value of science); the lack of prior reports on this relationship may simply reflect a lack of prior study. The science teaching strategy which invoked a focus on applications or models was positively related to this aspect of science engagement; while no direct evidence seems to be available for the relationship between this science teaching strategy and this particular aspect of science engagement, a pattern of such relationships seems to be emerging, at least in my work.

**Science-related activities.** Females had lower levels of science-related activities than did males (Table 4.11); I did not identify literature support for this result. Father’s SES (positive association) and English language spoken at home (negative association) were also significant in my study. I speculate that economic and cultural opportunities enfranchised students with higher father’s SES to engage in science-related activities (Roemer, 2009); I also suggest that the tendency of non-English speakers to be more involved in science-related activities at home may possibly be related to my observed results with higher levels of general interest in learning science, instrumental motivation for science, and future-oriented science motivation among immigrant students. These
results could potentially relate to a perception among immigrant students that science could afford them with a measure of upward social mobility.

Larger school size was tied to higher levels of science-related activities (outside of the school per se); I speculate that larger schools may have had inadequate in-school science activities, along with high academic competition among students in science, forcing students to look outside of school for science-related activities. This line of reasoning seems to be well-matched to my additional result: increasing student-teacher ratios reduced science-related activities. In any case, the science teaching strategy which involved interactions among students was significant (and a positive factor) for science-related activities. Vedder-Weiss and Fortus (2011) argued that the school culture inculcated in their Israeli context, which involved significant student-to-student accountability, was a key factor in continuing motivation for science-related activities.

**Science achievement as the outcome variable.** Ten multilevel models used science achievement as the outcome variable: nine which potentially included one of the aspects of science engagement at the student-level, and a tenth iteration which included none of the aspects of science engagement. This tenth model was run to function as the baseline model to compare the proportion of variance accounted for by this models at the student-level to that of the nine multilevel models which ultimately did include the individual aspects of science engagement. Since all ten of these models utilized the same outcome variable (science achievement) and a similar suite of student background measures and school characteristics as model inputs (only the inclusion—or not—of an aspect of science engagement differed), it is unsurprising that the results of the ten models were similar in the subsets of variables which were found to significantly
influence science achievement. Hence, my literature review of the results follows that trend; I will first compare my results with those of others for each of the aspects of science engagement, then for significant student background measures, and finally, for school characteristics.

As was the case for aspects of science engagement as outcome measures, the international literature base for science achievement as the outcome measure is rich and diverse for some aspects of science engagement, and almost entirely absent for other aspects of science engagement. I underscore here that the cutting-edge uniqueness of my results is that all nine aspects of science engagement positively influenced science achievement, and nearly all had medium to large effect sizes. Thus, this study is truly ground-breaking in providing a comprehensive view of not only science engagement per se (see above) but also the comprehensive influence of the nine aspects of science engagement on science achievement. Where international literature support for my results is available, I am encouraged by that and willingly reference such results below. On the other hand, I affirm that this study is unique, especially under U.S. conditions, and thus some of my results will naturally lack extensive confirmation in the currently existing literature.

Science achievement as influenced by science self-efficacy. My positive results with U.S. students (see Table 4.13, large effect size) have been extensively corroborated in the literature. Science self-efficacy has been positively associated with science achievement across 15 nations (Perera, 2014), and in Canada (Areepattamannil et al., 2011), Finland (Lavonen & Laaksonen, 2009), Germany (Scherer, 2013), Hong Kong
Science achievement as influenced by science self-concept. Table 4.14 shows that science self-concept had a strongly positive influence on science achievement in my work (large effect size); widespread research has consistently confirmed this result. Science self-concept has enhanced science achievement in Canada (Areepattamannil et al., 2011; Areepattamannil, 2012b; Areepattamannil & Kaur, 2013), East Asian nations/regions (Shen, 2005; Yu, 2012), Finland (Lavonen & Laaksonen, 2009), Saudi Arabia (Tighezza, 2014), Singapore (Mohammadpour, 2013), Taiwan (Jen et al., 2013), and the U.S. (Lau & Roeser, 2002; Shen, 2005; Yu, 2012). Two reports, both from the same world region, provided contrasting results. Anagün (2011), using PISA 2006 data for his nation, found no relationship between science self-concept and science achievement for Turkish students, while Bouhlila (2011) who used TIMSS data for 16 nations, observed a negative relationship between these measures for students from a group of MENA nations. In such nations, the pronounced trend was for these eighth grade students to hold relatively high science self-concepts in spite of low science achievement scores. Regional differences may be at play in this case.

Science achievement as influenced by enjoyment of science. My results included a positive influence of enjoyment of science on science achievement, with a medium effect size, granting an effect size of 0.49 such status (Table 4.15). A positive relationship between enjoyment of science and science achievement has been observed in Canada (Areepattamannil et al., 2011), Finland (Lavonen & Laaksonen, 2009), Hong Kong (Lam & Lau, 2014), Malaysia and Singapore (Ng et al., 2012), Saudi Arabia
Science enjoyment was associated with science achievement of 2nd generation, but not 1st generation immigrants to Canada (Areepattamannil, 2012b). In contrast, enjoyment of science has been shown to be negatively related to science achievement for eighth grade students across 16 MENA nations (Bouhlila, 2011). Those students indicated a high enjoyment of science in the TIMMS survey; however, their mean science achievement was well below the international average (Bouhlila, 2011).

**Science achievement as influenced by general interest in learning science.**

Table 4.16 displays my positive results (with medium effect size) for the influence of general interest in learning science on science achievement. While general interest in science was positively associated with science achievement in Qatar (Areepattamannil, 2012a), this relationship was negative for students in both Canada (Areepattamannil et al., 2011) and Finland (Lavonen & Laaksonen, 2009). Note that all of the above authors were using PISA 2006 as their data source for their research; regional differences may again be involved in this case.

**Science achievement as influenced by instrumental motivation for science.** In my work, instrumental motivation for science positively impacted science achievement, and had a medium effect size (Table 4.17). Instrumental motivation for science positively impacted science achievement of students across 15 nations (Perera, 2014), in Hong Kong (Sun et al., 2012), and in New Zealand (Acosta & Hsu, 2014a).

**Science achievement as influenced by future-oriented science motivation.**

While future-oriented science motivation had a positive influence on science achievement in my work, its effect size was very small (0.16; Table 4.18). Both immigrant and non-
immigrant students across Canada had positive associations between future motivation for science and science achievement (Areepattamannil & Kaur, 2013).

**Science achievement as influenced by general value of science.** General value of science positively impacted science achievement in my research, and had a large effect size (Table 4.19). In Hong Kong, students with higher general value of science had higher science achievement (Acosta & Hsu, 2014b; Lam & Lau, 2014).

**Science achievement as influenced by personal value of science.** In a manner similar to that of general value of science, personal value of science enhanced science achievement (with a large effect size) among students in my U.S. sample (Table 4.20). Non-immigrant students in Canada showed no relationship between personal value of science and science achievement; in contrast, for immigrant students, this relationship was negative (Areepattamannil & Kaur, 2013). I note that the work of Areepattamannil & Kaur (2013) was based on PISA 2006 data for Canada, and I resort to my notion of regional differences in this case.

**Science achievement as influenced by science-related activities.** Science-related activities enhanced science achievement in my work, with a medium effect size (Table 4.21). Engagement in science-related activities has been shown to enhance science achievement in Hong Kong (Ho, 2010), Turkey (Kalendar & Berberoglu, 2009), and the U.S. (Sha et al., 2015; Tran, 2011).

**Science achievement as influenced by student background.** While father’s SES significantly influenced science achievement in all ten multilevel models (each of the nine including a single aspect of science engagement along with the model which included no such aspects); mother’s SES also influenced science achievement in nine of
the ten models (the model including general value of science was the lone exception).
Thus, my results showed significant and independent influences of father’s and mother’s SES on science achievement, a finding which is not often identifiable in the literature, as most reports simply consider SES at the family level. Family SES is indeed a critical factor influencing science achievement, having been documented in numerous cases around the world; a few examples are cited here: 31 nations (Fuchs & Wößmann, 2007), 16 MENA nations (Bouhlila, 2011), Croatia (Gregurović & Kuti, 2010), Ireland (Gilleece et al., 2010), Spain (Gil-Flores, 2011), Taiwan (Chen et al., 2012; Tsai & Yang, 2015), Turkey (Dincer & Uysal, 2010; Kalender & Berberoglu, 2009), the U.K. (Gorard & See, 2009), and the U.S. (Muller et al., 2001; Sousa et al., 2012).

Immigration background was significant in only one model: that which included general interest in learning science (Table 4.16). Native students had higher science achievement than did immigrant students. Lower science achievement was observed for students with immigrant status across 31 nations (Fuchs & Wößmann, 2007), across 15 nations (Perera, 2014), and across 3 European nations (Song, 2011), as well as in Canada (Adamuti-Trache & Sweet, 2013), Spain (Cordero Ferrera et al., 2011), and Switzerland (Meunier, 2011).

English language spoken at home had a positive influence in nine of the ten multilevel models (general interest in learning science was the lone exception). I believe that this outcome was related to the nature of science achievement as defined by PISA; that is, as science literacy (OECD, 2007c). Thus, a given student’s facility in reading English in order to grasp the context of the science problem could indeed influence their science achievement when assessed as science literacy. Students who spoke a language
other than the exam language at home had lower science achievement results across 15 nations (Perera, 2014), across 16 MENA nations (Bouhlila, 2011), and in Canada (Areepattamannil & Kaur, 2013), Ireland (Gilleece et al., 2010), and Taiwan (Tsai & Yang, 2015).

**Science achievement as influenced by school characteristics.** Increasing school size (a school context measure) negatively impacted science achievement in all ten multilevel models tested in my work; however, for each 100 additional students in a school above the school size mean of 1346, the average decrease in science achievement was only about 1 point on a U.S. average science achievement score of approximately 505. Thus, while my school size effects were indeed negative, they were modest and with small effect sizes. The literature provides a mixed picture on the relationship of school size to student achievement, particularly if math achievement research is considered along with science achievement research. Larger school size enhanced science achievement of native (but not immigrant) Canadian (Areepattamannil & Kaur, 2013) as well as Indian students (Areepattamannil, 2014). Math achievement was influenced in different ways by school size: i) large schools had the highest math achievement (Schreiber, 2002), ii) large schools had lower math achievement (Martín et al., 2008), and iii) very small and very large schools had the highest math achievement (Werblow and Duesbery, 2009).

School-mean father’s SES (a school context measure) showed a consistent, positive influence on science achievement in all ten multilevel models. Like family SES, school SES has been previously shown to be an important explanatory factor for science achievement; examples of this relationship include: 15 nations (Perera, 2014), 17
collated studies (Sellström & Bremerberg, 2006), Australia (McConney & Perry, 2010),
China (Zhang & Campbell, 2015), Ireland (Gilleece et al., 2010), Turkey (Acar, 2009;
Dincer & Uysal, 2010), and the U.S. (Borman & Dowling, 2010). School-level SES was
the only statistically significant influence on science performance for Irish students in
PISA 2006; the authors raised a national-level school equity question based on this
finding (Gilleece et al., 2010). Based on their intensive review of Spanish PISA 2009
data, de Mendizabal and Calero Martinez (2013) called for a national policy of
“maintenance of equity” at the school-level due to the tendency of science (and math and
reading) achievement to be tied to school-level SES measures (p. 563). I identified just
one research report (Marks, 2006) which argued that school-level SES did not influence
student performance.

School responsibility for curriculum and assessment (a school climate variable)
had a significant positive influence on science achievement in two multilevel models: i)
the one including science self-efficacy, and ii) the one which included no aspects of
science engagement. While research relating this particular variable to science
achievement is apparently not readily available, this U.S. sample had a relatively high
average for this measure (0.51; see Table 4.1) compared with the OECD standardized
mean of zero (OECD, 2009).

The science teaching strategy which involved hands-on activities was significant
and showed a positive influence on science achievement in six models: those which
included the aspects of science engagement enjoyment of science, general interest in
learning science, general value of science, personal value of science, science-related
activities and the model which included no aspects of science engagement. Pickens and
Eick (2009) identified hands-on activities as a key science teaching strategy to engage the less motivated students in their classrooms. Unfortunately, hands-on instruction showed a negative association with science achievement in the 15 nation study of Perera (2014); I note that while her study did include results from the U.S., the analysis was conducted across nations rather than on a national scale.

The science teaching strategy which invoked student investigations resulted in a consistently negative influence on science achievement in all ten multilevel models tested. As was the case for hands-on activities, Perera (2014) identified a negative relationship between student investigations and science achievement in her 15 nation study. Areepattamannil & Kaur (2013) also concluded that such investigations negatively impacted science achievement in Canada. It is possible nonetheless that low performing schools in science attempt to employ this science teaching strategy to improve student performance in science. On the other hand, instructional contexts which included experimentation and/or investigation promoted science achievement in Turkey (Kalendar & Berberoglu, 2009; Kingir et al., 2013) and the U.S. (Odom et al., 2007).

**Policy Implications of This Research**

My intent in this section is to present policy recommendations on the foundation of the above discussion; that is, making use of my U.S. results with some assistance of the published literature to suggest appropriate policies for educational reforms in science education in the U.S. Both family SES (separately identified as father’s SES and mother’s SES in my work) and school-mean father’s SES had consistent, positive relationships with science achievement; these trends have been well-established in prior literature (reviewed above) and are not unique to this work. What is truly unique is my
focus on the influence of aspects of science engagement above and beyond a suite of student background and school characteristics on science achievement of U.S. students. In fact, all nine aspects of science engagement enhanced science achievement, and eight had medium or large effect sizes (assuming such status is granted for the 0.49 effect size for enjoyment of science). With its very small effect size (0.16) on science achievement, only future-oriented science motivation failed to reach that high standard. Thus, my recommendations for education policy makers in the U.S. will focus primarily on enhancement of these eight aspects of science engagement. Further, since my study design also assessed both student background and school characteristics which directly influenced each aspect of science engagement, I am able to provide insights on issues relevant to students’ backgrounds and appropriate school context and school climate strategies to improve not only these aspects of science engagement but also science achievement per se.

The development of Next Generation Science Standards (NGSS Lead States, 2013a, 2013b), based on a carefully crafted K-12 science education framework (Quinn, Schweingruber, & Keller, 2011), has dramatically influenced the context into which any policy recommendations must be made in the U.S. science education context. These NGSS, adopted intact by a number of states (e.g., Kentucky in 2013 [Kentucky Department of Education, 2016]) have formed a basis for a new instructional focus in science education. The most salient aspect of the NGSS is that its three dimensions (disciplinary core ideas [often referred to as content], engineering and scientific practices, and cross-cutting concepts) are intended to be integrated at each grade level from K through 12. The key connection of this approach to the current dissertation is that the
engagement of students in their own learning is to be fostered by alignment of content and concepts with practice through utilization of NGSS; meanwhile, my dissertation focuses on specific strategies to enhance aspects of science engagement of students based on their backgrounds or through implementation of particular science teaching strategies. The value of coupling the policy recommendations below with the recent adoption of the NGSS by many U.S. states is that the focus on aspects of science engagement and science teaching could well serve to amplify the impact of the tri-dimensional configuration of NGSS. A danger of connecting these conversations is that science educators could miss the importance of focusing on particularly strong factors in this dissertation research (e.g., the linkages of science self-efficacy and science self-concept with science achievement) in the midst of trying to adopt the complex elements of the NGSS (NGSS Lead States, 2013a).

Two key policy recommendations are thus made as a result of this dissertation: i) because science engagement is so important to science achievement, U.S. educational policy-makers, school leaders, and instructors should focus on enhancing the eight identified aspects of science engagement which strongly influenced science achievement, and ii) the same educational group should also emphasize two key instructional strategies shown to either directly or indirectly (through aspects of science engagement) enhance science achievement, that is, science teaching which includes a focus on applications or models and science teaching which includes hands-on activities. Note that since the first policy recommendation will cover eight different aspects of science engagement, I will clarify the prioritization within that overall suite of eight parts of that recommendation. In addition, this section will also describe the specific context of both science teaching
strategies studied in this dissertation in order to clarify the appropriateness of inferences which may be drawn.

Enhancing eight aspects of science engagement. This overall recommendation advocates for the enhancement of eight aspects of science engagement; the first four to be discussed below (science self-efficacy, science self-concept, general value of science, and personal value of science) all had large effect sizes (on science achievement), and are thus considered to be the highest level priority for consideration by U.S. science educators. The second set of four aspects of science engagement discussed below (enjoyment of science, general interest in learning science, instrumental motivation for science, and science-related activities) each had medium effect sizes (on science achievement), and are thus considered to be of a second level priority for consideration by U.S. science educators.

School-level initiatives are included in the following discussion as mechanisms to enhance particular aspects of science engagement. Although all null models for aspects of science engagement as outcome measures showed very modest proportions of variance to be attributable to schools, variance components were statistically significant. I believe that this result may provide opportunities for both researchers and practitioners to explore the possibilities of influencing these aspects of science engagement through particular school interventions, especially, two well-supported science teaching strategies (see second policy recommendation below).

Enhancing science self-efficacy. Four different student background measures (gender, age, father’s SES, and language spoken at home) influenced science self-efficacy, albeit with small effect sizes (Table 4.3). Students at an apparent disadvantage
for developing strong science self-efficacy were females, older, had lower father’s SES, and those who spoke a language other than English at home. Chapter two discusses factors which promote the formation of science self-efficacy; mastery experience has been shown to have the strongest influence in this realm of academic self-efficacy (Britner & Pajares, 2006; Kiran & Sungur, 2012). Thus, providing opportunities for U.S. students to personally experience success in science-related tasks would seem to be essential for their development of science self-efficacy, especially for those described above as disadvantaged for the development of this key aspect of science engagement. Other research initiatives have described an additive effect (above and beyond the four sources of science self-efficacy described by Britner & Pajares [2006]): those science students who viewed their science abilities as flexible developed higher self-efficacies than did otherwise similar peers who considered their science abilities to be fixed (Chen & Pajares, 2010; Chen & Usher, 2013). While my research did not delve into the question of fixed/flexible abilities of students (see limitation section for further discussion), this would also seem to be an appropriate direction for investment, given that some researchers believe students can be persuaded their ability set is more flexible than they have thought. For example, Aronson et al. (2002) persuaded African-American college students to think of their own intelligence as incremental (rather than fixed); as a result, these students were more engaged in their academics and had higher grade point averages. Thus, there appears to be a series of interventions which could indeed enhance science self-efficacy of U.S. students, and particularly those currently at a disadvantage.

In addition, hands-on instruction was a school climate characteristic which influenced science self-efficacy in my work; given the definition of science self-efficacy
in the context of this dissertation (see chapter one) as a student’s confidence in performing challenging new science-related tasks, the positive influence of hands-on learning may well be related to the above student background disadvantages. Indeed, Von Secker (2004) also noted a protective influence of hands-on science instruction on science achievement (not specifically on science self-efficacy) across multiple risk factors of low SES, minority status and female gender; further, the protective influence of this approach was more pronounced for older minority students. As a point of emphasis (rather than redundancy), hands-on instruction would seem to be ideally suited to generate the mastery learning experiences which are key to the formation of science self-efficacy (e.g., Britner & Pajares, 2006). Further, utilization of NGSS strategies should result in more hands-on activities in science classrooms.

Science self-efficacy should be a top level priority for U.S. science educators simply because of its large effect size (on science achievement). As an added bonus, the globally-available literature base not only supports my results in other national/international contexts, it also provides abundant suggestions on mechanisms for the enhancement of science self-efficacy.

**Enhancing science self-concept.** Two student background measures (gender and father’s SES) influenced science self-concept. Females and students with low father’s SES had lower science self-efficacy. At first glance, addressing these two student background responses may seem difficult; however, I believe that both can be successfully managed by U.S. science educators. I will treat the gender scenario below, as part of a frame of reference consideration of proportion of girls in a school (or classroom). More importantly, I emphasize an instructional strategy which helps make
science more relevant to their daily lives could conceivably enhance science self-concept of all students.

Two school characteristics influenced science self-concept: proportion of girls enrolled in schools (a school context variable) and science teaching which focused on applications or models (a school climate measure). That science teaching which emphasized applications or models was a positive influence on science self-concept seems entirely reasonable, even in the absence of corroborating literature, since this self-belief emphasized the learning and understanding of science concepts, processes which would seem to be facilitated by enhanced application/relevance to a student’s daily life. As stated above, I believe that this science teaching strategy could enhance science self-concept of all students including low SES ones (Niewsandt & Shanahan, 2008; Bottia et al., 2015). In addition, the integrative nature of science classrooms operating under the influence of NGSS should be a complimentary influence toward this type of instruction in the U.S. The influence of increasing the proportion of girls in a school or classroom may also deserve renewed attention as a result of my work. An increase in the proportion of girls in a school may have resulted in an adjustment of the frame of reference for girls within that school, thereby enhancing their science self-concept (Kessels & Hannover, 2008). Given that the science self-concept of males may be insensitive to the gender proportion in a classroom (Kessels & Hannover, 2008) or possibly in entire schools, and given that my work showed increasing the proportion of females in a school enhanced overall science self-concept of student population (in spite of generally lower science self-concept for females), enhanced female participation in science-related learning
activities within classrooms as well as such activities (e.g., science clubs) at the school level should be actively encouraged.

Science self-concept, as stated above, should be a top level priority for emphasis among U.S. science educators simply because its effect size (on science achievement) was large. As was the case for science self-efficacy, the availability of an extensive literature base for science self-concept not only supports my results in other national/international contexts, it also provides abundant suggestions on the enhancement of science self-concept.

**Enhancing general value of science.** Females held lower general value of science, as did students with lower father’s SES. Parents in Hong Kong were able to successfully communicate their high general value of science to their children (Acosta & Hsu, 2014b). Teachers and schools may need to take responsibility for enhancing general value of science among females and students with low father’s SES; science teaching with a focus on applications or models seems to have potential as an intervention (House, 2009). Simply due to its large effect size (on science achievement), enhancing general value of science should be a top level priority among U.S. science educators. Presumably, students in states which have opted fully into NGSS should develop a higher general value of science, due to the integration of content with practice under NGSS.

**Enhancing personal value of science.** Female students and older students had lower personal value of science in my work. An increasing student-teacher ratio negatively influenced personal value of science; the obvious remedy for that school-level issue is to provide adequate instructional staffing (although this might be a temporary or long-term financial issue in some schools). On the other hand, science instruction which
focused on applications or models improved personal value of science, and could conceivably prove valuable for female and older students. As was the case for general value of science, on the basis of its large effect size (on science achievement) alone, enhancing personal value of science should be a top level priority among U.S. science educators. Personal value of science would seemingly be enhanced for students in schools which had fully adopted NGSS, again, because content and practices are closely linked in this context.

**Enhancing enjoyment of science.** Females had lower enjoyment of science in my work; efforts to address this deficit are appropriate (Riegle-Crumb et al., 2011). Students with low father’s SES had lower enjoyment of science, perhaps because they are less likely to see this as an area of opportunity for them. Science teaching which focused on applications or models improved enjoyment of science in my work; this result was corroborated by Hampden-Thompson and Bennett (2013). Enjoyment of science merits consideration of U.S. science educators as a second-level priority due to its medium effect size; particularly given the current emphasis on affective outcomes in science education (e.g., Chen & Pajares, 2010; Fensham, 2009; Tsai, 2000; Ziegler et al., 2014). Since the science teaching strategy which invoke a focus on applications or models positively influenced enjoyment of science, NGSS should be seen as a positive development for enhance enjoyment of science (due to the integrative nature of science instruction involved in NGSS).

**Enhancing general interest in learning science.** Older U.S. students in my study held lower general interest in learning science. Potvin and Hasni (2014) had similar results with French-Canadian students. Immigrant students, perhaps sensing an
opportunity in science-related fields, held higher general interest in science; unfortunately, this interest did not result in higher science achievement for immigrant students (in fact, native students had significantly higher science achievement). Teacher shortage had a negative influence on general interest in learning science; school leadership reporting this measure would obviously not be surprised at any number of adverse impacts of a teacher shortage (including this one). My interpretation of the negative influence of in-school science promotion activities (see above) is that schools with relatively weak emphasis on science instruction may attempt to make up for that weakness by using this strategy. Science teaching which emphasized hands-on activities was a key factor in spurring general learning in science, both in my study and in prior research (Jocz et al., 2014; Swarat et al., 2012). There is some dissonance in the literature about the relationship of general interest in learning science with science achievement (see discussion above). General interest in learning science showed a medium effect size (on science achievement) and immigrant students showed higher levels of this particular aspect of science engagement. Schools with substantial immigrant populations may be inclined to focus on this aspect of science engagement. Some school leaders may choose this aspect of science education as an important focal point, and therefore rate it as a second-level priority. Given the connection of hands-on activities with general interest in science, and the high level of scientific practices involved in NGSS, this aspect of science engagement would presumably be enhanced in NGSS-focused schools.

*Enhancing instrumental motivation for science.* Father’s SES was positively associated with instrumental motivation for science; perhaps the key point here is that
while students whose fathers are of relatively high SES may derive instrumental motivation for science from their father’s life standing, those with fathers of lower SES may require instructor or school support to develop/affirm such a motivation. As was the case for general interest in learning science, immigrant students held higher instrumental motivation for science than did native students; perhaps for similar reasons. There was no influence of immigration/native background on science achievement. Only one school characteristic—science teaching strategies which invoked applications or models—significantly influenced instrumental motivation for science; Hampden-Thompson and Bennett (2013) found similar results. Apparently, making science relevant to students through this instructional strategy helped them to perceive the instrumental value of science in their lives. Owing to its medium effect size (on science achievement), enhancing instrumental motivation for science clearly deserves second level priority for emphasis by U.S. science educators. As was noted above for general interest in learning science, schools with relatively high immigrant enrollments may wish to give more consideration to this aspect of science engagement. Given that the science teaching strategy involving a focus on applications or models was positively associated with instrumental motivation for science, and given that NGSS calls for integration of content, concepts, and practices, instructional contexts in which NGSS has been implemented should make enhancement of instrumental motivation for science more likely.

**Enhancing science-related activities.** Female students, those with lower father’s SES, and those who spoke English at home had lower science-related activities. I have already speculated that students from families who were immigrants may see more opportunities in science, and therefore hold higher general interest in learning science and
instrumental motivation for science. Logically then, it follows that students who speak languages other than English at home may perceive science as an opportunity for them and preferentially choose to be engaged in science-related activities outside of their school contexts. School characteristics which enhanced science-related activities included school size (positive), student-teacher ratio (negative), and science teaching involving student interactions (positive). Perhaps larger schools had inadequate science activities and thus forced students outside the school to find science-related activities (my science achievement results also showed larger schools to have lower science achievement scores). As was the case for personal value of science, the negative relationship between student-teacher ratio and science-related activities (more students per teacher leads to lower science-related activities) is unsurprising and the remedy is obvious. Science-related activities was the only aspect of science engagement for which the science teaching strategy involving student interactions was significant; perhaps this result has parallels with the work in Israel by Vedder-Weiss and Fortus (2011) in a school culture which invoked a high level of student-to-student accountability. On the basis of its medium effect size (on science achievement), I affirm science-related activities for second-level focus by U.S. science educators (among the eight recommended aspects of science engagement). Schools with higher proportions of students who speak languages other than English at home may wish to consider this aspect of science engagement for special attention. The rationale for an amplification of the influence of the above measures on science-related activities in the context of NGSS-structured science education is less clear than for other aspects of science engagement.
**Emphasizing two key science teaching strategies.** Discussion was included above on these two key science instruction strategies as mechanisms for enhancing many of the aspects of science engagement identified for focus by the U.S. science education community. In fact, because these two science teaching strategies positively influenced seven of the eight aspects of science engagement above, I believe further emphasis here as a second policy recommendation is appropriate. Notably, the emergence of these science teaching strategies as significant influencing factors for these aspects of science engagement over and above the influence of student background (individual differences) and in the presence of any other significant school characteristics (school effects) indicates that they provide a special opportunity to enhance these aspects of science engagement. Schools may choose to focus on enriched implementation of these science teaching strategies as a key step toward enhancement of the above aspects of science engagement (and thereby also indirectly improve science achievement through their influence on aspects of science engagement). That approach, based on my results, would seem to be a reasonable step in the right direction. However, the powerful influences of the eight above-mentioned aspects of science engagement on science achievement call for the use of every available strategy to enhance these aspects of science engagement. That being said, since the pair of science teaching strategies below provide such broad and positive influences on these aspects of science engagement, U.S. science educators should clearly implement them as part of an overall strategy to improve science achievement. Here is a key point where connections can be made with the NGSS work: the integration of core content and cross-cutting concepts with practices (NGSS, 2013a) matches well with a focus on applications or models as a science teaching strategy (this
dissertation), and the emphasis on practices (e.g., skills; detailed extensively in NGSS, 2013b) meshes well with hands-on activities as a science teaching strategy (this dissertation).

**Focus on applications or models.** This science teaching strategy, aggregated from individual student observations as a school-mean measurement, significantly and positively influenced five of the eight above-emphasized aspects of science engagement: science self-concept, enjoyment of science, instrumental motivation for science, general value of science, and personal value of science. Thus, this science teaching strategy appears to hold broad merit in fostering enhancements in the aspects of science engagement uncovered by this dissertation as key factors toward improved science achievement of U.S. students. Numerous authors (e.g., Niewsandt & Shanahan, 2008; Bottia et al., 2015) have called for implementation of science teaching methods involving applications or models, in order to make such learning environments more relevant to students. Hampden-Thompson and Bennett (2013) have confirmed a positive relationship between this science teaching strategy and both enjoyment of science and instrumental motivation for science. Note that this instructional strategy, as described by the prompts provided to students (see Appendix B) involves considerable involvement by science teachers in helping their students perceive the relevance of science to daily life. Thus, instructors implementing this strategy must be quite proactive about their lesson planning and implementation.

**Hands-on activities.** This science teaching strategy, also aggregated from individual student observations as a school-mean measurement, significantly and positively influenced two additional aspects of science engagement (beyond the five
influenced by science teaching which focused on applications or models): science self-efficacy and general interest in learning science. Since mastery experience has been shown to be the key formative factor for science self-efficacy (e.g., Britner & Pajares, 2006; Chen & Usher, 2013; Kiran & Sungur, 2012), and since hands-on instruction provides opportunities for such mastery experience, it is not a surprise that this science teaching strategy was closely related to science self-efficacy. General interest in learning science was also enhanced by this science teaching strategy, perhaps because this instructional approach helps students perceive the practical utility of learning science disciplines toward their daily lives. As a further endorsement of hands-on activities as a science teaching strategy, I also underscore my results with science achievement as an outcome measure. In that case, five of the eight multilevel models including the individual aspects of science engagement discussed in the first policy recommendation above included science teaching with hands-on activities as a significant and positive influence on science achievement. Thus, this approach to science instruction has not only a direct influence on a pair of aspects of science engagement (which I have shown themselves to influence science achievement), it also has its own influence on science achievement per se. Finally, as noted above for the science teaching approach which focused on applications or models, the strategy involving hands-on activities is conducted under the well-organized supervision of the science teacher (see Appendix B).

**Limitations of This Research**

While the dataset utilized for this research provided some extraordinary advantages (e.g., the inclusion of nine aspects of science engagement, science achievement assessed as science literacy, the capacity to utilize data available
internationally which can thus be compared and contrasted, and the readiness of the data for analysis through multilevel modelling), this very dataset also left my research with some inherent limitations. I will briefly mention five such limitations here, and then explain the context and suggest possible remedies in ensuing research below.

The five primary limitations of this research, in my view, are as follows: i) the age of the dataset (ten years old at this writing), ii) the lack of racial/ethnic identification among the students sampled, iii) the relatively low proportion of student-level variance accounted for by my multilevel models with aspects of science engagement as outcome variables, iv) the lack of class-level measures in the dataset, and v) the failure of the dataset to include measures of students’ epistemological beliefs along with self-reflective conceptualization of their own fixed/flexible development in science.

**Age of the dataset.** Data utilized in this dissertation were drawn from PISA’s 2006 science-focused iteration (OECD, 2007a), and are thus fully a decade old at the time of this writing. Many national-scale reports on science education (e.g., NSTA, 2003) were published around that time, and several national-level initiatives started around that time (for example, the update of the Elementary and Secondary Education Act in 2001 [US Department of Education, 2016], christened by then-president George W. Bush as “No Child Left Behind”) have been ended. Hence it is indeed reasonable to ask whether or not the results of this study remain relevant within the U.S. context after the span of a decade. Two trains of thought seem to indicate an affirmative answer is appropriate. First, only modest improvement has been noted in PISA’s measures of science achievement in the 2009 (OECD, 2010b) and 2012 (OECD, 2014b) assessments of U.S. students (note that the 2012 U.S. average was actually no better than the 2009 U.S.
average, even though the 2009 U.S. average showed modest improvement over the 2006 U.S. average). Secondly, while other nations have taken the PISA results quite seriously, U.S. science educators and the public alike seem to have paid relatively little attention to these results (Bieber & Martens, 2011). Since this is the only dataset available with extensive consideration of aspects of science engagement in relationship to science achievement, and since that was a key component of my research focus, I was constrained in my choice to this particular dataset. The next science-focused PISA iteration in 2015 included an even more extensive array of aspects of science engagement in the student questionnaire (OECD, 2014a). These results are due to become available to researchers in December of 2016, and should thus provide an opportunity to address questions related to this dissertation in a fresher context. Hopefully, the U.S. will be able to mark some progress in science achievement in that assessment. Research opportunities for the future, particularly as afforded by the impending release of PISA 2015, include a thorough assessment of any potential changes in the relationships between the noted aspects of science engagement, science teaching strategies, and science achievement from the established PISA 2006 baseline from this dissertation. My study has provided considerable insights on the issue of engagement in relation to achievement and has opened doors for future research to confirm or balance key findings in this study. Given that enhancement of these aspects of science engagement has not been a high-level priority among U.S. science educators over the years since PISA 2006 was published, following up this dissertation (and any related publications) with confirmatory work from PISA 2015 could be even more powerful in bringing the
attention of the community of U.S. science educators and policy makers to the importance of U.S. students’ science engagement.

**Lack of racial/ethnic identification.** As discussed above in chapter two, merely asking minority groups to identify their status on an assessment instrument can adversely influence academic achievement (Steele & Aronson, 1995). Unfortunately, assessments which do not address questions such as racial/ethnic status may suffer from key limitations in terms of the development of appropriate policy strategies to provide remedies. In the context of this particular dissertation, racial/ethnic status was not collected as part of the student questionnaire; my suite of available student background variables included only gender, age, father’s SES, mother’s SES, immigration background, and language spoken at home. The inclusion of measures of race/ethnicity in research such as the multilevel modelling strategy employed in this dissertation would be very likely to provide better control over individual differences and thus a more refined assessment of the aspects of science engagement or perhaps a clearer picture of the influence of the aspects of science engagement on science achievement. In fact, I believe that the only important missing critical piece of student background in the current research may have been race/ethnicity (particularly in the U.S. context); my discussion of individual differences would be more inclusive and informative if I had been able to include a measure of race/ethnicity. Using language spoken at home and immigration status (the best proxies available in the dataset employed) were unfortunately not reliable measures for race/ethnicity.

**Low proportion of student-level variance accounted for by multilevel models with aspects of science engagement as outcome variables.** Even though being
responsible for huge proportions of variance at the student level, these multilevel models accounted for a range from 0% (in the case of instrumental motivation for science) to 9% (in the case of general value of science) of the student-level variance. Thus, the vast majority of the student-level variance remained unaccounted for in the multilevel models for aspects of science engagement as outcome variables. The lack of a good identifier for race/ethnicity likely might play some (limited) role, but these models strongly suggested that researchers need to explore far more student-level variables beyond student background. Furthermore, nearly all significant student background effects had small (or very small, i.e., < 0.20) effect sizes. These models therefore might also indicate a need for researchers to explore student-level variables with large predictive powers of science engagement.

**Lack of class-level measures.** A key advantage of the TIMSS datasets is that they address classrooms as an intermediate hierarchical level between students and schools. Of course, the multilevel modeling technique used in this dissertation is fully capable of handling a third level, and provides researchers using TIMSS data with the ability to draw inferences about the influence of the classroom level (in this context, science classrooms) on outcomes such as aspects of science engagement or science achievement. Classroom-level data could have amplified my results, particularly as related to science teaching strategies. As discussed above in my second policy recommendation, science teaching strategies involving a focus on applications or models and hand-on activities both positively influenced aspects of science engagement. The inclusion of classroom-level data could have provided me with the opportunity to not only study the science teaching strategies in more detail, it could have potentially given
me more insight into the utility of these science teaching strategies in classrooms populated by students who commonly show lower science engagement (females, low SES students, for example). Overall, the importance of having some measures at the classroom level is to gain a fuller understanding of science teaching practices so that the researcher would be in a better position to use science teaching strategies to promote science engagement.

Lack of inclusion of students’ epistemological beliefs and fixed/flexible self-understandings. Chen has been particularly active in research focused on students’ sense of how science knowledge is constructed, as well as their own capacities to grow and develop in their science capabilities (e.g., Chen & Pajares, 2010; Chen & Usher, 2013). The work of Chen with epistemological beliefs and fixed/flexible self-understandings especially relates to two aspects of science engagement among my top-level priority for focus by U.S. science educators, namely science self-efficacy and science self-concept. For example, some U.S. students with high science self-concept but a fixed self-understanding of their own capacity to grow and develop in science have shown lower science achievement results (Chen & Usher, 2013). Thus, the inclusion of measures of students’ epistemological and fixed/flexible beliefs may not only improve my ability to assess the relationships of the aspects of science engagement with science achievement, they may also open new and closely related windows of understanding for U.S. science educators. I am painfully aware that this dissertation has inadequately addressed both aspects of Chen’s work; this is related to the first limitation mentioned above (the age of the dataset). In the case of the science-focused iteration of PISA, such an assessment only occurs every nine years. Unfortunately, the lack of these measures
(student epistemologies and student fixed/flexible belief structures on their own possibilities for growth in science understanding) has prevented the current dissertation from even addressing these important emerging questions in a meaningful way. Fortunately, the next iteration of PISA has included these features in the student questionnaire (OECD, 2014a) and should thus provide a considerably enhanced opportunity to address these recently emerging concepts. One approach to a next round of research could be to treat epistemological beliefs and fixed/flexible beliefs as student background variables, and assess their influence on aspects of science engagement as outcome variables. Another approach could be to set them alongside aspects of science engagement as outcome measures, potentially influenced by student background and school characteristics (apart from the involvement of any aspects of science engagement). Both approaches have intellectual merits.

Conclusions

Set against the backdrop of stagnantly low science achievement in the U.S., the purpose of this dissertation was to investigate whether enhanced science engagement might improve science achievement. Research questions focused first on nine aspects of science engagement (science self-efficacy, science self-concept, enjoyment of science, general interest in learning science, instrumental motivation for science, future-oriented science motivation, general value of science, personal value of science, and science-related activities) as outcome variables, with student background and school characteristics as level-one and level-two measures, respectively, and focused second on science achievement per se with those same aspects of science engagement, along with student background measures, entered into level-one of multilevel models as control over
individual differences and school characteristics included in level-two of these models as control over school effects. For statistical, literature-related, and conceptual reasons, I concluded that the nine aspects of science engagement indeed represented different facets of the theoretical framework of science engagement drawn from the work of Fredricks et al. (2004). When the nine aspects of science engagement were treated as outcome variables, ensuing multilevel models produced different patterns of significance among student background and school characteristics. Females (seven times) and students of increased age (three times) were at a disadvantage in these models; meanwhile, increased father’s SES (six times) and the presence of an immigrant background (three times) advantaged students in some models. Appropriate selection of science teaching strategies was identified as a school climate measure which enhanced all nine aspects of science engagement; focus on models or applications and hands-on activities emerged as the most broadly influential (on aspects of science engagement) science teaching strategies. When science achievement was treated as the outcome variable, each of the nine aspects of science engagement was included in their respective models (by meeting the significance level of $p < .05$ for inclusion) and had positive influences on this key measure. Notably, eight of the nine aspects of science engagement had medium or large effect sizes (allowing 0.49 for enjoyment of science to be identified as a medium effect size). Student background measures which proved influential on science achievement were father’s SES, mother’s SES, and language spoken at home (English compared with all other home languages). Among school context variables (across all multilevel models with science achievement as the outcome variable), school size negatively impacted science achievement, while school-mean father’s SES showed a positive influence.
Among school climate measures, two science teaching strategies produced frequent (hands-on activities; positive) or consistent (investigations; negative) influences on science achievement. Of the nine aspects of science engagement evaluated in this study, all but one (future-oriented science motivation, effect size 0.16) showed medium or large effect sizes. Science self-efficacy, science self-concept, general value of science, and personal value of science all had large effect sizes (on science achievement). Meanwhile, enjoyment of science, general interest in learning science, instrumental motivation for science, and science-related activities all had medium effect sizes (on science achievement).

Two policy recommendations were made as a result of the conclusions above: i) U.S. educational policy-makers, school leaders, and instructors should focus on enhancing the eight identified aspects of science engagement which strongly influenced science achievement; ii) the same educational group should also emphasize science teaching strategies which focus on applications or models and involve hands-on activities. That eight of the nine aspects of science engagement significantly influenced science achievement with medium or large effect sizes is a truly remarkable result, and deserves to have the full attention of the U.S. science education community. The four aspects of science engagement which had large effect sizes (on science achievement), namely, science self-efficacy, science self-concept, general value of science, and personal value of science, were all identified as top level priorities for focus by U.S science educators. In addition, the four aspects of science engagement which had medium effect sizes (on science achievement), namely, enjoyment of science, general interest in learning science, instrumental motivation for science, and science-related activities, were
emphasized as second level priorities for enhancement by U.S. science educators. My second policy recommendation was based on the existence of significant variance in science engagement among schools. Two particular science teaching strategies—focus on applications or models and hands-on activities—were highly recommended for implementation in U.S. classrooms and schools because they significantly influenced aspects of science engagement (over-and-above the influences of student background and other school characteristics). Thus, U.S. science educators would seem wise to add (or augment) these science teaching strategies in their schools and classrooms.

I identified five key limitations of my research project, all related to the use of the PISA, 2006 dataset (OECD, 2007a). While this dataset provided me with a unique opportunity to investigate the relationships of aspects of science engagement to science achievement in a U.S. context, the age of the dataset (a full decade at this writing), the lack of racial/ethnic identifiers, the low proportion of student-level variance accounted for by multilevel models with aspects of science engagement as outcome variables, the lack of class-level measures, and the lack of inclusion of students’ epistemological beliefs and fixed/flexible beliefs about their capacities to grow and develop in their understandings of science have each limited the range of policy recommendations which can be justified by this work. While the next iteration of PISA (OECD, 2014a) will provide more contemporary results and will address the issue about epistemic and fixed/flexible belief structures of students, even that assessment may still lack a reliable measure of race/ethnicity appropriate to the U.S. condition.
### Appendix A

PISA Items Descriptive of Various Aspects of Science Engagement

<table>
<thead>
<tr>
<th>Science Self-efficacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>How easy do you think it would be for you to perform the following tasks on your own?</td>
</tr>
<tr>
<td>(a) Recognize the science question that underlies a newspaper report on a health issue. (b) Explain why earthquakes occur more frequently in some areas than in others. (c) Describe the role of antibiotics in the treatment of disease. (d) Identify the science question associated with the disposal of garbage. (e) Predict how changes to an environment will affect the survival of certain species. (f) Interpret the scientific information provided on the labelling of food items. (g) Discuss how new evidence can lead you to change your understanding about the possibility of life on Mars. (h) Identify the better of two possible explanations about the formation of acid rain. (1 = I could do this easily, 2 = I could do this with a bit of effort, 3 = I would struggle to do this on my own, 4 = I couldn’t do this).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science Self-concept</th>
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</thead>
<tbody>
<tr>
<td>How much do you agree with the statements below?</td>
</tr>
<tr>
<td>(a) Learning advanced science topics would be easy for me. (b) I can usually give good answers to test questions in science. (c) I learn science topics quickly. (d) Science is easy for me. (e) When I am being taught science, I can understand the concepts very well. (f) I can easily understand new ideas in science. (1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Enjoyment of Science</th>
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<tbody>
<tr>
<td>How much do you agree with the statements below?</td>
</tr>
<tr>
<td>(a) I generally have fun when I am learning science topics. (b) I like reading about science. (c) I am happy doing science problems. (d) I enjoy acquiring new knowledge in science. (e) I am interested in learning about science. (1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree).</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>General Interest in Science</th>
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<tbody>
<tr>
<td>How much interest do you have in learning about the following science topics?</td>
</tr>
<tr>
<td>(a) Topics in physics. (b) Topics in chemistry. (c) The biology of plants. (d) Human biology. (e) Topics in astronomy. (f) Topics in geology. (g) Ways scientists design experiments. (h) What is required for scientific explanations? (1 = high interest, 2 = medium interest, 3 = low interest, 4 = no interest).</td>
</tr>
</tbody>
</table>
Instrumental Motivation for Science

How much do you agree with the statements below?

(a) Making an effort in my science class is worth it because this will help me in the work I want to do later on. (b) What I learn in my science class is important for me because I need this for what I want to study later on. (c) I study science because I know it is useful for me. (d) Studying science is worthwhile for me because what I learn will improve my career prospects. (e) I will learn many things in my science class that will help me get a job. (1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree).

Future-oriented Science Motivation

How much do you agree with the statements below?

(a) I would like to work in a career involving science. (b) I would like to study science after high school. (c) I would like to spend my life doing advanced science. (d) I would like to work on science projects as an adult. (1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree).

General Value of Science

How much do you agree with the statements below?

(a) Advances in science and technology usually improve people’s living conditions. (b) Science is important for helping us to understand the natural world. (c) Science and technology usually help improve the economy. (d) Science is valuable to society. (e) Advances in science and technology usually bring social benefits. (1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree).

Personal Value of Science

How much do you agree with the statements below?

(a) Some concepts in science help me see how I relate to other people. (b) I will use science in many ways when I am an adult. (c) Science is very relevant to me. (d) I find that science helps me to understand the things around me. (e) When I leave school there will be many opportunities for me in science. (1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree).

Science-related Activities

How often do you do these things?

(a) Watch TV programs about science. (b) Borrow or buy books on science topics. (c) Visit web sites on science topics. (d) Listen to radio programs about advances in science. (e) Read science magazines or science articles in newspapers. (f) Attend a science club. (1 = very often, 2 = regularly, 3 = sometimes, 4 = never or hardly ever).

Sources: OECD (2007e, 2009)
Appendix B

PISA Items Descriptive of Various Dimensions of Science Teaching

Focus on Models or Applications

When learning science topics at school, how often do the following activities occur?

(a) The teacher explains how a science idea can be applied to a number of different phenomena (e.g. the movement of objects, substances with similar properties. (b) The teacher uses science to help students understand the world outside school. (c) The teacher clearly explains the relevance of science concepts to our lives. (d) The teacher uses examples of technological application to show how science is relevant to society. (1 = never or hardly at all, 2 = in some lessons, 3 = in most lessons, 4 = in all lessons)

Hands-on Activities

When learning science topics at school, how often do the following activities occur?

(a) Students spend time in the laboratory doing practical experiments. (b) Students are required to design how a science question could be investigated in a laboratory. (c) Students are asked to draw conclusions from an experiment they have conducted. (d) Students do experiments by following the instructions of the teacher. (1 = never or hardly at all, 2 = in some lessons, 3 = in most lessons, 4 = in all lessons).

Interaction

When learning science topics at school, how often do the following activities occur?

(a) Students are given opportunities to explain their own ideas. (b) The lessons involve students’ opinions about the topics. (c) There is a class debate or discussion. (d) Students have discussions about the topics. (1 = never or hardly at all, 2 = in some lessons, 3 = in most lessons, 4 = in all lessons).

Student Investigations

When learning science topics at school, how often do the following activities occur?

(a) Students are allowed to design their own experiments. (b) Students are given the chance to choose their own investigations. (c) Students are asked to do an investigation to test out their own ideas. (1 = never or hardly at all, 2 = in some lessons, 3 = in most lessons, 4 = in all lessons).

Sources: OECD (2007e, 2009)
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The author’s career has included creating positive learning environments for students in a wide array of courses and contexts, including plant and soil sciences, natural resources, food decision-making, and cultural anthropology, especially in the context of faculty-led Education Abroad courses. He has received several awards including the Ken Freedman Outstanding Faculty Advisor Award in 2009, the University of Kentucky Provost’s Award for Outstanding Teaching in 2009, the NACTA Teaching Fellow Award in 2009, the College of Agriculture Academy of Teaching Fellows in 2009, the Agronomic Resident Education Award from the American Society of Agronomy in 2002, and the Gamma Sigma Delta Master Teacher Award in the College of Agriculture in 1988. He served as Associate Editor (1990 to 1996) and as Editor (1997 to 2001) for the Journal of Natural Resources and Life Sciences Education. He has been involved in numerous departmental, college, university, and national committees and leadership roles related to life sciences education. He has published 12 refereed research articles, 1 book chapter, 16 short pieces, and 28 professional abstracts on instructional topics. His research with grain crops has resulted in an additional 19 refereed journal articles, 2 book chapters, 15 extension publications, and 84 professional abstracts.

Larry J. Grabau

April 27, 2016

Date

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