

Analysis and Contextualization of Large-Scale International Structure Assessment Tests in Germany and Taiwan

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To Philipp and in Memory of My Father Feng-Yien

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Abstract

As greater emphasis is placed on science education globally as a means of generating a high rate of return to national growth, there has been an increasing focus on regular monitoring of science performance and its antecedents. Although numerous studies have provided valuable indications that psychological characteristics and contextual factors are strongly and significantly related to children's achievement, relatively less research has focused on the subject area of science.

Guided by an ecological model and expectancy-value theory, this cross-national comparative study aims to gain a clearer understanding of how psychological and contextual factors benefit or hinder children's science outcomes by comparing the phenomena in two contrasting country contexts. Particular attention is given to teachers' and parents' expectations, children's motivational beliefs about learning science, student gender and family circumstances that might magnify or reduce the gap in science achievement between Germany and Taiwan, specifically. Using TIMSS 2019 data and applying several HLM analyses, this quantitative study empirically and comparatively examines the ways in which both student and school attributes are related to science achievement.

Results indicate that several affective and contextual characteristics, including students' attitudes toward science, family socio-economic status and parents' expectations, are related positively to student science achievement, both in Germany and Taiwan. No relationship, however, is found between teacher quality and science outcomes within each selected nation. Teachers' expectations and student gender are key predictors of science achievement only in Germany, and not in Taiwan. Further, teachers' and parents' expectations, respectively, impact the relationship between students' attitudes toward science and science achievement in Taiwan.

Distinct social and cultural backgrounds across countries result in the differences observed in the ways that children are expected to be, and are, motivated between Germany and Taiwan, which may explain the gap in science outcomes between nations. Findings suggest that strengthening the connections among children, parents and teachers would help build a trusty, respectful and encouraging learning climate and environment benefiting the quality of science education and improve science achievement for each child regardless of their social origins and cultural background.

Chapter 1: Introduction

1.1 Background

“If education is a preparation for life, it must prepare pupils for life in a world in which science and its applications in technology have key roles” Harlen and Qualter (2014, p. 9).

Education is implicated not only in a country’s economic and social development, but also in the personal development of its citizens. Schooling is commonly expected to be fair and to pave the way for social upward mobility, since a person’s education is closely linked to their life chances, income and well-being (Battle & Lewis, 2002). Also, the effectiveness and quality of education determine the competitiveness of a nation in an increasingly global economy. In particular, with the rapid development of scientific knowledge and the advent of new technology, the current Information Age and global marketplace have made science education more critical. Science, as an important human achievement, has a pervasive impact on virtually every aspect of modern life. It is a major area of human mental and practical activity and its applications play a vital part in national defence, policy, economy and welfare. In today’s technologically advanced world, economic access and full citizenship depend crucially on science literacy (Moses & Cobb, 2001), so that all members of society must have an understanding of the implications of science for individuals, communities and the world. Numerous researches have indicated that better educational outcomes, particularly in science, are considered integral to economic and social productivity (Hanushek & Wößmann, 2010; Schofer et al., 2000). This is especially salient in the current era in which the world economy is becoming increasingly integrated, as proficiency in science is deemed necessary to respond to technological and scientific changes. As Glenn (2000) pointed out, the future well-being of a country depends not just on how well the children are educated generally, but on how well they are educated in science specifically. Accordingly, science has become a main instructional focus in schools and an important subject to which many policymakers and education researchers have paid attention around the world. It is, therefore, important to have a clear understanding of what benefits or hinders one’s science educational attainment.

As greater emphasis is placed on science education globally as a means of generating a high rate of return to national growth, there has been an increasing focus on cross-national comparisons of science achievement. It is essential to investigate educational phenomena and schooling contexts with respect to science teaching and learning internationally. By exploring the relationship between science outcomes and potential predictors across nations, policymakers, researchers and educators can learn the advantageous or disadvantageous effect

of different contextual variables on student science achievement. In order to compare student achievement internationally, the Organisation for Economic Co-operation and Development (OECD) and the International Association for the Evaluation of Educational Achievement (IEA) conduct a number of international assessments and provide periodic data on comparisons of student academic achievement across nations. Many fruitful studies can be produced using these international large-scale databases and they are also essential in generating hypotheses about how contextual variables influence student achievement within and across nations (Raudenbush & Kim, 2002). As a result, cross-national comparative studies serve as a basis for countries to evaluate the effectiveness of their policy for improving science education.

1.2 Purpose of the Study

Children's developmental outcomes are the product of the interaction between children and their multiple environmental systems (Bronfenbrenner, 1979). These systems are nested hierarchically from proximal to distal and center on the child (Bronfenbrenner, 1979; Bronfenbrenner & Ceci, 1994). The proximal environment is one such as the family or school environment to which children are commonly exposed (Bronfenbrenner & Ceci, 1994). The distal environment consists of the broader social and cultural context, in which the proximal environment is embedded (Rogers et al., 2009; Tan & Goldberg, 2009). As the layer closest to the child, the family environment is widely recognized as one of the most significant important contributors to a child's success at school (Jacobs & Harvey, 2005; Rumberger, 1995; Swick & Duff, 1978). Nevertheless, the family environment differs depending on family background characteristics, such as family structure, socio-economic status (SES), parental involvement and parenting style. Among these family background variables, educational research has especially emphasized that both SES and parental involvement have significant positive, direct and indirect associations with students' success throughout school and in their eventual educational attainment (Jacobs & Harvey, 2005; Kaplan et al., 2001).

Parents are a continual, stable and efficacious force in their children's development (Trusty, 1998). As one of the important social agents, parents are seen as mediators of socialization progress (Phillipson & Phillipson, 2007), who hold goals and sociocultural values for their children to grow in various developmental aspects. Within the family environment, parents are motivated to interact with their sons and daughters in specific ways to internalize those goals and values (Wentzel, 1999) that subsequently form their children's academic affective characteristics. For example, parents may be involved in children's education by

expecting their children to perform well academically (Benner et al., 2016; Wilder, 2014). Such practice may provide specific direction for children with respect to their education (Hou & Leung, 2011) and offer them an education-oriented home environment, which, in turn, influences their educational outcomes. However, parents' educational expectations contribute to student achievement, depending on personal characteristics such as gender, race and internal motivations. In other words, parental expectations not only relate directly to children's achievement, but also indirectly, through children's affective characteristics across gender and ethnicity groups (Jacobs & Harvey, 2005; Neuenschwander et al., 2007; Rice et al., 2013; Yeung et al., 2010). Although these parental expectations are generally shaped by sociocultural model (Pomerantz et al., 2014; Taylor et al., 2004) and socio-economic status (SES) (Eccles, 1993; Trusty, 2000), some results indicated that parental expectations can reduce the negative effect of family background (Neuenschwander et al., 2007), such as low SES, single-parent families, uninvolved parents, etc., and contribute significantly to school achievement (Marjoribanks, 1977). In sum, parents play a critical role in forming their boys' and girls' motivation for learning science, and in structuring the educational life opportunities in science for them (Teachman, 1987; Useem, 1992; Williams, 1980) overall through their educational expectations that eventually determine their children's science achievement (Chen, 2005; Hooper et al., 2013; Phillipson & Phillipson, 2007; Urdan et al., 2007; Wang & Staver, 2001; Wilkins & Ma, 2003; Zhang, 2018). Accordingly, this study will examine parental expectations as an important psychological factor of the parental educational involvement practice that constructs a home environment influencing children's science achievement.

More and more recent studies have started to address the importance of non-cognitive factors in academic success (Al-Mutawah & Fateel, 2018). For example, students' affective characteristics such as attitudes toward learning are related to academic outcomes (Hidi et al., 2004; Lau & Roeser, 2002). The relationship is bidirectional, with attitudes and achievement mutually influencing each other (Martin et al., 2012). The interrelationships between these attitudinal affective variables such as self-confidence, values and interest seem to emerge as salient factors affecting science achievement (Martin et al., 2008; Singh et al., 2002). Developing positive attitudes toward science has thus become an important goal of the science curriculum in many countries (Martin et al., 2008), and each successive TIMSS assessment has shown a strong positive relationship between students' attitudes toward science and their science performance. Moreover, the motivation children have for learning science is commonly believed to be one of the possible explanations for the variation in science achievement

between boys and girls. Although many researchers have discussed the positive influence of students' motivational factors on academic performance, it is also important to explore further which factors have a critical impact on students' motivation for learning. According to previous results, interactions between students and teachers suggest that certain aspects of pedagogy may influence students' performance in the classroom. These influences include specifically teachers' expectations of students' academic potential and progress. Either consciously or unconsciously, teachers treat students differently based on the beliefs and assumptions they have about students that may subsequently affect students' cognitions and motivation. Similarly, children's academic development is influenced greatly by parent-child interactions in the family context. Within the home environment, parents are involved in children's education through their expectations (Benner et al., 2016; Wilder, 2014), which provide children with specific educational guidance and create an education-oriented environment that may further shape children's motivation for learning. In this study, students' attitudes toward science are considered a major variable in exploring the potential influence of children's psychological characteristics on their science outcomes. Further, the multiple relationships among the characteristics of students, family and teachers will also be investigated to uncover the formation of students' attitudes toward science, which may further interpret the gender disparity in science achievement.

Gender differences in science performance have been popularized since the late seventies and early 1980s. Many previous results suggested that boys were better than girls in science. Statements of male superiority in science also used to explain a lack of female workforce in the science, technology, engineering and mathematics (STEM) field. However, current results generally support a change, showing reduced gender gaps, especially in science. As indicated by the trends in international comparative studies, gender advantages in science performance aren't consistently achieved by males; that is, boys do not routinely outperform girls. Additionally, there are a number of countries in which females perform better than males in science. Not only does this suggest a shift in who has a science advantage, boys or girls, it also suggests that something other than biology can better explain the differences in science performances, or lack of, between the two groups. The heart of this study is gender equity. Through the investigation on family, school and sociocultural environments, this study may shed light on how these contextual factors, as well as personal characteristics of students, parents and teachers, influence science education. It may further offer a different explanation as to why there may or may not be gender differences in science outcomes between nations.

Further, economic changes globally over decades have enhanced the interest in how social position and economic resources affect families and the development of children. Socio-economic status (SES) is another important family contextual factor that is closely tied to home environment and dictates the quality of home life for children. The role of SES in determining student school performance has always been an area given considerable attention in science education. A great number of studies have established a positive empirical relationship between family SES and student science achievement. Researchers have further clarified that parents with higher SES are likely to invest their economic, educational and occupational capital in ways that facilitate the well-being of their children from childhood into the adult years. As an acquired characteristic, family SES may lead to clear inequities in educational resources, opportunities and achievement, which may nevertheless be further increased or decreased by other factors. In order to improve the socio-economic inequalities in education, this study builds on the existing research around family SES and achievement by exploring in more detail the conditions in schools, classrooms and families between nations that may reduce the negative effect of SES on student science achievement.

In terms of school context, teachers are one of the most important school-based resources in determining students' future academic success and lifetime outcomes (Chetty et al., 2014; Rivkin et al., 2005; Rockoff, 2004). Similarly, the important role of teachers has been emphasized as an essential element in structuring and facilitating student learning of science (Reiser et al., 2001; Thomas & Strunk, 2017). In particular, teachers' role in the early formation of children's attitudes toward science suggests that elementary science teachers wield heavy influence on boys' and girls' interests, expectations and achievement in science (Thomas & Strunk, 2017). A consistent finding in the literature suggests that specific characteristics referring to teacher quality are strongly related to teacher effectiveness, which in turn is associated with student achievement (Gerritsen et al., 2017). Therefore, high-quality science teachers are considered to play an essential role in promoting students' science achievement (Burroughs et al., 2019c; Harris & Sass, 2011; Zhang & Campbell, 2015). A well-qualified teacher is commonly identified as fully certified, experienced, possessing an advanced degree, demonstrating competence in both subject matter knowledge and subject-specific knowledge for teaching, participating continually in professional development activities and always feeling ready to teach. Further, raising the quality of teachers has been considered not only a crucial element in producing human capital, but also the best opportunity to reduce racial and socio-economic gaps in school achievement. Such findings have the potential to provide

insights into the importance of developing qualified teachers, who are better able to help students achieve in science, and provide direction for ongoing teacher training (Wayne & Youngs, 2003).

As suggested by previous literature mentioned above, students' ultimate success or failure in school is significantly affected by differing personal beliefs in education (Schullo & Alperson, 1998), for instance, parental expectations, students' attitude toward learning and teachers' expectations. As another important aspect of pedagogy, teachers' expectations of students' academic potential and progress have gained increasing attention with recent evidence of their potential influence on student achievement. Findings have indicated that teacher expectations play a significant role in determining how well and how much students learn (Bamburg, 1994). The process begins when teachers develop academic expectations of their students based on students' characteristics such as prior achievement, classroom behaviour, physical appearance and demographic information, namely gender, family SES and ethnicity. In addition to students' characteristics, the characteristics of teacher quality also influence the formation of teachers' expectations. These expectations influence how teachers interact with and treat their students differently. Through those interactions and that differential treatment, students interpret and respond to their teachers' actions in ways that confirm or internalize the expectations, which subsequently shapes their attitudes toward learning a particular subject, including science. Accordingly, students tend to live up or down to the expectations that teachers have for them. For instance, when teachers believe in students, students believe in themselves (Raffini, 1993). Conversely, when students are viewed as lacking in ability or motivation and are not expected to make significant progress, they tend to accept this perception of themselves. In other words, students' expectations and their motivation often mirror the expectations of their teachers, and the longer they are exposed to a teacher's expectations, the more they begin to view themselves in a manner consistent with the view held by that teacher (Rosenthal & Jacobson, 1968; Weinstein, 2002). In sum, this study will also pay special attention to another proximal environment, school or classroom context, to which children are also commonly exposed, by exploring the effect of two influential teachers' characteristics on student science achievement, to show how teacher quality and expectancy-related classroom practices determine children's learning context (Kuklinski & Weinstein, 2001; Weinstein, 2002) and students' psychological characteristics, which in turn strongly relate to their science performance (Cooper & Tom, 1984; Jussim & Harber, 2005; McKown & Weinstein, 2002; Rist, 1970).

Although the knowledge base for school learning depends mainly on proximal variables in home, classroom and school environments, these contexts are deeply influenced by the culture of a nation. This most distal environment consists of the broader social, educational, political and economic ideologies, in which all the other environments are embedded (Cala & Soriano, 2014). School and family are, for example, embedded in these complex and layered cultural contexts that influence the development of students and teachers. The philosophical principles and social beliefs in Germany and Taiwan have their roots in both countries' history and cultural values (Hackling et al., 2017). Both Germany and Taiwan have distinct sociocultural and historical factors that frame the ways in which education systems, schools and classrooms operate. Differences in these contextual factors help further explain the differences observed in the ways that science is taught and learned, which in turn may be associated with the achievement gap in science between Germany and Taiwan. The analysis of German and Taiwanese schooling structures and cultural contexts in this study thus draws attention to the important influences of social and philosophical values and the educational expectations of parents and teachers on student science achievement in both nations. Moreover, due to the social and cultural similarity between Taiwan and East Asian countries, as well as the likenesses of schooling structures and educational philosophy between Germany and most of the Western nations, Germany and Taiwan represent a wide range of geographic, contextual and educational diversity between the West and the East. Therefore, the results of this international comparison between Germany and Taiwan may be further generalized across those Eastern and Western countries, where similar education systems are in place and parallel pedagogic beliefs among the general public are commonly shared.

The goal of this study is to uncover psychological and contextual factors that may magnify or reduce the gap in science achievement between Germany and Taiwan. Accordingly, this study will examine the educational expectations of parents, teachers' expectations regarding student achievement and students' attitudes toward science as important psychological factors, as well as teacher quality and family SES, which construct a proximal environment influencing children's academic development. Further, the key role of students' characteristics such as gender and nationality that contribute to their science achievement is considered, as is the distal contextual factor of cultural background. To explain the issues discussed in this study, two theoretical frameworks provide insight when examining the influence of educational expectations of teachers and parents as well as students' attitudes toward learning science on science achievement gains. These theoretical frameworks include

Bronfenbrenner's ecological model (Bronfenbrenner & Morris, 2006) and the expectancy-value theory proposed by Eccles, Wigfield and their colleagues (Eccles et al., 1983; Eccles & Wigfield, 2002; Wigfield & Eccles, 2000). In addition, this study also investigates the role of gender to understand the way in which the psychological characteristics of teachers and the parental involvement practice may contribute to boys' and girls' science achievement. In order to conduct this quantitative and cross-national comparative study, the Trends in Mathematics and Science Study 2019 (TIMSS 2019) fourth-grade student and teacher data sets are used, and several HLM analyses are applied to explain the relationships between science achievement and the characteristics of student, family and teacher.

1.3 Research Questions

The overarching research question investigated in this study is as follows:

How do the characteristics of student, parent and teacher and contextual factors of school and home relate to teaching and learning science in Germany compared to Taiwan?

To answer this question, the following more specific questions are addressed:

RQ1: Is there a significant variability in the average fourth-grade student science achievement among schools in each selected country? How much of the variance in the fourth-grade student science achievement can be accounted for at the student and the school level?

RQ2: What are the relationships between the student predictors and science achievement in each selected country?

RQ3: Which factors are associated with science achievement at the school level and how are they associated in each selected country?

RQ4: Is there any significant interaction effect across the student level and the school level in each selected country?

1.4 Significance of the Study

Culture refers to the values, traditions and beliefs mediating the behaviours of a particular social group. It has been created within local and historical contexts and carried through and across generations. The interrelationship between schooling and society is strongly related and school organizations are believed to be a reflection of the society. Social and

cultural processes are therefore important to understanding the educational development of all students.

Although many studies address the importance of cognitive factors in academic success, ultimate success or failure is affected by non-cognitive factors as well (Al-Mutawah & Fateel, 2018). In educational psychology, culture has begun to be recognized as a major shaper of mental processes (Markus & Kitayama, 1991; Tyler et al., 2008). Psychological factors such as teachers' beliefs, parents' values and students' mindsets are directly and indirectly influenced by the sociocultural context of a nation. A focus on psychological variables is thus essential in this study, and students' motivation for learning and educational expectations of teachers and parents are considered important psychological predictors of students' science achievement.

Parents and teachers exert a considerable influence on children's academic growth, especially as young children are highly involved in interactions with their parents at home and with teachers in school. Parents and teachers are also seen as significant mediators of the socialization process, who filter cultural and psychological beliefs before passing them on to children. Educational research has further emphasized that parents and teachers play a critical role in promoting students' academic achievement overall through their educational expectations. However, the educational expectations of parents and teachers are not only related directly to students' achievement, but also indirectly, through personal affective characteristics such as academic attitudes across gender and ethnicity groups. Children's attitudes toward learning are internal motivations that are influenced by other social agents and determine their educational outcomes. Nonetheless, previous researches have fallen short in pursuing the psychological relationship among teachers, parents and students. Previous literature has documented widely but separately the crucial effects of parental expectations, teachers' expectations or children's affective characteristics, particularly their perceived academic competence, on educational achievement. Even so, few studies have explored the relationship among the educational expectations of parents and teachers as well as other students' internal motivational variables related to academic attitudes, such as values and interest. Further, little research has examined whether those expectations of parents and teachers are associated with children's academic achievement because they have positive effects on children's attitudes toward learning. Thus, the way in which parents and teachers help students succeed in school by promoting their internal motivation remains poorly understood. In addition, with respect to the specific subjects of academic achievement, the

research has largely focused on the outcomes of mathematics and reading, while little research has investigated science achievement.

Specifically in terms of the subject of science, a handful of international comparative studies have reported an achievement disparity based on gender and nationality. Scholars have observed that gender and ethnicity moderate the educational expectations of social agents (Dandy & Nettelbeck, 2002a, 2002b; Georgiou, 1999; Stevenson et al., 1990; Suizzo & Soon, 2006; Tenenbaum & Leaper, 2013). Nonetheless, few studies have explored further the way in which parents' and teachers' educational expectations may contribute to children's science achievement depending upon gender and race in diverse social and cultural contexts between different nations. Thus, there remains a gap in the understanding of the way in which parents' and teachers' educational expectations may contribute to children's science achievement depending upon individual and diverse family backgrounds. This study thus pays special attention to different sociocultural and psychological effects on science achievement. It will begin with the understanding of the similarities and differences in the culture and education systems between Germany and Taiwan, and then expand the previous findings to children's science achievement and emphasize the significant role of the educational expectations of parents and teachers in cultivating children's positive educational development during elementary school. Further, the key role of children's characteristics, including gender, nationality – German or Taiwanese – and their affective characteristics of attitudes toward science that contribute to their science achievement are considered, as are other contextual factors of family and school, such as family SES and teacher quality.

1.5 Overview of the Study

The objectives of this study are as follows:

1. to apply quantitative methods to large-scale databases
2. to examine the percentage of the school level in explaining the total students' science achievement variance within the country context
3. to investigate the relationship of student- and school-level factors associated with students' science achievement within the country context
4. to examine the interactive effects across the school and the student level within the country context
5. to investigate the relationships between students' science achievement and psychological factors (i.e., students' attitudes toward science, teachers'

expectations, parental expectations) at the macro level (i.e., national level) and at the micro level (i.e., student level)

In order to achieve these research objectives, this dissertation consists of several chapters. Chapter 2 contains a literature review to summarize important characteristics associated with students' science achievement. The theoretical framework is described in Chapter 3. Methods are presented in Chapter 4, including the models and statistical method used to examine the pathways of associations among the variables in this study and technical issues regarding international large-scale database analyses. Results are provided in Chapter 5, which answers the research questions proposed in Chapter 1. Finally, conclusions and future research directions are presented in Chapter 6.

Chapter 2: Literature Review

2.1 Introduction

Characteristics related to students' science achievement at different levels are summarized in this section. These characteristics are either at the student level or school level based on their location in either the TIMSS 2019 student background data set or teacher background data set. The following literature review consists of comparisons of the cultural contexts and education systems in Germany and Taiwan, as well as predictors of students, parents and teachers toward students' science achievement such as students' attitudes toward science, parental expectations, family socio-economic status, teachers' expectations regarding student achievement, teacher quality and gender issues.

2.2 The Importance of Country and School Contexts in Making International Comparisons

It is not only important to understand achievement gaps within a country, but also achievement differences between countries (Stevenson & Stigler, 1992). The international perspective on academic achievement is valuable in providing a unique angle to examine and improve national and global educational quality (Jiang, 2018; Mullis et al., 2016). Identifying the characteristics of high-achieving countries allows educators, researchers and policymakers to have a deeper understanding of country-level variables that may play a role in influencing educational achievement (Areepattamannil et al., 2015; Jiang, 2018). Yet it must be borne in mind that countries differ from one another in fundamental ways, and educational systems, which are the result of a series of decisions made in response to the specific goals, priorities, politics, resources and historical traditions of government representatives and citizens, reflect these differences (Kelly et al., 2020; Mullis et al., 2016).

In terms of academic performance in science, cross-national differences in science achievement have been studied since the 1960s (Husen, 1967; Wiersma, 1969). More recent international assessments showed a persistent achievement gap between countries over the past 20 years (Martin et al., 2016), and further indicated that the world's best science-performing countries were mainly a few East Asian nations such as Singapore, Korea, Japan, Hong Kong and Taiwan (OECD, 2016). Although Germany and Taiwan have a fine tradition of primary science education, in international science assessments, the sample of Taiwanese pupils has usually had a higher average scale score than the children in Germany (Hackling et al., 2017). For example, in the 2019 TIMSS study of 58 participating countries and six benchmarking

entities at the Grade 4 level, Taiwan was ranked fifth with an average scale score of 558 and Germany 28th (518). The mean scale score for both countries was significantly higher than the TIMSS scale centre point of 500. Given the sterling performance of Taiwanese students in science, it is crucial to examine the factors, particularly student- and school-level factors, contributing to variability in student performance (Hackling et al., 2017).

School is viewed as an entity, as a construction that is determined partly by sociocultural contexts as well as political conditions (Hubber & Ramseger, 2017). Within any country and educational community, these unseen and often unvoiced contextual and conditional factors appear in many forms, such as principles, philosophies and beliefs, and they are recognized as being influential (Pepin & Moon, 1999). Alexander (2000) explained that “life in schools and classrooms is an aspect of our wider society, not separate from it: a culture does not stop at the school gates”. Cogan et al. (2001) indicated that schooling is part of a nation’s culture and a curriculum can be viewed as a cultural artefact. The character of schooling, the philosophy and traditions of a particular education system, national curricula, teachers’ pedagogies and expectations of students, parents and teachers are informed and shaped by the social and cultural contexts in which they are all embedded (Hackling et al., 2017; LeTendre et al., 2001; Pepin & Moon, 1999). Hence, without taking a step back from the culture and society one is exposed to, it is difficult to gain a clear picture of one’s own approaches to learning. For instance, Germany and Taiwan may have the common goal of teaching and learning science, yet national and regional contexts and instructional situations can differ dramatically depending on their particular national characteristics, such as resources, culture, demographics and educational philosophies (Kelly et al., 2020). A number of theories and approaches have also been proposed to explain cross-national differences in academic achievement from a sociocultural perspective, which considers environmental influences such as family, school and cultural milieu on individuals’ beliefs, values, behaviours and ultimately academic achievement (Bronfenbrenner, 1994; Eccles, 1983; Else-Quest & Grabe, 2012; Jiang, 2018). Consequently, cross-national studies provide magnificent opportunities to explore how various national cultures guide the socialization of academic achievement in a larger international context (Jiang, 2018), as well as how governments establish and maintain the cultural socialization process through education in society (Chou & Ching, 2012b).

Therefore, science teaching and learning needs to be viewed as a cultural-contextual process influenced not only by the attributes of individuals, but also by the various levels of environment (Lewthwaite, 2006). The layered spheres of social and cultural influence

surrounding science teachers spread out from their own knowledge and beliefs to the expectations and support of their colleagues, the school philosophy and curriculum priorities, parental and community expectations, curriculum policies of the government and border social values (LeTendre et al., 2001; Lewthwaite, 2006). Similarly, cultures also influence student science achievement through a number of social and psychological constructs (Eccles, 1983; Gestsdottir et al., 2014; Wigfield & Eccles, 1992, 2000). According to expectancy-value theory, the beliefs of parents and teachers reflect the broad cultural milieu and these socializers play an active role in further shaping children's motivation, which in turn influences their educational choices, persistence, performance and career aspirations (Eccles, 2007; Wigfield & Eccles, 2000). Given that classrooms and schools are embedded in complex and layered sociocultural contexts and the achievements of students are understood as outcomes that emerge from interactions amongst layers of a complex system, any comparisons of science education across countries need to take account of the contextual factors that shape the nature and quality of teaching and learning in those countries (Hackling et al., 2017; Pepin & Moon, 1999). One of the important purposes of this study is thus to instil an appreciation of the uniqueness of the educational settings in Germany and Taiwan.

2.2.1 National Characteristics and Educational Contexts in Germany and Taiwan

Countries and education systems have their own unique national contexts in which their children live and learn. Understanding these contexts is important for interpreting and making sense of achievement results and for understanding more broadly the varied ways in which education works across nations (Kelly et al., 2020). This section, therefore, provides a framework to consider the broader sociocultural and contextual factors that shape the ways in which science education is transacted in Germany and Taiwan (Hackling et al., 2017). This framework identifies the demographics, education systems, social values, educational philosophy, parental involvement, science curriculum emphases and policies related to science education, including teacher education and professional development. This background information is considered an indispensable resource for policy and research in comparative education, which provides an important vehicle for comparing and contrasting the common and unique features of country contexts between nations (Kelly et al., 2020) that may further help explain differences in students' science achievement between Germany and Taiwan.

2.2.1.1 Country Profiles.

2.2.1.1.1 Germany.

The Federal Republic of Germany is Europe's most industrialized modern country and the continent's economic giant. With the fall of the Berlin Wall in 1989 and the collapse of the Soviet Union, East Germany was reunited with West Germany in 1990. Germany has an area of 357,021 sq. km and a population of 83 million. About one-fifth of the population have an immigrant background and 30% of students aged six to 20 are immigrants (Wendt et al., 2016). In Germany, the official language of administration and the judiciary is German, which is also the language of instruction in schools. Apart from German, Turkish and Russian are the most commonly spoken languages in families. The former West Germany was one of the founding countries of the European Union and the eurozone and Germany remains one of the economic powerhouses of Europe, contributing about a quarter of the eurozone's annual gross domestic product (Hackling et al., 2017). It is one of the leading countries in terms of exports. Following the reunification, the East German states adopted the West German political model and their education systems were also largely adjusted to West German systems (Döbert, 2007). Today, Germany comprises 16 federal states that are collectively referred to as "Länder". Each state has its own state constitution and is largely autonomous in regard to its internal organization and education system. Thus, the demographic, cultural and social heterogeneity in Germany differs among regions (Wendt et al., 2016).

2.2.1.1.2 Taiwan.

While Taiwan is currently officially known as the "Republic of China", in the international arena it was formerly named "Formosa", meaning "beautiful", by the Portuguese upon their arrival on the island in 1624 (Chou & Ching, 2012c). Before the Chinese and the Europeans arrived, the island was already home to Austronesian people, whose first settlements can be dated back to 15,000 years ago (Cheng & Jacob, 2002). Located off the south-eastern coast of mainland China, at the western edge of the Pacific Ocean, Taiwan is a small island with an area of 36,000 sq. km and a population of 23 million. Less than 2% of the population is indigenous and 98% are descendants of immigrants from mainland China (Hackling et al., 2017). The official language of Taiwan is Mandarin Chinese, but many people also speak dialects, and some elderly people can speak Japanese. In schools, Mandarin Chinese is the language of instruction, and courses are offered in Taiwanese dialects and foreign languages as well (Jen et al., 2016).

Taiwan has a history of colonization, having been ruled by the Dutch, China and Japan. After 50 years of Japanese colonial rule (1895–1945), Taiwan was restored to Chinese rule at the end of World War II and then began to reflect a new tendency to transform itself gradually from a colony to a society governed by self-rule (Hackling et al., 2017). The government of Taiwan is the unitary government that exercises control over Taiwan and other islands in the free area. According to the Constitution of the Republic of China, the President is the head of state. The central government consists of the Presidency and five authorities, which are the nation's supreme administrative, legislative, judicial, examination and control bodies. The local government in Taiwan is subdivided into special municipalities and provinces, which are further divided into counties and cities. Currently, Taiwan comprises six special municipalities, 13 counties and three cities. All these 22 local governments set up a bureau of education to deal with affairs of the city or county schools.

Taiwan has undergone many drastic political, social and economic changes during the past few decades (Chou & Ching, 2012c). Over the past 60 years, rising from island status to a presence on the global stage, Taiwan has dealt successfully with its difficult international situation and managed to achieve remarkable feats in terms of democratization, education, and economic construction. In particular, due to opening up the polity and society in the late 1980s and introducing a direct electoral system in the 1990s, Taiwan has established itself as a modern democracy (Chen, 2013). Also, through decades of hard work and robust economic management, Taiwan has created an economic miracle and transformed itself into an economic power that is a leading producer of high-tech goods, driven by sophisticated, capital- and technology-intensive industries and with a shift toward developing the service sectors. All of these changes are directly related to its unique historical past with China and Japan (Chou & Ching, 2012c). Chinese culture-related content was emphasized in the school curriculum, Japanese influences were purged and education played an important role in establishing a national identity and economic development (Hackling et al., 2017). Current political, social and economic educational reforms have helped place Taiwan in a position to better face global challenges and remain competitive in areas of education and economic development (Chou & Ching, 2012c).

2.2.1.2 Demographics.

Germany and Taiwan represent a wide range of geographic and cultural diversity. Factors such as population size and economic resources impact educational policies, and the

following table presents selected information about the demographic characteristics of Germany and Taiwan, primarily taken from the World Bank's DataBank (<http://databank.worldbank.org>), a repository of databases that include a range of economic, educational and human development indicators.

Table 2.1

Selected Characteristics of Germany and Taiwan

Country	Germany	Taiwan
Population Size (in Millions)	83.1	23.6
Area of Country (1,000 Square Kilometres)	358	36
Life Expectancy at Birth (Years)	81	80
Infant Mortality Rate (per 1,000 Live Births)	3	4
Gross National Income per Capita (in US Dollars)	48,520	25,501
Public Expenditure on Education (% of GDP)	5	3
Net Enrolment Ratio in Primary Education (% of relevant group)	90	97
Primary Pupil-Teacher Ratio	12	12

As the table shows, Germany and Taiwan vary widely in terms of population size and geographic area. With regard to indicators of health, both countries have life expectancies of 80 years or higher and infant mortality rates of four or lower out of 1,000 live births. Economic indicators, such as the data for gross national income per capita, reveal some degree of disparity in the economic resources available to these two nations, as well as differences in policies regarding the percentage of funds spent on education. Both countries have 90% or more of their primary students enrolled in school and the pupil-teacher ratio in primary education between Germany and Taiwan is very similar.

2.2.1.3 Structure of Schooling.

The transformation of the traditional educational administration system can be classified as a centralized system, a regional decentralization system or something in the middle (Chou & Ching, 2012b). The centralized system is usually set up by a unified national education system, which is in charge of regulations, policies, funding and the administration of national education standards, on behalf of the state, such as in France, the former Soviet

Union, China and so forth. In the regional decentralization system, the local governments of each province, state or municipality, or local school districts hold their own authority over educational management, which is commonly seen in the United States, Germany, Australia (Xie, 2007) and Switzerland (Yang, 2003).

2.2.1.3.1 The Federated Nature of Educational Policy and Practice in Germany.

Germany has never, except during the Third Reich, had a centralized and uniform education system (Auernheimer, 2005; Mitter, 1981). Constitutional federalism implies sovereignty for each federal state in all matters of culture, including its school education (Auernheimer, 2005; Hackling et al., 2017; Pepin & Moon, 1999; Wendt et al., 2020). For example, individual states regulate their own curricula and schedules, professional requirements, teacher recruitment and quality development in schools (Wendt et al., 2016). In order to achieve a certain amount of comparability between standards and recognition of certificates across the Federal Republic, the states have set up on a voluntary basis the Standing Conference of the Ministers of Education and Cultural Affairs (Ständige Konferenz der Kultusminister der Länder der Bundesrepublik Deutschland, referred to as the “KMK”) in the Federal Republic of Germany as a forum, which also meets regularly to coordinate the activities in the areas of education, science, research and culture (Wendt et al., 2016). Therefore, certain crucial aspects of the German school system are standardized across the country through interstate agreements (Wendt et al., 2020).

In terms of school curricula, these are decided by each state (Hackling et al., 2017). However, national educational standards (Bildungsstandards) for the core subjects, i.e. German language, mathematics, science and English, agreed upon by the KMK in 2003, have been influential in defining the content of curricula and serve as binding objectives for all states (Hackling et al., 2017; Wendt et al., 2016). Generally, the respective Ministries of Education and Cultural Affairs in each state publish the curricula as compulsory for teachers. The curricula are formulated in a general way, allowing teachers considerable freedom with regard to content, objectives and teaching methods. Teachers of a particular subject are encouraged to work together to reach consensus on the instructional methods and assessment criteria. The Institute for Educational Quality Improvement (IQB), established by the KMK, monitors and evaluates progress toward meeting these standards with regular national and international assessments of student competencies (Wendt et al., 2016).

2.2.1.3.1.1 Education System.

Compulsory schooling for all children begins in most states the year they turn the age of six, and it involves nine years of full-time schooling (Wendt et al., 2016). The majority of students in Germany are enrolled in state-sponsored public schools, which are free of charge and generally co-educational (Hackling et al., 2017; Wendt et al., 2016). Currently around 8.5% of students attend private schools, with many of these being denominational schools or reform-oriented schools, and the states accredit, supervise and, to a certain extent, subsidize all private schools (Hackling et al., 2017). Children with special needs have traditionally been sent to special schools. Since Germany has ratified the UN Convention on the Rights of Persons with Disabilities, efforts are currently being undertaken towards inclusion in regular schools (Hackling et al., 2017).

2.2.1.3.1.2 Early Childhood Education and Care.

Traditionally, pre-primary education in Germany basically includes children aged three to six (Wendt et al., 2016). Most children attend a kindergarten from the age of four (Hackling et al., 2017). In 2013, the federal government introduced the legal right to early childhood education and care in a daycare centre for children from the age of one (Hackling et al., 2017; Wendt et al., 2016). In 2004, the KMK agreed on a binding framework for basic education in pre-primary institutions, which specifies language, reading and writing skills, mathematics, natural science and information technology as explicit educational areas. While not compulsory, pre-primary education is a universal right in Germany that encourages children to take an active role in investigating their own physical and social environment, thus supporting an autonomous and independent self (Kultusportal Baden-Württemberg, 2011).

2.2.1.3.1.3 Primary Education.

Elementary school generally starts at the age of six and lasts for four years in all states except for Berlin and Brandenburg, where primary education lasts six years (Hackling et al., 2017; Wendt et al., 2020). Students must, in principle, attend their local primary schools. However, in some states, parents are allowed to participate in choosing a primary school (Wendt et al., 2016). The total instructional time, as well as subject-specific instructional time, differs between grades and across states (Wendt et al., 2016). Traditionally in Germany, instruction in primary schools is organized for half-day attendance with educational programmes ending by 1.30 pm at the latest (Hackling et al., 2017; Wendt et al., 2016).

Recently, all-day schooling has been promoted by the state nationwide, partly to meet the demands of working parents and partly with the aim of offering additional support for students from underprivileged backgrounds (Hackling et al., 2017). Throughout primary education, German, mathematics and integrated science (Sachunterricht, an integrated subject of natural and social sciences) are considered main subjects and are mandatory in all states. Art, music, physical education, foreign language instruction and, in most states, religious education are also taught throughout primary school (Wendt et al., 2016).

Teachers are completely free to choose their teaching methods and materials. Specialized publishing houses provide a selection of textbooks approved by the states (Hackling et al., 2017). Teachers often resort to photocopied worksheets. Parents are presented with a list of books needed for each topic at the beginning of every school year. The use of Internet resources has risen markedly over the past decade and interactive whiteboards (IWBs) are increasingly available (Drossel et al., 2012). In class, students are allowed to present extended and reasoned arguments and explanations to the class. In view of the heterogeneity of students in primary schools due to demographical changes, the integration of children with special needs and related educational reforms, such as multi-grade classes and inclusion, German primary teachers are increasingly expected to develop individualized learning opportunities adapted to the specific needs of each child. For example, in multi-grade classes students will often work on different tasks individually or in small groups (Hackling et al., 2017).

2.2.1.3.1.4 Secondary Education.

After successful completion of primary school, children typically are assigned to different secondary school tracks (Bildungsgaenge), namely in-depth general education (Gymnasialer Bildungsgang), extensive general education (Realschulbildungsgang) and basic general education (Hauptschulbildungsgang), in accordance with their prior achievement and predicted academic aptitude (Auernheimer, 2005; Hackling et al., 2017; Wendt et al., 2020). These three school forms of the tripartite system are taught separately and were originally associated with German knowledge traditions: the Gymnasium with the humanist tradition; the Hauptschule with naturalistic traditions; and the Realschule with neo-encyclopaedic traditions (Pepin & Moon, 1999).

Secondary education is divided into lower and upper secondary education. Lower secondary education generally begins at Grade 5 and ends at Grade 9 or 10 and is taught

separately either at specific types of secondary schools or in parallel within schools that offer two or three of the tracks (Wendt et al., 2020). After completing lower secondary schooling, most students are assigned to different types of upper secondary schooling depending on the qualifications they obtain at the end of their lower secondary education. One type is full-time general education, comprising Grade 11 to Grade 12 or 13, which leads to the General Higher Education Entrance Qualification (Allgemeine Hochschulreife, Abitur). Another type is full-time vocational education, which consists of a dual system of theoretical learning and vocational apprenticeship training at the workplace (Wendt et al., 2020). As in many European countries, attendance at highly academic schools is almost a prerequisite for university entrance in Germany (Marks et al., 2006), while vocational schooling mainly prepares students for entry to the workplace.

The peculiarities of the German secondary education system highlight the extremely high degree of social selection (Auernheimer, 2005). Currently around 40% of all children attend a Gymnasium for six or seven years, which leads to a higher education entrance qualification and on to university as well as other tertiary education (Hackling et al., 2017; Wendt et al., 2020). Some students also opt for comprehensive schools (Gesamtschule) (Hackling et al., 2017). About a quarter of all students attend the Realschule until Grade 10 and then continue with vocational training, upper secondary school or a vocationally oriented upper secondary school (Fachoberschule) that may qualify students for universities of applied sciences (Wendt et al., 2016). The remaining 10–15 % of students are sent to the Hauptschule and leave at the end of Grade 9 or 10 with considerably less chance of continuing their education or finding a job (Hackling et al., 2017; Wendt et al., 2016). Although these school types are the most common in secondary education, there are several other types in the various German states that may differ considerably from this structure (Wendt et al., 2016).

2.2.1.3.2 A Unified, Two-tiered Education System in Taiwan.

The education system in Taiwan used to be a highly centralized, top-down system and the Ministry of Education (MOE) played a major role in determining financing, policy and curricula. Triggered by democratization, the liberation of the educational system and the diversification of curricula have become the core issues in education reforms over the past 20 years (Hackling et al., 2017). To adapt to social changes, educational reforms have eventually led to an increase in the authority of local governments over educational policy (Jen et al., 2016). Today, the administration of education in Taiwan is carried out in a unified, two-tiered

system that includes the MOE at the central level and bureaus of education at the local level (Jen et al., 2016, 2020). The current education system basically supports at least 22 years of study (Hackling et al., 2017). The total time that students spend in formal education varies but generally includes two years of pre-primary school, nine years of compulsory education, including six years of primary school (ages 7–12), and three years of junior high school, three years of senior high school or senior vocational school and four to seven years of college or university. After college or university, advanced education programmes leading to a master’s degree (one to four years) or a doctoral degree (two to seven years) are optional. At all levels of formal education, special education programmes are available to students with physical or mental disabilities (Jen et al., 2020).

2.2.1.3.2.1 Instruction in Primary Education.

In Taiwan, a school year consists of 200 school days, and students must attend school five days per week. School days include periods of subject area learning and alternative learning. In general, learning periods last 40 minutes in elementary school, and there are 25 periods of subject area learning per week for fourth-grade students. However, the curriculum development committee in each school may adjust the learning periods for each subject area, the duration of each period, and the number of weeks during a semester to align with curriculum implementation and student needs (Jen et al., 2016).

2.2.1.3.2.2 12-Year Basic Education.

A plan to implement a national education programme for 12 years has long been a topic of discussion and the expectation of many citizens in Taiwan (Chou & Ching, 2012a). Since 2014, the national 12-year basic education system has been fully implemented by the central government to include upper secondary school as part of basic education with the aim of alleviating exam pressure on secondary students and increasing the potential of Taiwan’s human capital resources to meet the demand in the twenty-first century (Chou & Ching, 2012b; Hackling et al., 2017). To initiate this programme, a new curriculum framework for Grades 1 to 12 was officially implemented in 2019 (Jen et al., 2020). Based on the principles of “exemption from entrance exams, free tuition and non-compulsory”, this policy serves as the inspiration for a new age of education reform in Taiwan (Chou & Ching, 2012a). To create an adaptive learning environment for the 12-Year National Education Programme, the Ministry of Education has further provided special education programmes for both students with

disabilities and gifted students (Jen et al., 2020). Starting from 2014, multi-track admission approaches to high school have been adopted (Hackling et al., 2017). The decades-old method of admitting junior high school students to senior high schools through annually held national joint entrance examinations, which determined students' access to higher-rated senior high schools and in consequence created great pressures for them (Chiu & Chen, 2012), is now no longer the only option. Supposedly, this new policy should ease the pressure on students and parents; however, due to the competitive nature of getting into prestigious senior high schools, students' discontent and parents' doubts about the effectiveness and fairness of the multi-track admission programme still remain high.

2.2.1.4 Values and Educational Philosophy.

2.2.1.4.1 The Ideal of Bildung Is Put into Practice in Germany.

The German education system is influenced by the idealist philosophy of Humboldt, who espoused the ideal of "Bildung" (Hackling et al., 2017). The term "Bildung" literally means "formation", but also "education" and "cultivation" (Gellert, 2001). This cultivating and drawing out of the intellectual and cultural development of an individual has remained a central tenet of German education. The German tradition emphasizes humanistic views, combined with naturalistic tendencies (Pepin & Moon, 1999). The concept of Bildung, the search for rational understanding of the order of the natural world, incorporates encyclopaedic rationalism as well as humanist moralism, which attempts to express the unity of academic knowledge and moral education. Therefore, the humanist rationale exists alongside a high respect for the study of science subjects. In the German sense, the naturalistic view combines child-focused approaches with work-orientated ones. The "wholeness" of education emphasizes the belief that educative experiences are not necessarily intellectual. Rather, every occupation has dignity and the work of every job should be carried out with maximum commitment and thoroughness (Pepin & Moon, 1999). Accordingly, like other Western nations, more importance is placed on education in German schools than on examinations themselves.

In the late nineteenth and early twentieth century, the German reform movement advocated a strongly child-oriented pedagogy and experimented with alternative forms of teaching and learning (Hackling et al., 2017). Democracy education is an essential part of the curriculum. The German education system is based in theory on meritocratic principles, i.e., children's chances of succeeding within the education system should depend on their personal

ability and not on their family background. Nonetheless, contrary to this ideal of equal chances, the results of international assessments have pointed to a particularly high correlation between family socio-economic status and school success (Baumert et al., 2003), and children with an immigrant background are particularly at risk of low educational attainment and are generally under-represented in higher education.

2.2.1.4.2 A Modern Reiteration of the Old Confucian Tradition in Taiwan.

Education is highly valued in Taiwanese society (Hackling et al., 2017). Not only is it a key measure of self-realization and social mobility, it is the foundation of national growth, and it is believed that the quality of education determines the competitiveness of Taiwan. Indeed, the success of its educational development over the last few decades has contributed substantially to Taiwan's vibrant political and economic development.

2.2.1.4.2.1 Confucian Culture.

Teachers' high expectations, parents' high expectations and competition between schools lead to Taiwan's success in international testing programmes (Chiu & Chen, 2012). These expectations have their roots in "three traditional power hierarchies present in Taiwanese culture: teacher-student, male-female and parent-child. To some extent, these hierarchies may have derived from the teachings on Confucius (551–479 BC) and the hierarchies have endured in modern Taiwanese society" (Baron & Chen, 2012). Like other East Asian societies, Taiwan's society has been very much influenced by Confucian values, such as local organizations, academic examination systems, saving habits, family systems and networks (Tu, 1995). Education has been regarded as a priority in Confucian culture, and study is interpreted as hard work, persistence, cultivation and rigidity (Yao, 2000; Zhou, 2000). Confucian morals, imparting knowledge and resolving doubts are the major responsibilities of teachers. Students pay great respect to teachers and are also attentive to books, which are regarded as beneficial and sacred (Hackling et al., 2017). Therefore, the study of books, reading and self-reflection are recommended learning strategies. However, this traditional Chinese valuing of "academic rationalism" has created a critical issue concerning test-driven and textbook-oriented pedagogical norms that many schools have maintained as part of their goal of pressing for the intellectual growth of students in academic courses (Ambussaidi & Yang, 2019; Chen, 2013). Consequently, Taiwanese society places much emphasis on credentials and the practice of taking examinations (Chou & Ching, 2012b).

2.2.1.4.2.2 Credentialism.

The imperial examination in ancient China (694–1895) had the functions of diminishing the effect of social and family origin on social mobility and enforcing the social control of the ruling class by identifying intellectuals for the governing class through public examinations (Chou & Ching, 2012b). Like other East Asian countries, Taiwan is also deeply influenced by this tradition, in which the examinations are expected to be fair and to pave the way for social upward mobility. It is thus commonly believed that graduating from a higher-ranked educational institute leads to a promising future (Tsai et al., 2015). For example, the Taiwanese high school and college entrance examination system played a role between the 1950s and 2000 as one of the major educational filters for tracking students into different types of schools according to their test results, which in turn led to different career opportunities (Ling, 2001).

However, this examination system in Taiwan has overwhelmingly dominated the education system for decades (Chou & Ching, 2012b). For cultural values as well as those of tradition, Taiwanese parents expect their children to have a successful career with high social status and a good salary in the hope that their children will take care of them in their retirement (Chou & Ching, 2012b; Hackling et al., 2017; Tsai et al., 2015). Therefore, they are eager to ensure children's academic success even in primary schooling. With this social norm of competitiveness, after school, students are often sent by their parents to additional private courses or talent classes to improve their school performance. Accordingly, approximately 10% of the entire family budget in general, in comparison to education expenses in many countries (in terms of funds, time or resource investment), is spent on children's preparation for examinations, which generates enormous pressure not only on the general family life, but also on teachers and students at the expense of teenagers' healthy body and soul (Cohen, 1988; Einhorn, 2005).

2.2.1.4.2.3 Social Gender Role.

A well-known issue in Asian societies and, of course, Taiwan is the practice of putting males first culturally and socially (Chou & Ching, 2012b). Male dominance is a traditional benchmark in Taiwan, where girls and women “without talent” traditionally always came second in a society in which priority was given to boys and men in the inheritance of family names and properties. Accordingly, in a traditional Taiwanese society, the burden of filial piety

rested squarely on the shoulder of the males of a family, with females being accepted by their husband's family and often required to live with, and care for, their in-laws (Tsai et al., 2015). For practical purposes, it was hence most economically efficient for Taiwanese parents to invest the greater share of their efforts in the education of their boys and to imbue sons with a sense of responsibility to care for their parents. Consequently, there used to be a trend that married couples tried every method in order to have a male child.

Notwithstanding its traditions and cultural history, Taiwanese society has become a more open-minded and industrialized state that values gender equity and the social welfare of the disadvantaged. In order to encourage the development of a modern society in Taiwan, the government has implemented several laws to promote more awareness of gender equity education via curricula, instruction, assessments and teaching training. As a result, in terms of educational achievement, the number of women enrolled at all levels of education, particularly in higher education, has grown over the past few years (Chou & Ching, 2012b). Further, the increased national gender equality is significantly associated with a reduced gender gap favouring boys in academic achievement, especially in mathematics (Guiso et al., 2008) and science. Though females in Taiwan still have a long way to go in the job market and political participation, the first female president, Tsai Ing-Wen, was elected and has served her terms since 2016. These examples all indicate that gender equity education has improved the status of women in Taiwan (Chou & Ching, 2012b).

2.2.1.4.2.4 Equity of Educational Opportunity.

The demand for a higher level of education in a society ultimately favours the most competent ones and usually those from a family with higher socio-economic status (Chou & Ching, 2012b). Blau and Duncan (1967) also indicated that there is a positive correlation between family backgrounds and educational opportunity. In Taiwan, as in any other Asian society, the higher the socio-economic status of the family, the higher the educational expectations. Unlike in Western societies, where cultural capital counts, in the Taiwanese context it is family educational resources and extra tutoring lessons that make the difference in the schooling process (Zhang & Huang, 1997). In terms of income distribution, Taiwan used to be considered a relatively equitable society and has been seen as being fair with regard to educational opportunity. Nevertheless, in comparison to Western developed societies, Taiwan shows similar trends in terms of a close tie between family background and academic

achievement. In other words, family background continues to be a major factor in determining Taiwanese children's educational opportunity.

2.2.1.5 Parental Involvement.

With schooling being compulsory and home-schooling explicitly forbidden, German parents are allocated substantial rights with regard to their children's schooling. As well as information rights they can also influence the development of schools, the choice of learning materials and the teaching methods of their children's school to some extent and they use their presence on school boards as well as local and state committees to represent their interests (Hackling et al., 2017). However, parents of high socio-economic status tend to be over-represented on school committees and are generally better informed about their rights than parents of low socio-economic status (Sacher, 2009). Further, parents' expectations are high, while trust in the German education system has decreased, particularly due to the mediocre performance of students in international assessments, as the rising numbers of students enrolled at private schools suggest (Weiß, 2011).

Recognizing the importance of effective involvement and management with regard to pertinent government as well as parent expectations, most schools in Taiwan work closely with local government and the community to incorporate various resources to strengthen their instructional environments for learning (Hackling et al., 2017). Taiwanese parents have a legal right to participate in school affairs and to cooperate with teachers to improve their children's education. They are often engaged in school activities such as school festivals, safety and security, environmental maintenance and a variety of volunteer work. In terms of science education, parents with a professional career in science are vigorously involved in supporting science teaching and learning, as well as extended activities like science fairs (Hackling et al., 2017).

2.2.1.6 Teacher Education and Professional Development.

The specific education routes to becoming a teacher vary across countries, and even within countries there can be multiple paths to achieving that goal (Kelly et al., 2020). Both Germany and Taiwan currently require teacher candidates with a university degree or higher as well as a supervised practicum. Following this they are expected to pass a qualifying examination. Recognizing the need for teachers' ongoing learning and growth, a number of countries have instituted programmes or initiatives that recognize teachers as professionals and

incentivize them to engage in sustained professional development and growth and raise their stature in the profession (Kelly et al., 2020). Similarly, both Germany and Taiwan also provide in-service professional development to teachers, with the aim of continuing to develop and strengthen teachers' skill sets.

The individual states in Germany regulate teacher education, although a resolution agreed on by the KMK guarantees recognition of university examinations for the teaching profession in the different states. In 2004, the KMK issued national teacher education standards specifying key requirements and general competencies as well as subject-specific competencies (Wendt et al., 2016). Prospective teachers have to complete a three-year bachelor's degree comprising discipline studies plus education studies, and then a master's programme in education, which often lasts for one year for primary teachers and two years for secondary teachers. Students are required to take courses in general educational theory and in their chosen subjects. Subsequently, they have to complete 18 months of in-service training through an internship and pass another final exam (Hackling et al., 2017). German teachers are mostly employed as civil servants and enjoy a positive image in society (Ricken, 2007). Primary teachers are required to teach 28 45-minute lessons per week. Further, to ensure ongoing professional development, teachers are required to participate regularly in training and development. In-service training focuses on keeping teachers up to date in the subjects they teach and the teaching methods they use, as well as in the broader fields of psychology and sociology of education (Wendt et al., 2020).

In 1994, the Teacher Education Law replaced the Normal Education Act in Taiwan. Since then, the teacher cultivation policy has changed from one that trains teachers in a planned manner with graduates assigned to designated schools to one that selects individuals through diverse channels with some having to pay for their normal education (Hackling et al., 2017). The highly controlled system of teachers' colleges training primary teachers and normal universities training high school teachers has been deregulated. All colleges and universities with an education department or a teacher education centre are able to establish their own teacher preparation programmes from kindergarten to senior high school levels and offer postgraduate educational credit (Jen et al., 2016). Further, these teacher education institutions are also responsible for providing in-service training and guidance for local education practitioners. This system, however, has created a large oversupply of trained teachers (Chen, 2013; Jen et al., 2016). Pre-service primary teacher education includes compulsory education concentration courses including both pedagogical and pedagogical subject-specific courses in

three or four areas, and a six-month practicum (Jen et al., 2016). In order to guarantee a good quality of education, Taiwanese teachers in public primary schools are offered reasonable working conditions (Hackling et al., 2017). Their salaries are higher than the average per capita income in Taiwan and they have pensions after retirement. From this point of view, the social status of teachers is relatively high in Taiwan. According to a survey conducted by the Ministry of Education, more than 35% of primary teachers have a master's degree and the average teaching experience for primary school teachers is 12.37 years (Hackling et al., 2017). Moreover, teachers are encouraged to participate in workshops and communities for professional development and plenty of these opportunities are provided by schools, teacher education institutions and local education bureaus (Jen et al., 2020).

2.2.1.7 The Science Education Context.

There is widespread appreciation across countries of the need to strengthen science education and boost students' preparation for, and interest in, careers in science, technology, engineering and mathematics (STEM, in German, MINT) fields. Some efforts focus on coordinating and harnessing support from across government, provide a framework for action or link universities and schools to promote STEM education. Many countries have programmes aimed at giving students opportunities to develop their STEM skills and grow their interest in science through national competitions, enrichment programmes, camps and celebratory events (Kelly et al., 2020).

Over the last decade, a number of educational reforms have been implemented in all German federal states, with an emphasis on science teaching in primary schools (Hackling et al., 2017). Due to the results of international assessments as well as the need for a more widespread general scientific literacy, science education in Germany has received renewed interest in recent years (Möller et al., 2012). The KMK has further emphasized the importance of STEM education for the German economy, particularly in view of the acute shortage of high-skilled labour in technical and science-related fields. A resolution was therefore issued in 2009 recommending the enhancement of STEM education, which is especially essential in helping citizens to make informed decisions in a world increasingly influenced by scientific and technological innovations. In recent years, there have been efforts to increase the amount and quality of science instruction in Germany from early science in kindergarten to science education in primary and secondary school (Kultusministerkonferenz, 2011). A number of national and regional initiatives are also designed to encourage students to pursue careers in

STEM that aim to support the development of new products, innovative training and continuing education services to meet the increasing demand for highly skilled workers in Germany (Kelly et al., 2020). As well as formal education, science presently also enjoys increased popularity in general. Since the 1970s, basic science topics have been part of the subject called Sachunterricht (literally translated: “teaching things”) in German primary schools (Möller et al., 2012; Ramseger & Romain, 2017). Sachunterricht is an interdisciplinary subject that is designed to give young children a general introduction to different aspects of life deemed culturally important. This subject covers contents from the areas of natural science and social science, such as biology, chemistry, physics, technology, geography, history, economics and politics (Wendt et al., 2020). Given the broad spread of topics, Sachunterricht is generally taught by the home classroom teacher, who also teaches most other subjects (Wendt et al., 2016).

Pressed by various civil education groups urging for educational changes, there have been serious reform efforts since 2002 aimed at improving science education and related policies in Taiwan (Hackling et al., 2017) that subsequently have had a major impact on science education in the last decade (Jen et al., 2020). Since then, greater emphasis has been given to science teaching at primary level and the science curriculum has moved from a national need to societal and personal needs; from standards to guidelines; from a national version of textbooks to multiple versions of textbooks; from elite education to general disciplines; from a content orientation to cultivating competencies; from centralization to decentralization; and from an academic rationalism approach to a personal and social relevance approach (Chiu, 2007). In recent years, a dramatically decreasing birth rate and changing economic structure in Taiwan have caused another new wave of education reform. The 12-Year National Education Programme aims to cultivate students’ science literacy through revisions to the old curriculum. Echoing this new programme, the local education bureaus are building demonstrating centres for students to explore careers related to science and technology. The new curriculum guidelines for science and technology for Grades 1–12 are also implemented nationwide, and most schools, at least in cities, are well equipped with laboratories and sophisticated ICT resources (Ramseger & Romain, 2017). In General, science is taught by specialist teachers at most primary schools, and the need to enhance the interest and self-confidence of Taiwanese pupils in learning science has been highlighted (Jen et al., 2016, 2020). Thus, science has been regarded as an important learning area, and Taiwanese students are also aware of the great

value of learning science due to their competitive learning environment and parental expectations.

2.2.1.7.1 Science Curriculum at the Primary Level.

There are no nationwide standards defined for science at the primary school level in Germany (Hackling et al., 2017; Wendt et al., 2020). However, the Society for Didactics of Sachunterricht (Gesellschaft für Didaktik des Sachunterrichts, in short, “GDSU”) has issued a Perspectives Framework, which contains goals and competencies for teaching Sachunterricht from different perspectives (GDSU, 2013) and has been used as a guideline for the curricula in most states. The framework follows a constructivist approach to learning and emphasizes a child-centred approach. It is further organized according to five perspectives, namely social science, natural science, geography, history and technology. Ideally, students should be encouraged to engage with a given phenomenon of interest and consider it from all the above perspectives (Hackling et al., 2017).

In Taiwan, the Ministry of Education and the National Science Council (2003) collaboratively developed the White Paper for Science Education in 2003, which identified missions for science education for the short and long term, and suggested that, at the primary level, the standards of science education should be established so that the goals, curriculum, teaching, assessment and policies in relation to science teaching and learning would be consistent with each other. Further, science teachers’ professional knowledge and skills should be advanced (Chiu, 2007) and the goal of the science curriculum is to increase science literacy, which encompasses eight domains, namely knowledge of science and technology, science processing skills, development of processing intelligence, scientific applications, designing and producing, understanding the nature of science, understanding the development of science and technology, and development of scientific attitudes (Jen et al., 2020).

2.2.1.7.2 The Evaluation of Science Performance.

The results of examinations provide teachers with information about the strengths and weaknesses of their students, as well as subject-specific pedagogical and educational psychology recommendations to help them improve their instruction (Wendt et al., 2020). In Germany, examinations are based on curriculum requirements, as well as on the level of knowledge, abilities and skills students are expected to have acquired in class. In state-run schools, teachers monitor individual student progress continually throughout the academic

years (Wendt et al., 2016). Teachers are free to decide on the methods of assessment: for example, written, oral or practical forms of evaluation, such as portfolios, science logs and presentations in class (Hackling et al., 2017). In addition, teachers are required to develop special monitoring and feedback methods for low performers (Wendt et al., 2020). In general, individual student progress and development are documented and defined within performance standards for science on report cards, which are issued once or twice a year and may determine students' promotion to the next grade or entry to upper secondary school or university (Hackling et al., 2017; Wendt et al., 2020).

Taiwanese schooling is characterized by features that are historical artefacts of the formerly strongly centralized and government-controlled education system, namely the dependence on textbooks in teaching and the use of high-stakes assessment to determine academic progression (Hackling et al., 2017). Government-sanctioned textbooks define the curriculum to be covered and the content that will be assessed through testing. Given the extensive content in the curriculum and textbooks that will be tested, teachers need to cover all the content at a fast pace. Also, paper-and-pencil tests play a major role in evaluating students' science performance.

2.2.1.7.3 Instruction and Teaching Materials/Equipment for Science.

In Germany, primary teachers are expected to teach in all major subject areas including Sachunterricht, even if they have not received specialized training in science (Wendt et al., 2016). Nonetheless, more than half of pupils attend science classes taught by teachers with a university degree in science. In class, textbooks are available, but they are rarely used in Sachunterricht. Instead, many teachers resort to worksheets, while some may ask the students to produce a portfolio or keep a science logbook (Hackling et al., 2017). Laboratories are generally rare in primary schools; however, students are frequently asked to research something using the Internet or books (Wendt et al., 2016). Inquiry-based learning is generally encouraged and hands-on activities with everyday materials are often part of science lessons, which sometimes take place outdoors (Hackling et al., 2017). Teachers often use a more conversational instruction since they try to involve the whole class in a discussion. The emphasis is on understanding, which is part of Humboldt's humanistic ideals. For example, the mistakes made by students in homework or class exercises are typically discussed with the whole class in order to deepen their understanding (Pepin & Moon, 1999).

In Taiwan, about a quarter of primary teachers have a major in STEM-related fields, and science at primary schools is often taught by specialist science teachers (Hackling et al., 2017). In Grade 4, science constitutes approximately 10 to 15 % of the subject area learning periods (Jen et al., 2016). Basically, at least one science classroom or a science laboratory is set up for the purpose of science education at each primary school, and some schools even have a purpose-built “future classroom” equipped with advanced high-tech facilities. Most Taiwanese teachers rely on textbooks in their teaching (Chiu, 2007). All textbooks in science for elementary schools are allowed to be edited and published by private publishers, but they must be approved by the educational authority (Jen et al., 2016). The curriculum development committee in every school is able to select its own teaching materials from various versions of textbooks. The textbook market is, therefore, highly competitive, with publishers often providing teachers with comprehensive teaching materials, digital resources and sample test items.

2.2.2 Contextual Differences in Education between the East and the West

As one of the economic giants of the world, Germany is embedded in a Western sociocultural orientation where democracy and autonomy are highly valued (Grolnick & Ryan, 1989; Hofstede, 2001; Inglehart, 1997; Rimm-Kaufman & Wanless, 2012; Trommsdorff, 2009). Teachers and parents typically encourage children’s autonomy and separateness (Kagitcibasi, 1996). As such, Western cultures adhere to the model of independent agency and share an orientation towards independence (Trommsdorff, 2009). Also, the institutional natures of formal education in many European countries have much in common: for example, school systems are often tracked; in Germany as well, students are assigned to different school types officially on the basis of their prior performance (Pepin & Moon, 1999). These tracks prepare students for different educational and labour market destinations. In the West, there is the cultural view that every occupation has dignity and that the work of every occupation should be carried out with maximum commitment and thoroughness. Schools and teachers value highly the development of the individual as an educated and self-directed person who can contribute positively to society. Students’ thoughts, ideas and interests are particularly emphasized. Accordingly, in most Western nations, including Germany, more importance is placed on education in school than on an examination itself (Chou & Ching, 2012b).

Similarly, the cultural values and educational philosophy commonly shared by East Asian countries strongly impact Taiwanese economic growth, national examination systems,

instructional practice, curriculum structures and educational risks. The economically viable countries in this area, such as Japan, Korea, Singapore, Taiwan, Hong Kong and China, share the common culture of frugality, hard work, Confucian tradition, and strong kinship and family ties. These are the foundations of the spirit of industry, peacefulness and order that contributes to high economic incentive, respect for the elderly and authority, and the harmony of society (Chen, 2001). The other specific cultural characteristic of East Asian countries – the spiritual realm of man and society – makes the pursuit of educational and economic development, coupled with the goal of national growth, a priority. These factors all contribute to a strong ethical framework and are the basis for putting the needs of society before individual needs and rights. Accordingly, East Asian countries had a later start than their Western counterparts in regard to guaranteeing their people human rights, equity, privacy and security.

However, there has been a real educational challenge, the exam-oriented phenomenon, commonly faced by many nations in the Pacific Rim, which needs to be dealt with urgently as a sophisticated cultural issue of credentialism and a belief about education among the general public. The examination in Imperial China is used to serve as a crucial stable selection mechanism for maintaining the authoritarian regime and society throughout the history of China, Japan, Taiwan and Korea. The influence of this competitive examination system continues to take the lead over teaching and learning in these nations (Chou & Ching, 2012b). Credentials are highly regarded in these societies, where the school curriculum and classroom instruction have a high correlation with examinations. Thus, parents and teachers value highly students' academic success over other accomplishments at school, believing only higher exam scores can bring them to a promising future, which in turn leads to the fact that test results often carry more weight than actual teaching and learning. This overemphasis on examinations places enormous pressure on a student's life and attitude towards learning. Although many Asian countries, including Taiwan, have gone through a series of education reforms in the last decade, in the hope of solving the problem of excessive exam competition among schools, the outcome is still unclear.

In sum, each of the two countries studied has distinct cultural values, philosophical principles and historical factors that frame the ways in which education systems, schools and classrooms operate. Differences in these contextual factors help explain the differences in the ways that science is taught and learned. The analysis of German and Taiwanese education systems and cultural background draws attention to the important influences of social and philosophical values, education policies and curriculum frameworks, as well as the

expectations of schools, teachers and parents toward students' academic outcomes (Hackling et al., 2017). In addition, due to the social and cultural similarity between Taiwan and other East Asian countries, as well as the likenesses of schooling structures and educational philosophy between Germany and many other Western nations in Europe and North America, Germany and Taiwan represent a wide range of geographic, contextual and educational diversity between the West and the East. This study aims to provide a cross-national educational comparison considering the broader sociocultural factors that shape the ways in which teaching and learning are transacted in Germany and Taiwan. The result of this international comparison between Germany and Taiwan may be further generalized across those countries of the West and the East where similar education systems are in place and parallel pedagogic beliefs among the general public are commonly shared.

2.3 Gender Differences in Science Achievement

Global gender disparities in science remain not only a concern for educators but a serious issue for the scientific and technical community across many developed nations (OECD, 2011; Sugimoto et al., 2013). Despite the significant progress made in gender equality across other areas of society in recent decades, females are still under-represented in science, technology, engineering and mathematics (STEM)-related fields. The National Science Foundation (2011) also indicates that women in research remain a minority across most nations. For example, more males than females complete bachelor's and master's degrees in STEM fields, and disparities in the proportion of women completing doctoral degrees in STEM are unfortunately even greater. Two of the causal factors responsible for the under-representation of women in STEM fields are gender differences in science achievement during compulsory schooling (Else-Quest et al., 2010) and attitudes towards science (Nosek et al., 2002). These factors especially contribute to the decision-making processes that lead students to undertake or avoid further STEM-based studies and careers (Eccles, 2013; Jacobs et al., 2002; Simpkins et al., 2006). In addition, as noted across many developed nations, there is a shortage of science graduates to meet the needs of industry. Many national science boards, therefore, have identified increasing the number of females studying STEM-related degrees as an important intervention target (Handelsman et al., 2005). Moreover, educators and policymakers stress the importance of science literacy for full participation in today's society, which refers to a desirable social good (OECD, 2016). It is above all interesting to find out the extent to which gender differences in science achievement may vary across countries and cultures (Greenfield,

1997; Jiang, 2018), as increasing female participation in STEM fields is crucial for strengthening the STEM workforce (Beede et al., 2011). The relationship may be weakened or strengthened due to the broad culture milieu and socio-economic environment. Thus, pursuing the goal of gender equality of educational outcomes remains an issue of importance nowadays and further research into gender differences in science is viewed as a priority (Hyde, 2005; Marsh et al., 2008).

2.3.1 The Phenomenon and the Trend of Global Gender Differences in Science

Achievement

Persistent and significant cross-national differences in educational achievement and gender differences have been observed and well explored in the past several decades (Akpınar et al., 2009; Chiu, 2011; Else-Quest et al., 2010; Hong & Lin, 2011; Jiang, 2018; Liu et al., 2010; Martin et al., 2016; Mohammadpour, 2013; Tsai et al., 2015; Velayutham et al., 2012). Many contributions suggest that gender has a significant impact on school performance, regardless of the adopted educational system (Bijou & Liouaeddine, 2018). With regard to gender equity in scientific outcomes, which varies across nations, there are complex and mixed results from previous studies (Jiang, 2018). Some researchers suggested that boys have a general advantage in science over girls (Bijou & Liouaeddine, 2018; Nosek et al., 2009), while a number of studies revealed that there was no clear advantage to either gender when viewed from a global perspective (Else-Quest et al., 2010; Hyde et al., 2008; Liu et al., 2010). Nevertheless, the most recent empirical literature even reported that within several countries, there was a slight trend towards higher science achievement for females (Bijou & Liouaeddine, 2018; Marsh et al., 2008; Mohammadpour, 2013; Mullis et al., 2016; Reilly et al., 2019; Tsai et al., 2015).

According to the latest reports from international large-scale assessments, there are changes in gender differences in science achievement – a decrease in the difference favouring boys and the emergence of a difference favouring girls. In earlier waves of these international assessments, most countries showed a significant gender gap in science performance favouring males (Neuschmidt et al., 2008). A markedly different pattern of gender differences apparently emerged, with a large number of countries reporting a significant female advantage in science outcomes. This was sufficient to lead to an elimination of global gender disparities in science. Taking the report from 20 years of TIMSS as an example, it indicated that there has been a closing of the achievement gap in science among the participating countries over 20 years.

More than two decades ago, in the most comprehensive international assessment of student achievement at that time, TIMSS 1995 found that in science achievement the boys' advantage was pronounced, with boys outperforming girls in about half the countries at fourth grade and in almost all countries at eighth grade (Beaton et al., 1996; Martin et al., 1996). These findings of a large gender gap favouring boys in science seemed to confirm a solid and even enduring advantage for boys. Compared to 1995, these results from 2015 portray quite a different situation with regard to gender differences in science, with far fewer countries where boys had higher achievement and quite a few countries where girls had higher achievement. For instance, the boys outperformed the girls in 11 countries (about a quarter), which was considerably less than in 1995, and girls performed better than boys in 11 countries (about a quarter), which was a new development. This represented a considerable evolution since 1995 with regard to science education, and the 20-year trends for the countries that participated in both 1995 and 2015 generally support this change, showing a reduced gender gap in science (Mullis et al., 2016).

2.3.2 Gender Differences in Attitudes toward Science

Gender differences in science achievement play a role, in conjunction with affective factors such as attitudes. Gender differences in attitudes may be even more important than a gender gap in aptitude for explaining the gender inequality in STEM-related occupation (Else-Quest et al., 2013; Reilly et al., 2019; Smeding, 2012). Researchers have, therefore, begun to focus on the important role that science attitudes play in the decision to undertake further scientific study in high school, at college or university, and eventually in pursuing a STEM-based career (Eccles, 2007; Jansen & Stanat, 2015). Attitudes represent the emotional orientation of an individual toward the topic at hand (Brandwein et al., 1958). Within the framework of motivation, attitudes are conceptualized as an individual's characteristics interacting with a particular environment or subject (Bandura, 2001). According to Osborne et al. (2003), attitudes towards science are the feelings, beliefs and values held about an object that may be the enterprise of science, school science, the impact of science on society or scientists themselves. Thus, an individual's attitudes towards science reflect their personal response towards this subject (Narayan, 2011).

Average gender differences in science attitudes have been observed in many countries (Jones et al., 2000; OECD, 2007; Taskinen et al., 2015). Numerous cross-national comparisons and large-scale studies conducted in several nations have indicated that boys expressed greater

general interest in science and registered more positive affect towards science than girls did (Else-Quest et al., 2010; Jansen & Stanat, 2015; OECD, 2008; Reilly et al., 2019; Schreiner & Sjøberg, 2010). Not only did girls show a lower interest in science but they also had weaker science self-concepts (Beilock et al., 2010; Jacobs et al., 2002; Jansen & Stanat, 2015) and fewer extracurricular experiences related to science compared to boys (Erickson & Farkas, 1987; Rennie, 1987). This observation was also confirmed through the meta-analysis on student attitudes towards science conducted by Reilly et al. (2019). Velayutham et al. (2012) also applied multi-group analysis to examine gender differences and revealed that the influence of task value on self-regulation in science performance was only statistically significant for boys (Tsai et al., 2015). Hong and Lin (2011) further indicated that girls derived less enjoyment from learning science and that they were less positive in valuing science than boys (Thomson, 2008). In line with these previous studies, a number of results suggested that gender difference in science attitudes favours male students even though the two genders demonstrate equally high achievement (Jansen & Stanat, 2015; OECD, 2007; Reis & Park, 2001). Jiang (2018) further indicated that females performed even better than males in science when controlling for self-concept and valuing science, which suggests that females tended to have lower self-concept of science ability and they barely value science, compared to males. These findings showed that female students tended to underestimate their scientific abilities, and this lack of alignment between the achievement and motivation of girls in science is of concern.

However, gender differences in science attitudes favouring boys were not universal for all nations (Reilly et al., 2019). Although boys generally reported more positive attitudes towards science across cultures, the mean effect size was small. There was wide variation across countries, with some nations showing a small-to-medium effect size and other nations showing negligible differences or even a slight female advantage. For example, in some scientific fields, girls demonstrated the same interest, a similar self-concept and the same career aspirations as boys did (Greenfield, 1997; Krapp & Prenzel, 2011; Su & Rounds, 2015). Tsai et al. (2015) and Akpınar et al. (2009) even suggested that there were significant differences between female and male students in terms of positive affect towards science, with females expressing greater enjoyment of science learning. Additionally, with respect to self-efficacy beliefs in science ability, Greenfield (1997) reported that girls more than boys seemed convinced that females are as capable as males of studying science and becoming scientists, whether or not they particularly like the science courses they take. In other words, girls had no doubts about their ability to study science. The fact that these girls and boys expressed similar

positive science attitudes may directly impact on girls' willingness to participate actively in a science class and eventually to pursue science as a career (Greenfield, 1997).

Taken together, these mixed results show that gender differences in attitudes toward, and achievement in, science are not universal, but that important differences still remain for specific countries. Girls traditionally scored below boys in measures of science achievement and attitudes (Greenfield, 1997; Jones et al., 1992; Kahle & Lakes, 1983; Mullis et al., 1991; Reilly et al., 2019; Rennie et al., 1994; Shemesh, 1990; Simpson & Oliver, 1985, 1990; Smith, 1995; Weinburgh, 1995). These poor attitudes toward science have the potential to undermine girls' confidence in undertaking science tasks (Burkam et al., 1997; Reilly et al., 2019) and may also impair performance in science tests via the mechanism of stereotype threat (Spencer et al., 1999; Steele, 1997). Compared to boys, girls took fewer science courses in school and majored in STEM-related areas much less often (American Association of University Women, 1991, 1992a, 1992b, 1992c; Holmes, 1991; Matyas, 1984; Mullis et al., 1991; Otto, 1991; Peltz, 1990; Shemesh, 1990). However, this situation is now beginning to change (Catsambis, 1994; Saltzman, 1994). As demonstrated by the higher female self-efficacy beliefs than those among males in several countries, and educational interventions designed to improve girls' attitudes towards STEM, poorer female attitudes towards science are no longer inevitable and immutable (Luzzo et al., 1999; Reilly et al., 2019).

2.3.3 Evolutionary Psychological Perspective versus Sociocultural Perspective

Observation of gender differences in educational achievement raises the question of aetiology (Reilly et al., 2019). Unger (1979) cautioned that while gender can be a subject variable reflecting an internal trait, it can also be a stimulus variable that elicits a change in how one is perceived and treated. While there are still some researchers who argue for biological determinism of gender differences from an evolutionary psychological perspective (Geary, 2010; Kimura, 2000, 2002; Su et al., 2009) and categorize greater male variability at the population level as an immutable biological attribute (Feingold, 1992; Shields, 1982), most researchers endorse a biopsychosocial model of gender differences that stresses the importance of sociocultural factors in shaping differences between males and females (Halpern et al., 2007). If gender differences in science are the result of innate and immutable biological differences between males and females, then it follows that significant differences in quantitative reasoning will be found universally as claimed by the evolutionary and biological psychology perspectives (Geary, 2010; Kimura, 2000). However, large fluctuations in the magnitude and

direction of gender differences between nations would bolster evidence of the role that culture, educational policies and environmental factors play in the development of gender disparities, supporting sociocultural perspectives (Bijou & Liouaeddine, 2018; Bronfenbrenner, 1994; Eagly et al., 2000; Eccles, 1983; Jiang, 2018). The sociocultural perspective in particular considers environmental influences on individuals' behaviours, psychological development and educational achievement (Bronfenbrenner, 1994; Eccles, 1983). For example, boys and girls typically differ in early socialization experiences (Lytton & Romney, 1991; Martin & Ruble, 2004) and quickly acquire cultural stereotypes and norms concerning the sex typing of intellectual pursuits such as mathematics and science. Greenfield (1997) also suggested that the gender difference is due primarily to social variables such as continuous media exposure to male science figures in books, films, television commercials and newspaper. These gender-role stereotypes are acquired by children early in life and can thus become magnified under the influence of both home and school factors to impose limits on their academic and career choices later in life (Greenfield, 1997). Considerable cross-cultural variability is thus supportive of the role that environment and culture values play in the development – or suppression – of gender differences in STEM fields (Reilly et al., 2019).

2.3.4 Gender-specific Stereotypes

The broad cultural milieu of valuing science is strongly associated with gender stereotypes, which subsequently deeply affect people's beliefs about the gender role in STEM fields (Jiang, 2018). Moreover, national differences in the strength of gender-science stereotypes are correlated with national gender gaps in science scores (Nosek et al., 2009; Reilly et al., 2019). A large body of literature has demonstrated that parental and teacher beliefs about gender stereotypes in STEM affect children's subsequent STEM attitudes, achievement scores and even career choices later in life (Gunderson et al., 2012). In regard to gender biases of teachers with respect to instructional strategies in the science classroom, a number of studies have documented the fact that girls and boys experience qualitatively different educational situations and that these differences can have impacts that extend through college and into the professional years. For example, at the school level, it has been shown that in the science classroom boys receive more attention from teachers than girls do, as they are called upon more frequently to answer questions, given more freedom to call out answers and receive more detailed feedback on their work efforts (Jones & Wheatley, 1990; Kahle & Lakes, 1983; Sadker & Sadker, 1994; Tobin et al., 1990). Thus, from an early age, children show rigid gender typing

of science as inherently masculine, while reading and language are regarded as feminine. In addition, the limited number of female role models in science (Cheryan et al., 2011; Taskinen et al., 2015) also leads to stereotypes about scientists or science subjects at school that are detrimental to the development of motivation or career interest in girls. Due to gender-role intensification, in which conformity to gender-role stereotypes becomes increasingly important with age (Hill & Lynch, 1983), implicit gender stereotypes of children persist into adulthood and are found cross-culturally, even when such stereotypes are not explicitly endorsed (Nosek et al., 2002). It is therefore a particularly serious issue, as negative gender-specific stereotypes not only impair girls' performance in science through the mechanism of stereotype threat (Spencer et al., 1999; Steele, 1997) but also undermine their self-efficacy beliefs in science ability, decrease their valuation of science and weaken their commitment to science (Jiang, 2018; Kessels, 2015; Kessels & Hannover, 2007; Taskinen et al., 2015).

2.3.5 The Gender Invariance and Similarities Model

Global gender differences in science achievement have been reported in the literature across many decades (Hedges & Nowell, 1995; Maccoby & Jacklin, 1974; Reilly et al., 2019). Based on a meta-analysis covering 100 studies, Hyde et al. (1990) came to the conclusion that the extent of the difference in students' achievements between genders has decreased over the years. Small- to medium-sized gender differences in science achievement were found for most individual nations (from $d = -.60$ to $+ .26$), although the direction varied and there were no global gender differences overall (Reilly et al., 2019). However, researchers are divided over how significant these gender gaps may be, with some arguing that the gaps are small but still meaningful (Benbow et al., 2000; Gallagher & Kaufman, 2005; Reilly et al., 2015), and others that these gaps are so small, in fact, as to be characterized as negligible (Hyde et al., 2008; Spelke, 2005). In line with the trend that girls increasingly perform better than boys in a variety of educational outcomes, numerous findings for achievement in science are also largely consistent with the gender similarities and invariance hypothesis, as the differences between males and females are small (Jansen & Stanat, 2015). Contrary to the gender-stereotypic perspective, in Hyde's (2005) meta-analytic review of gender differences, she emphasized that males and females are more similar than different in most variables and therefore posited the gender similarities model, which predicts that gender differences in motivation and educational outcomes tend to be small and do not vary much with school subject, age or gender of the teacher (Marsh et al., 2008; Tsai et al., 2015). In line with the gender similarities hypothesis,

Marsh (1993) supports empirically and theoretically the invariance hypothesis. He identified a more long-term perspective based on nationally representative samples showing that gender differences favouring girls were becoming larger, whereas gender differences favouring boys were becoming smaller and the relations among variables considered in his research were largely invariant over gender (Marsh, 1989a, 1989b, 1993; Marsh et al., 2007; Marsh et al., 2005; Martin & Marsh, 2005). Overall, in contrast to predictions based on the gender-stereotypic model, more and more cross-international studies revealed that there was no clear advantage to either gender in science achievement when viewed from a global perspective (Else-Quest et al., 2010; Hyde et al., 2008; Liu et al., 2010). This trend of gender equality in science is the best support for the gender invariant and similarities model.

2.4 Students' Attitudes toward Science

2.4.1 Importance of Fostering Students' Attitudes toward Science

Numerous studies in education have investigated the factors that influence academic achievement. Most of these studies concentrate on cognitive factors, but many recent studies have started to address the importance of non-cognitive factors in academic success (Al-Mutawah & Fateel, 2018). Hannula et al. (2004) describe non-cognitive factors as “affective variables” such as emotions, attitudes, values, beliefs, motivation, anxiety and grit. Some of the previous results confirm that both socio-emotional and cognitive skills are valued equally in determining how successful a student could be in school and throughout life (Al-Mutawah & Fateel, 2018), while others emphasize that affective factors such as attitudes are even viewed as having more lasting power than the knowledge acquired by students in science (Kelly, 1986). Gardner (1975) also stated: “The first task and central purpose of science education is to awaken in the child the sense of the joy, the excitement and the intellectual power of science,” and: “A science education developer should care about developing the joy, excitement, satisfaction, wonder and delight since the development of cognitive abilities in science is not enough and the ultimate aims of science education should include attitudes as well.” The importance of attitudes toward science in science education has been recognized (Hooper et al., 2013; Koballa, 1995; Schibeci, 1984; Simpson et al., 1994), and there have been many attempts to measure student attitudes in understanding the relationship between students' attitudes toward science and student science performance, which is important to elucidate as it gives science educators better insight into understanding the learning paradigm (Akpınar et al., 2009;

Caldas & Bankston, 1997; Caleon & Subramaniam, 2008; Chang & Cheng, 2008; George, 2006; Hong & Lin, 2011; Kalender & Berberoglu, 2009; Martin et al., 2008; Mohammadpour, 2013; Myrberg & Rosén, 2006, 2008; Papanastasiou & Zembylas, 2004; Reid & Skryabina, 2002; Senler & Sungur, 2009; Tsai et al., 2015).

The importance of developing attitudes toward science is an issue that has received long-standing attention in science education (Barmby et al., 2008; Collette & Chiappetta, 1989; Heiss et al., 1950; Hurd, 1969; Juan et al., 2018; Mager, 1968; Osborne et al., 2003; Sund & Trowbridge, 1967; Thurber & Collette, 1964), and positive attitudes toward science have also been well explored across various cultures and populations. For example, Singh et al. (2002) examined the effects of motivation, attitudes and academic engagement on students' achievement in science and found that attitudes toward science had the second-largest effect on science learning, after the academic time factor. Simpson and Oliver (1985) also revealed that attitudes are not only a substantial predictor of science achievement, but they also explain a large portion of the variance in achievement. Moreover, according to social cognitive models, positive attitudes toward science are one of the important constructs that exert substantial influence on students' pursuit of science-related careers (Becker & Park, 2011; Correll, 2001; George, 2006; Maltese & Tai, 2011; Maple & Stage, 1991; Rice et al., 2013; Wang & Staver, 2001; Ware & Lee, 1988). Examining the effect of attitudes from the pre-college perspective, Wang (2013) revealed that an intent to major in STEM fields is subject to early attitudes toward science. Similarly, Sadler et al. (2012) stated that experiences and attitudes developed prior to high school contribute enormously to an interest in STEM careers. Specifically, Rice et al. (2013) showed that students with greater support from parents, teachers and peers were likely to have more positive attitudes toward science, and thus they reported greater competence in these subjects. Therefore, fostering students' positive attitudes toward science is the first step toward attracting more students to the STEM fields. Given that attitudes influence heavily not only students' science achievement (Cannon & Simpson, 1985; Ozel et al., 2013; Papanastasiou & Papanastasiou, 2004; Papanastasiou & Zembylas, 2002; Reynolds & Walberg, 1992) but also their decisions to pursue science-related careers (Abd Majid et al., 2018; Juan et al., 2018), reinforcing students' attitudes toward science has proved to be an important goal of the curriculum in many countries (Jansen & Stanat, 2015; Mullis et al., 2005).

2.4.2 Students' Attitudes toward Learning

Attitudes are one of the major determinants of human behaviour (Tsai et al., 2015) and can be defined as the feeling that a person possesses about an object (Morgan, 1991), based on her or his knowledge and belief about that object (Hong, 2010; Kind et al., 2007). This definition is based on the model that attitudes are composed of three components of cognition, affect and behaviour. Attitudes are a personal factor and refer to one's positive or negative judgement about a concrete subject (Abd Majid et al., 2018). Attitudes are determined by analysis of the information regarding the results of an action and by the evaluation of these results (Ajzen & Fishbein, 1977). Attitudes are a phenomenon that is attained through learning, which guides the behaviours of an individual and causes subjectivity (Abd Majid et al., 2018). Having positive attitudes toward a school subject would involve behaviours such as willingness to participate in a lesson, satisfaction from responding to questions and accepting one's own value (Ozcelik, 1998). In summary, attitudes represent the emotional orientation of an individual toward topics (Brandwein et al., 1958) and are conceptualized as an individual's characteristics interacting with a particular environment within the framework of motivation (Bandura, 2001).

In educational research, there are numerous theories on how student motivation and confidence can lead to engagement and academic achievement (Hooper et al., 2013). Previous studies also suggest that motivation and academic self-concept are closely related (Bong & Clark, 1999; Green et al., 2006; Pajares & Schunk, 2001). Students being motivated to learn is essential to academic success. The source of academic motivation and how it can be facilitated within the school, classroom and home has been a recurrent area of research (Bandura, 1997; Csikszentmihalyi, 1990; Deci & Ryan, 1985). Most of the literature separates motivation into two distinct constructs: intrinsic motivation and extrinsic motivation. Intrinsic motivation is an "energizer of behaviour" (Deci & Ryan, 1985). Students who are intrinsically motivated to learn science find the subject interesting and enjoyable (Deci & Ryan, 1985). Although it is theorized that all human beings are born with intrinsic motivation to learn, the home and school can either facilitate or suppress this inner motivation. Extrinsic motivation refers to the drive that comes from external rewards like praise, career success, money and other incentives. Students' perceived competence in a subject is linked to their subject-specific self-concept. If students believe that academic tasks are outside the scope of what can be completed successfully, they will view the exercise as futile, and this will affect their motivation. In contrast, if students are confident, they are more likely to persevere to successfully complete school tasks (Bandura, 1997). Self-concept is often estimated in relation to students' peers or

experiences and is a multidimensional construct; that is, students have distinct mathematics and science self-concepts (Marsh & Craven, 2006). Consequently, students' attitudes can be affected by their self-confidence in learning the subject as well as whether they find the subject enjoyable, place value on the subject, and think it is important in the present and for future career aspirations.

2.4.3 Definition of Attitudes toward Science

Students' attitudes toward science are the feelings, beliefs and values held about an object related to science, which may be the enterprise of science, science learning, the impact of science on society, science-related issues or scientists themselves (Caygill, 2008; Gardner, 1975; Osborne et al., 2003; Schibeci, 1983) and reflects their personal response toward the subject including general and enduring positive or negative feelings about science (Koballa & Crawley, 1985; Narayan, 2011). Attitudes offer an emotional evaluation of science and are significant determinants of behaviour in relation to the learning process (Juan et al., 2018). In addition, attitudes toward science are a reflection of the school climate and culture and highlight the social context in which learning takes place. Positive attitudes toward science are also considered to be a central component of an individual's scientific literacy (Juan et al., 2018). As such, understanding attitudes is important in the interpretation of achievement results. Thurstone (1931), Fishbein (1967) and Mueller (1986) favoured a unidimensional concept of attitudes, defining the construct as the affect for or against a psychological object. By accepting this unitary view, attitudes toward science can be defined as a general and enduring feeling about science, and a predisposition to learn science (Koballa & Crawley, 1985; Lovelace & Brickman, 2013). Similarly, George (2006) described attitudes toward science as positive or negative feelings about science, especially science classes. On the other hand, according to psychologists supporting a multidimensional conception, attitudes include a myriad of variables, such as judgements of personal ability in science, the value of science to the individual, the value of science to society, attitudes toward methods of teaching science and attitudes toward scientific interests (Germann, 1988). Hassan (2008) mentioned that attitudes toward science include several subconstructs: motivation for science, lack of anxiety, the usefulness of science, self-concept of ability, ability to make choices and career interest. In summary, studies advocating a multidimensional perspective have incorporated a range of subconstructs as follows: the value of science, self-esteem about science, motivation toward

science, enjoyment of science, attitudes of parents toward science and so forth (Osborne et al., 2003).

The purpose of evaluating attitudes is to gain an understanding of students' general appreciation of science (Caygill, 2008), and attitudes have been found to be an important factor that influences the way in which students cope with future life challenges (Kelly, 1986). The study of students' attitudes toward science is a prominent research area as evidenced in the science education literature (Huang et al., 2019). Pell and Jarvis (2001) emphasized that attitudes affect students' attention, consistency and behaviour in the classroom (Germann, 1988; Weinburgh, 1995). Students who perceive science positively are more likely to pursue this subject after compulsory education (Pell & Jarvis, 2001). The commitment and motivation to learn science can be influenced by whether students enjoy the subject, attach value to it in terms of its usefulness to both themselves and society, and by their science self-efficacy, which relates to their self-confidence in their ability to accomplish science-related tasks and activities (Juan et al., 2018). Therefore, many studies have incorporated science confidence, science enjoyment and the importance of science into the study of students' attitudes toward science.

2.4.3.1 Confidence in Science/Science Self-Concept.

A common conceptualization for ability-related beliefs is the domain-specific academic self-concept (Marsh & Martin, 2011; Wigfield & Eccles, 2000), which refers to individuals' perceptions of themselves in particular school subjects (Marsh, 1993; Shavelson & Bolus, 1982). Science self-concepts are subjective beliefs about one's abilities in science domains that are formed through accomplishment (or the lack thereof) or comparison with the accomplishments of significant others (Möller et al., 2009). Liou (2017) found that self-concept is the most predictive motivational belief for science achievement. In a study by Wang and Berlin (2010), science confidence was recognized as "the extent to which a student is confident and feels successful in science class" (p. 2418). Confidence was relevant to motivational belief governed by students' belief in their own ability (Bryan et al., 2011, p. 1050; Simpkins et al., 2015, p. 1387). Grades that students received in class, the success or failure toward science process and the evaluation of capabilities influenced students' motivation and confidence in the subject (Nolen & Haladyna, 1989, reported in Tuan et al., 2005, p. 642; Sheldrake, 2016). The founder of the theoretical underpinnings of self-efficacy, Albert Bandura, stated that self-efficacy relates to a personal expectation of one's ability to perform in order to reach specific goals (Juan et al., 2018). Self-efficacy relies, in part, on a person's beliefs in their ability to

exercise control over their own functioning, as well as events that have an impact on their lives. When applying this to education, the expectation, in turn, affects students' motivation, interest and performance in a subject. This relates to all subjects, including science. Efficacy beliefs therefore affect how much effort students apply to an activity, how long they will continue when encountering obstacles (persistence) and how resilient they are – which contributes to the alleviation of stress and promotes adaptation and the development of skills to cope with adversity and change – when confronted with difficult situations.

The sources of self-efficacy can be grouped into four categories: mastery experience, vicarious experience, social persuasion and physiological states. Mastery experience results from students engaging in science tasks, interpreting the outcomes of those tasks and using this interpretation to formulate beliefs about their capability and capacity to perform the tasks. Successful outcomes result in confidence. Vicarious experience stems from students observing peers performing tasks, and then evaluating their own prospect of success in similar tasks. Social persuasion refers to judgements that other people make regarding the capabilities of a student. Positive persuasions build stronger beliefs in capabilities and in the successful attainment of goals. Physiological states are experienced when engaging in science tasks: anxiety, stress or excitement. The degree of confidence is gauged by the physical state that is experienced while engaging in a task. In summary, encouraging a sense of self- concept is crucial for students to reach their potential, and the degrees of self-confidence have been found to be able to predict educational outcomes (Sheldrake, 2016).

2.4.3.2 Interest in and Enjoyment of Science.

Students' enjoyment of, or interest in, science has often been referred to as intrinsic motivation, as “doing something because it is inherently interesting or enjoyable” (Ryan & Deci, 2000, p. 55 as reported in Palmer, 2005, p. 1858). That means a person feels pleasure or has fun when she or he is doing something she or he is naturally passionate about. Oon and Subramaniam (2013) considered it an internal factor and that it is fairly stable over time (Krapp & Prenzel, 2011). In other words, interest-based learning is closely related to the enjoyment of learning. This implies that an individual is more involved in, and is more likely to take – or even generate – opportunities to engage in, corresponding activities (Köller et al., 2001; Ryan & Deci, 2000). Therefore, one's interest in science is highly predictive of one's relationship with science. Eccles (2007) also noted that interest in science is often related to perceived relevance to future careers. As one of the major factors of attitudes, the enjoyment of science

is a crucial construct of a student's learning motivation (Eccles, 2005) and has the largest effect on performance (Ozel et al., 2013).

2.4.3.3 Relevance of Learning Science/Importance or Value of Science.

George (2006) reported that positive attitudes toward science are associated with positive attitudes toward the utility of science. According to Brophy (1998), motivation to learn is “a tendency to find academic activities meaningful and worthwhile and to try to derive the intended academic benefits from them” (Cavas, 2011, p. 32). In PISA, the relevance of learning science was described as the “general value of science” (OECD, 2007) as in TIMSS 2011 and 2015 (Hooper et al., 2013; Michael et al., 2012). Values, i.e., ideas about what is good, right and desirable, are central features of culture and important sources of motivation (Schwartz, 1997). In particular, utility value refers to how a task fits into an individual's current and future plans. Expectancy-value theory explicates the relationship between individuals' values and their educational choices, achievement and persistence (Eccles, 1983; Wigfield & Eccles, 2000). Encouragement from teachers and their attention to the teaching of science can foster positive attitudes toward the utility of science (George, 2006). Previous empirical studies found that students are more likely to engage in, and perform better in, science activities when they attach high subjective value to science (Hulleman & Harackiewicz, 2009). International assessments have also showed that strong positive relationships between students' subjective valuation of science and their science achievement exist within country (Abu-Hilal et al., 2014; Mullis et al., 2012; Wang & Liou, 2017).

2.4.4 The Relationship between Attitudes toward Science and Science Achievement

The relationship between students' attitudes and achievement is a key issue for consideration permeating much of the literature (Akpınar et al., 2009; Dhindsa & Gilbert, 2003). A review of literature showed that students' attitudes play an important role in determining their achievement (Abu-Hilal et al., 2014; Chiu & Klassen, 2010; House, 1995; Osborne et al., 2003; Papanastasiou & Zembylas, 2004; Prokop et al., 2007; Safavian & Conley, 2016; Schibeci, 1984; Shrigley, 1990; Trautwein et al., 2012). Attitudes and achievement are positively related, so higher achievement leads to more positive attitudes and vice versa (Papanastasiou & Zembylas, 2002; Reilly et al., 2019; Taskinen et al., 2015). Even at different ability levels, the increase in achievement is attributed to increments in attitude scores. A direct effect of attitudes on performance has also been shown by Pajares and Miller (1994) and a

positive significant correlation between students' attitudes and academic achievement has been observed in the works of Zimmerman et al. (1992).

Likewise, numerous studies have revealed that attitude toward science is an important predictor of science performance, science learning (Abd Majid et al., 2018; Akpınar et al., 2009; Barnes et al., 2005; Beaton et al., 1996; Burtner, 2005; Caleon & Subramaniam, 2008; Cannon & Simpson, 1985; Jiang, 2018; Leibham et al., 2013; Mattern & Schau, 2002; Martin et al., 2000; Neathery, 1997; Osborne et al., 2003; Papanastasiou & Zembylas, 2004; Rennie & Punch, 1991; Senler & Sungur, 2009; Stevens & Atwood, 1978; Thomson, 2008; Weinburgh, 1995; Willson, 1983), individuals' career aspirations (Eccles, 2005; Lent et al., 2000) and choices made in scientific fields (Simpkins et al., 2006). In line with expectancy-value theory (Eccles, 1983), previous findings indicated that attitude toward science was positively and significantly correlated to science achievement, participation in advance science courses (Al-Mutawah & Fateel, 2018; Jiang, 2018; Juan et al., 2018; Simpson & Oliver, 1990) and commitment to science (Chiu, 2011; George, 2006; Reid & Skryabina, 2002). In other words, students who expressed more positive attitudes toward science were more likely to show higher academic achievements in science-related subjects than those with negative attitudes toward science (Al-Mutawah & Fateel, 2018; Martin et al., 2008; Mohammadpour, 2013; Mohammadpour et al., 2015).

2.4.5 Students' Attitudes toward Science with TIMSS Items

Gardner (1995) cited a good example of an instrument developed by Coulson (1992) for measuring attitudes toward science. This instrument consisted of four scales, namely assessing students' confidence in doing science, their enjoyment of science at school, their feelings about the personal usefulness of doing science and their evaluation of the appropriateness of science for young children (Al-Mutawah & Fateel, 2018). The commonly used constructs of students' attitudes toward science reported in the pertinent literature include self-confidence (self-efficacy self-concept), positive affect (enjoyment/interest/motivation) and valuing science using Likert scales (Huang et al., 2019). In the case of the TIMSS attitudes items, three factors were also constructed based on a multidimensional conception of attitudes to measure students' attitudes toward science, namely *Students Like Learning Science* (SLS), *Students Confident in Science* (SCS), and *Students Value Science* (SVS) (Martin et al., 2016; Mullis & Martin, 2017), which relate to intrinsic motivation, academic self-concept and extrinsic motivation, respectively, in the science domains. The SLS scale is intended to

measure a student's intrinsic motivation to learn science (Mullis & Martin, 2017). Deci and Ryan (1985) defined intrinsic motivation as the energizer of behaviour. Specifically, academic intrinsic motivation is an orientation toward learning challenging, difficult and novel tasks (Gottfried, 1990). The SCS scale is meant to measure a student's academic self-concept (Mullis & Martin, 2017). According to Bong and Skaalvik (2003), academic self-concept pertains to individuals' knowledge and perceptions about themselves with respect to an achievement situation. The SVS scale assesses a student's extrinsic motivation to learn science, which is driven by external rewards such as praise and career success (Mullis & Martin, 2017). Additionally, the results of TIMSS international studies have consistently demonstrated that the scores for *Students Like Learning Science*, *Students Confident in Science* and *Students Value Science* have a strong relationship with students' academic performance in science (Mullis & Martin, 2017).

2.4.6 Studies on the Attitudes toward Science among Elementary Students

Many studies have investigated attitudes toward science at secondary school level (Chai et al., 2010; Kalman, 2010; Khishfe & Lederman, 2007; Vázquez-Alonso et al., 2014), although the same research questions at elementary grade levels are only approached in a few studies. In fact, attitudes toward science are formed early in life (Juan et al., 2018; Toma et al., 2019). Children aged between 10 and 14 are in a critical period when interventions can successfully focus on shaping their attitudes and aspirations toward science careers (Tai et al., 2006). Therefore, the elementary stage appears to be decisive for developing positive attitudes toward science. Additionally, the need to investigate the attitudes of elementary school students toward science in greater depth has also been stressed, especially attitudinal constructs related to the enjoyment of science and science self-concept; two internal factors assist educational and occupational choices in science (Eccles, 2007) and that may awaken science-related career aspirations. Therefore, for the TIMSS context questionnaire, two scales were constructed to measure fourth-graders' attitudes toward science at elementary school level: positive affect and self-confidence (Martin et al., 2016).

2.4.7 Factors affecting Students' Attitudes toward Science

Research into students' attitudes toward science points to different variables influencing their development during early childhood (Toma et al., 2019). These variables are mainly gender, age and cultural backgrounds. With regard to gender, most studies show that

boys hold more positive attitudes and aspirations toward science than girls (Caleon & Subramaniam, 2008; Denessen et al., 2015; DeWitt & Archer, 2015; George, 2006; Hacieminoglu, 2016). More specifically, girls appear to experience lower levels of enjoyment when learning science (Denessen et al., 2015) and show greater indecision over their preferences for science-related careers (Caleon & Subramaniam, 2008). Despite boys having more positive attitudes toward science, the attitudes of boys in contrast to those of girls diminish as grade levels increase (George, 2006). Nevertheless, this gender effect remains a controversial question. For example, Akpınar et al. (2009) found more interest in science among girl participants, and some studies discovered an absence of this gender effect in the attitudes of elementary students toward science (Khishfe & BouJaoude, 2016; Said et al., 2016). Some studies have revealed consistent data on age and grade level, showing a declining pattern in attitudes toward science as the age and grade level of the students increases (Akpınar et al., 2009; Ali et al., 2013; Denessen et al., 2015; DeWitt & Archer, 2015; George, 2006; Said et al., 2016). Students belonging to different cultural groups hold differing perceptions of science, so ethnicity and cultural variables may appear to affect the formation of attitudes toward science. However, few studies have compared student attitudes toward science based on ethnicity or cultural background and existing results are contradictory. For example, DeWitt and Archer (2015) explored variables connected to science aspirations at elementary school level, finding that students from ethnic minority backgrounds appeared to show stronger aspirations for science careers. Khishfe and BouJaoude (2016) showed that students from developing countries appeared to have more positive attitudes toward science than those from developed countries.

However, children are subject to influence, with parents and teachers shaping a child's view of science through attitudes, classroom climate and the provision of science-positive experiences (Bhanot & Jovanovic, 2009; Crowley et al., 2001; Frome & Eccles, 1998; Jodl et al., 2001; Lynch, 2002). According to self-determination theory (Deci & Ryan, 1985), motivation can be facilitated by creating an environment that fosters a sense of relatedness, competence and autonomy. Teachers can nurture the development of student motivation in science by creating an environment that allows students to work autonomously, while providing support, guidance and positive feedback (Craven et al., 1991; O'Mara et al., 2006; Reeve, 2002; Ryan & Deci, 2000; Ziegler & Heller, 2000). A socially welcoming school environment or classroom can also provide a sense of relatedness by giving students a sense of belonging (Goodenow & Grady, 1993). Additionally, supportive teacher-student relationships

are also important for fostering science achievement (Cornelius-White, 2007; Marzano et al., 2003), as well as for increasing student participation and student motivation to learn science (Cornelius-White, 2007; Fauth et al., 2014). In summary, students' attitudes toward science are not only shaped by their own inherent characteristics, but also by various sociocultural factors (Reilly et al., 2019). For example, important factors such as parental influences, teacher affective support, expectations from teachers or parents, classroom environment and early experiences with science may also motivate students, shape their attitudes toward science (Hooper et al., 2013) and make school science more engaging for students. In other words, attitudes can indeed be improved, and therefore are worthy of future investigation (Tsai et al., 2015).

2.5 Parents' Educational Expectations

2.5.1 The Significant Role of Parents in Cultivating Children's Educational Development

The home has a major influence on children's upbringing and their success in school (Jacobs & Harvey, 2005; Rumberger, 1995; Swick & Duff, 1978). Many family background characteristics have strong associations with students' success throughout school and in their eventual educational and occupational attainment (Jacobs & Harvey, 2005; Kaplan et al., 2001). Such variables include family structure, socio-economic status, parental involvement and parenting style. Researchers and educators generally agree that parents are an efficacious force in children's development (Trusty, 1998). Parents are also seen as significant mediators of the socialization process within a cultural context (Phillipson & Phillipson, 2007); they filter cultural beliefs before passing them on to their children (Kozulin, 2003). In social-cognitive models, social agents such as parents, teachers and peers are hypothesized to influence students' academic and career outcomes (Rice et al., 2013). However, parents logically have the advantage – over peers, educators and other professionals – of serving as a continual, and perhaps more stable, education and career resource for their children over the life span (Farmer, 1985; Peterson et al., 1986; Sebald, 1989; Trusty, 1996, 1998). Further, educational research has emphasized that parents play a critical role in promoting their children's academic achievement (Chen, 2005; Hooper et al., 2013; Phillipson & Phillipson, 2007; Urdan et al., 2007; Wang & Staver, 2001; Wilkins & Ma, 2003; Zhang, 2018) and structuring the educational life opportunities of their children (Teachman, 1987; Useem, 1992; Williams, 1980) overall through their involvement in school education (Fan & Williams, 2010; Vukovic et al., 2013).

Parental involvement can be seen as part of a larger mediation structure whereby parents are able to transfer their own psychological beliefs, academic values, career aspirations and educational expectations to their children, affecting, in turn, children's perceptions and behaviour, including academic engagement, career aspirations, career decision-making, internal motivations to learn, psychosocial competence, academic success and adaptive school behaviour (Bandura, 1997; Baumrind, 1991; Chubb & Fertman, 1992; Epstein, 1991; Farmer, 1985; Fredricks & Eccles, 2002; Frome & Eccles, 1998; Gniewosz & Noack, 2012; Hong & Ho, 2005; Jodl et al., 2001; Keith et al., 1998; Ma, 2001; S. Palmer & Cochran, 1988; Paulson, 1994; Penick & Jepsen, 1992; Phillipson & Phillipson, 2007; Rice et al., 2013; Rimkute et al., 2012; Schunk & Pajares, 2002; Steinberg et al., 1992; Steinberg et al., 1991; Trusty, 1996; Wilkins & Ma, 2003; Wilson & Wilson, 1992; Zhang, 2018). Although many different forms of parental involvement practices have been found to be associated with children's academic growth (Froiland et al., 2013; Yamamoto & Holloway, 2010), considerable research has underscored that parents' educational expectations have demonstrated a greater ability to predict children's academic achievement than have others (Castro et al., 2015; Dandy & Nettelbeck, 2002a; Fan & Chen, 2001; Hong & Ho, 2005).

In summary, parents play an important role in encouraging their children's learning motivation, achievement and career aspirations by practising different forms of parental involvement (Taskinen et al., 2015). The literature has also documented widely the crucial roles of parental involvement practices, and has emphasized the effects of parents' educational expectations on academic achievement (Froiland et al., 2013; Phillipson & Phillipson, 2007; Yamamoto & Holloway, 2010; Zhang, 2018).

2.5.2 The Definition of Parents' Educational Expectations

Parents' educational expectations are defined as their anticipation of their children's educational progress and achievement (Froiland et al., 2013; Jacobs & Harvey, 2005). Parents' educational expectations can be understood as a general belief of how much education they expect their children to obtain (Wilder, 2014), and are associated closely with the subject area in which parents want their children to succeed (Ing, 2014; Phillipson, 2009). Although scholars have not defined explicitly what concrete educational expectations parents have for their children, the measurements that researchers use reflect two categories of parental expectations. One is their general expectation that their children will obtain an educational degree, and the other can be considered parents' subject-specific expectations, which are based

on the assessment of a child's academic abilities in a particular subject (Yamamoto & Holloway, 2010; Zhang, 2018).

Through the lens of a parental involvement framework (Grolnick & Slowiaczek, 1994) and academic socialization (Hill & Tyson, 2009; Taylor et al., 2004), parents' educational expectations are viewed as a type of interaction between parents and children in which parents set an academic goal for their children by showing their educational expectations of them (Hong & Ho, 2005; Jeynes, 2005; Zhang, 2018). When children receive and accept these messages, they are likely to reach their academic goals and demonstrate high achievement. Academic socialization can also be subject-specific (Hooper et al., 2013). For example, parents can convey the value they place on science, and this can be associated with achievement in science (Hong et al., 2010; Sun et al., 2012). Sometimes socialization can be subtle, conveyed by parents' occupations or hobbies (Dabney et al., 2013), but it can also be more direct, such as parents encouraging children to participate in particular extracurricular activities and taking children on field trips or museum visits (George & Kaplan, 1998). When children understand that their parents expect them to do well in science and to earn a college degree in the future, they are likely to perform as anticipated (Zhang, 2018).

2.5.3 The Strong Predictive Power of Parents' Educational Expectations

The strong impact that parental involvement has on the life chances and academic outcomes of children has been frequently documented. However, parents' educational expectations are considered a crucial component of parental involvement because of their stronger power to predict children's academic achievement compared to other forms (Benner et al., 2016; Wilder, 2014). Further, other results indicated that parents' educational expectations had both direct and indirect influence on children's academic achievement (Zhang, 2018). More specifically, parents' educational expectations are related directly to children's achievement, and indirectly through children's academic characteristics such as attitudes toward learning across gender and ethnicity groups (Jacobs & Harvey, 2005; Neuenschwander et al., 2007; Rice et al., 2013; Yeung et al., 2010). Thus, as a form of parent-child interactions, educational expectations of parents not only predict their children's academic performance, but also promote children's positive academic characteristics (Benner & Mistry, 2007; Catsambis, 2001), which in turn is also strongly associated with children's success in school (Ahmed et al., 2010; Bowen et al., 2012; Ferry et al., 2000; Frome & Eccles, 1998; Schwinger & Stiensmeier-Pelster, 2012; Trautwein et al., 2009).

The impact of parental expectations appears to have a cumulative effect over time (Kirk et al., 2011). A considerable number of studies have documented a general significant, positive and strong association between parents' educational expectations and children's achievement (Benner et al., 2016; Bowen et al., 2012; Carpenter II, 2008; Davis-Kean, 2005; Froiland & Davison, 2016; Gecas & Seff, 1990; Houtenville & Conway, 2008; Ing, 2014; Jacobs & Harvey, 2005; Kaplan et al., 2001; Mau, 1995; McCaslin & Murdock, 1991; Okagaki & Frensch, 1998; Vukovic et al., 2013) throughout their education from primary to high school (Ainley et al., 1991; Byrnes & Miller, 2007; Catsambis, 2001; Entwisle & Alexander, 1990; Froiland et al., 2013; Marjoribanks, 1987) and beyond (Conklin & Dailey, 1981), and for students from a wide range of racial and ethnic backgrounds (Chung & Walkey, 1989; Mickelson, 1990; Neuenschwander et al., 2007; Zhang, 2018), as well as other investigations conducted on the subjects of reading (Bowen et al., 2012; Davis-Kean, 2005; Houtenville & Conway, 2008), mathematics (Ing, 2014; Vukovic et al., 2013) and science (Froiland et al., 2013; Jacobs & Harvey, 2005; Keeves, 1972; Sun, 2015; Zhang, 2018), even after controlling for family background characteristics (Zhang, 2018) and prior performance in each of these subject areas (Neuenschwander et al., 2007).

Like the self-fulfilling prophecy finding associated with teachers' expectations (Dusek & Joseph, 1983; Eccles & Wigfield, 1985; Jussim & Harber, 2005), parents' educational expectations positively predicted their children's performance: greater parental educational expectations tended to be associated with greater children's academic achievement (Neuenschwander et al., 2007). In more specific terms, academically successful students had parents with high expectations for their long-term educational development and future careers who subsequently provided them with more opportunities regarding academic engagement in family practices, such as discussion of current events and participation in cultural activities (Jacobs & Harvey, 2005). Additionally, several results emphasized that these expectations of parents are strongly related to children's academic success, even in financially impoverished contexts (Brooks-Gunn et al., 2005; Davis-Kean et al., 2002; Furstenberg et al., 1999). In this case, parents' educational expectations serve as a mediator of social class effects on academic outcomes, which mediate the negative effect of other family background variables (Neuenschwander et al., 2007), such as socio-economic status, single-parent families, uninvolved parents, etc., and contribute significantly to school achievement (Marjoribanks, 1977).

Taken together, this literature appears to suggest that parents' educational expectations were found to contribute to children's academic achievement in different subjects throughout their education, including elementary (Vukovic et al., 2013), middle and high school (Ing, 2014), across families from diverse sociocultural backgrounds (Davis-Kean, 2005), even when influential factors were controlled (Davis-Kean, 2005; Ing, 2014). These prior findings thus provided a significant background for understanding the relation between parents' educational expectations and children's science achievement and suggested that education programmes are necessary to increase parents' awareness of the influential roles their positive educational expectations play in establishing children's positive attitudes toward learning science, which are crucial factors that determine their science achievement (Zhang, 2018).

2.5.4 Factors Affecting Parents' Educational Expectations

2.5.4.1 The Role of Family Socio-economic Status (SES).

Researchers have explored the relationship between parents' educational expectations and various family structure variables, such as socio-economic status (Seginer, 1983), single-parent families (Thompson et al., 1988) and cultural differences (Chen & Uttal, 1988). However, among these family background characteristics, socio-economic status was most strongly related to educational expectations of parents (Alexander et al., 1994; Davis-Kean, 2005; Davis-Kean et al., 2003; Teachman et al., 1997; Trusty, 1998). In this case, parents' educational expectations were seen as a mediator of the connection between socio-economic status and students' academic outcomes; that is, socio-economic status explained student achievements indirectly, mediated by parents' educational expectations (Eccles, 1993; Trusty, 2000).

In accordance with previous studies, students who came from low socio-economic status families had significantly less school success than students from families with high socio-economic status (Martini, 1995; Rätty et al., 2002; Walker et al., 1998). Parents in such settings reported lower educational expectations, less monitoring of children's schoolwork and less overall supervision of social activities compared to parents with high socio-economic status. On the other hand, parents with high socio-economic status were able to create environments that facilitated learning (Teachman, 1987; Williams, 1980) and involved themselves in their children's school experiences and environments (Steinberg, Lamborn, et al., 1992; Useem, 1992). This suggested that academically successful students were likely to

come from family environments where their parents had strong academic backgrounds, were from higher social classes and possessed powerful financial resources, and were likely to have high academic and career expectations for their children (Jacobs & Harvey, 2005).

The expectations of parents with high socio-economic status were organized by a dualistic differentiation between cognitive and practical abilities, while those of parents with low socio-economic status were organized by their assessments of the child's cognitive competence and school orientation (Räty et al., 2002). School success for most parents with high socio-economic status was about academic achievement, and the importance of their children achieving highly was instilled in them from a very young age, together with the expectation that they will attend university (Jacobs & Harvey, 2005). These parents expected the schools to provide the necessary means to achieve their educational goals for their children. In contrast, parents with low socio-economic status did not believe that school success for their children was all about high academic results and tertiary studies (Jacobs & Harvey, 2005). These parents were more interested in their children's personal growth and character building, so the schools needed to provide a curriculum to encompass these non-academic requirements.

In summary, research on family influence on academic outcomes by and large showed that children raised in families with a higher socio-economic status performed better academically (Brooks-Gunn & Duncan, 1997; Magnuson, 2003; Marjoribanks, 2002; Sirin, 2005; Yeung et al., 2002). As a mediator, the educational expectations of parents played a crucial role in this significant positive relationship between family socio-economic status and children's academic achievement. Parents with high socio-economic status tended to have higher expectations for their children's academic outcomes than parents with low socio-economic status. Further, they also had different expectations for their children's educational development and for schools. Most parents with high socio-economic status considered school success in terms of academic results (Bynner, 1972). For them, this meant schools need to provide a strong academic focus. On the other hand, parents with low socio-economic status supported the view of Gallup (1975, 1980), who believed school success is about students' character, self-esteem and social development. Their expectations for schools were for a less academic focus, with these parents reporting that their educational priorities concerned co-education, school location, high-quality facilities and surroundings (Jacobs & Harvey, 2005).

2.5.4.2 The Role of Gender and Ethnicity.

Specifically in terms of the subject of science, a handful of comparative studies has reported an achievement disparity based on children's gender (Freeman, 2004) and racial groups (Else-Quest et al., 2013). Scholars have observed that children's gender and ethnicity moderate the effects of parental involvement practices and children's academic characteristics, as well as those of parents' educational expectations on children's science achievement (Zhang, 2018).

With respect to the moderating role of gender, based on the perspective of the sociocultural contexts of parental academic socialization (Taylor et al., 2004), parents may have different educational goals, beliefs and behaviours that influence their children's academic development, depending on the child's gender. Thus, the associations between parents' educational expectations and children's science achievement would vary with gender (Zhang, 2018). For example, Tenenbaum and Leaper (2013) found that parents involved in their children's science learning differed according to the gender of their child. Their research has shown especially that, in contrast to girls, parents appeared to have a greater expectation that their boys will do well in science and have a science-related job in the future, and they engaged their sons in science activities to a greater extent and stimulated their boys' science thinking more frequently (Tenenbaum & Leaper, 2003). This phenomenon that parents place less emphasis on science for daughters is consistent with gender-role expectations, since most science-related careers are stereotyped as masculine. More specifically, this could be an indicator of gender-specific socialization processes in the family context, which leads parents to react more strongly and provide more encouragement to their sons through positive communication about science (Eccles & Alfeld, 2007). In this case, girls are likely to experience difficulty in developing internal motivations to learn science (Taskinen et al., 2015).

Although sex differences in students' classroom experiences have been documented for decades (Wilkinson & Marrett, 1985), there are no conclusive results with respect to gender differences in science achievement (Zhang, 2018). For example, Jones et al. (2000) claimed that male students appeared to outperform females in science in elementary and middle school. However, more recently, Voyer and Voyer (2014) indicated that girls had consistently better grades in all course content areas, including science. These findings contradict the popular stereotype that boys excel in maths and science (Halpern et al., 2011). Nevertheless, all these prior investigations pave the way for researchers to explore further which factors may contribute to gender differences in science achievement in the new era.

In addition to children's gender, based on the perspective of the sociocultural contexts of parental academic socialization as well (Taylor et al., 2004), numerous studies regarding achievement disparity based on race and ethnicity suggested that the cultural context plays an influential role in parents' efforts to facilitate their children's academic development. In more specific terms, different cultures value education in different ways (Salili et al., 2001). In this case, parents with diverse backgrounds may have different values, goals and practices intended to foster children's educational achievement based on their own cultural beliefs (Huntsinger & Jose, 2009; Steinberg et al., 1992). Consequently, these families from various cultural backgrounds may use different academic socialization strategies to communicate their education values and goals to their offspring (Rogoff, 2003; Salili et al., 2001; Suizzo & Soon, 2006). Thus, children from different racial and ethnic backgrounds may also have different attitudes toward learning (Chen, 2001).

In science specifically, scholars and the official reports by TIMSS have observed that Asian students outperformed other ethnic groups (Else-Quest et al., 2013; Patton & Royer, 2009) and demonstrated the highest academic achievement in science (Martin et al., 2016; Martin et al., 2012). Parents of Asian students are more likely to emphasize effort in academic success and set strict academic standards (Dandy & Nettelbeck, 2002a), while Caucasian parents tend to emphasize ability (Stevenson et al., 1990; Suizzo & Soon, 2006) and have flexible educational attitudes (Dandy & Nettelbeck, 2002a, 2002b; Georgiou, 1999). For instance, in most Chinese regions and in countries such as Hong Kong, Taiwan, Singapore and China, parents and family are the basis of the cultural development of children based on the Confucian heritage. This heritage maintains beliefs such as "no pain, no gain", "scolding builds character" and "failure is the result of laziness" (Watkins & Biggs, 2001). Chinese parents' educational expectations closely reflect traditional Chinese culture, including the importance attached to "family-related" and "academic-related" attributes (Phillipson & Phillipson, 2007; Shek & Chan, 1999). In contrast, families from a Western tradition have an educational culture based on Socratic ideologies (Tweed & Lehman, 2002) that, in general, recognizes independence and individualism as the basis of children's upbringing and education (Chen & Stevenson, 1995; Georgiou, 1999; Stevenson & Stigler, 1992). Compared to Chinese parents, Western parents are likely to have more flexible expectations, and appear to put less pressure on their children to achieve academically (Dandy & Nettelbeck, 2002a, 2002b; Georgiou, 1999).

Viewing the previous comparative studies as a whole, they have suggested that the gender and ethnicity of children moderate the effects of parental involvement practices and children's academic characteristics, as well as those of parents' educational expectations for children's science achievement. Therefore, successful educational programmes should also suggest optimal parental educational expectations that will help parents promote their children's motivation to learn science, which in turn will contribute to their academic achievement, while taking into consideration the child's gender and ethnicity.

2.6 Family Socio-economic status (SES)

Previous studies have found that family socio-economic status (SES) is one of the important family background factors dictating the quality of the educational environment for children (Barry, 2006) and influencing their academic development (Haveman & Wolfe, 1995; Marjoribanks, 1996; Repetti et al., 2002; Westphal et al., 2016). A wide variety of explanations for the significant association between family socio-economic status (SES) and the educational progress of children have been offered, ranging from the macro-political/sociological, focusing on the inequitable distribution of resources and opportunities across social class (Haveman & Wolfe, 1995; Klebanov et al., 1994), to the micro-psychological, focusing on daily interactions within the family that influence children's development of psychological and intellectual capital (Conger et al., 2002; Marjoribanks, 2002; Schneider & Coleman, 1993). As a critical family background characteristic, family socio-economic status (SES) leads to clear inequities in children's academic achievement (Akukwe & Schroeders, 2016; Caldas, 1993; Coleman et al., 1966; Rumberger & Willms, 1992). Such socio-economic inequalities in education have been demonstrated in countless studies, and many of the policy initiatives in education over the past half century have been aimed at reducing these inequalities. Especially in a democratic society, socio-economic inequalities in educational outcomes should be minimal. However, the processes by which socio-economic background influences educational inequality are not well understood. Therefore, this current study aims to find ways to improve socio-economic inequalities in education by understanding the relationship between various dimensions of socio-economic status (SES) and students' academic outcomes, and exploring further in more detail the influential characteristics of students, teachers and parents, which may mediate the negative effect of disadvantaged families with low socio-economic status (SES) on students' educational outcomes.

2.6.1 The Definition and Measurement of Socio-economic Status (SES)

Socio-economic status (SES) is a construct that captures various dimensions of social position, including prestige, power and economic well-being (Barry, 2006; Hoff et al., 2002; Liu et al., 2004; Oakes & Rossi, 2003), and an aggregate of sociological indicators as well, and thus an amalgam of conceptually different family background variables (Akukwe & Schroeders, 2016). During the past few decades, different models have been proposed for how to measure family SES and its relationship with students' academic achievement (Yang & Gustafsson, 2004). In status-attainment studies, family socio-economic status (SES) typically is assessed as a composite of family income, and parental education and occupation (Abbott et al., 2002; Blishen, 1968; Bradley & Corwyn, 2002; Broom et al., 1977; Conger & Donnellan, 2007; Elley & Irving, 1972; Hollingshead & Redlich, 1958; Jeynes, 2002; Jones, 1971; Oakes & Rossi, 2003; Warner et al., 1949). However, SES is not a unidimensional concept. It reflects different aspects of home characteristics, such as economic level, education and learning environment, and cultural and educative resources (Yang, 2003). These aspects of SES have different impacts on students' academic achievement (Bloom, 1964, 1976; Coleman, 1988; Gustafsson, 1998; Keeves, 1972; Yang & Gustafsson, 2004). Therefore, the conventional way of treating SES as a single entity may hide the effects of different dimensions of SES on students' academic achievement. The relation between SES and attainment may, therefore, not be estimated correctly. In other words, with respect to educational research, family SES should be taken as a multifaceted and complex system, interacting with other ecological systems (Yang & Gustafsson, 2004).

2.6.2 Multidimensionality of Socio-economic Status (SES)

Socio-economic status (SES) is considered a multidimensional construct (Sirin, 2005). Bourdieu (1986), for example, conceptualized the dimensions of family socio-economic background in terms of different forms of capital. Three aspects, namely material/economic capital (i.e., family economic status), social capital (i.e., family social connections and network) and cultural capital (i.e., family cultural and educational consumption), have been identified (Bloom, 1964, 1976; Keeves, 1972). Bourdieu (1986) further stressed how the possession of one form of capital may influence the chance of possessing other forms of capital, and how social hierarchies are transformed into academic hierarchies by modern educational systems (Bourdieu, 1973; Bourdieu & Passeron, 1977). The importance of different forms of capital in social reproduction has also been emphasized both theoretically and in empirical studies

(Bernstein, 1975; DiMaggio, 1982; DiMaggio & Mohr, 1985; Gustafsson, 1998; Kalmijn & Kraaykamp, 1996; Lareau, 1987; Mercy & Steelman, 1982; Teachman, 1987). In addition, these material and cultural resources as well as the social network of a family not only influence children's intellectual development during their school years and, in particular, during early childhood (Coleman, 1988; Wong, 1998), but also contribute to socio-economic inequalities in education (Yang & Gustafsson, 2004).

2.6.2.1 Material/Economic Resource.

A material resource focuses on its roles in terms of poverty, income and wealth (Marks et al., 2006). There is empirical evidence that income and wealth are related to student achievement and other educational outcomes (Alexander & Eckland, 1974, 1975; Jencks et al., 1972, 1979; Orr, 2003; Pong & Ju, 2000). Explanations emphasizing material resources contend that differential access to material resources generates differences in student performance. For example, wealthy families can “purchase” educational success for their children by sending them to expensive elite schools or paying for supplementary tutoring classes. In contrast, poor families may not even be able to afford basic educational resources, such as a student desk and textbooks.

2.6.2.2 Social Resource/Social Networks.

Social capital in the original sense of the term includes social relationships, especially membership of certain groups (e.g., family and peers) (Akukwe & Schroeders, 2016). It can broadly be defined as services and relationships that people utilize to sustain quality of life (Gibson & Bejinez, 2002; Kozoll et al., 2003; Salinas, 2013; Stanton-Salazar & Dornbusch, 1995). Portes (1998) distinguished three basic sources of social capital: social control, family support and benefits through extra-familial networks. In other words, the involvement of family (e.g., parental involvement) and other adults with schoolwork is considered part of the social resource in the environment surrounding children (Akukwe & Schroeders, 2016). It is generally agreed that close and high-quality relationships between students, parents, schools and the local community are desirable (Marks et al., 2006). For example, families with high social status are “better connected” in that they are more likely to know people who can effectively help their children's educational and labour market outcomes. However, McNeal (1999) indicated that the social relationships surrounding a student are important for behavioural outcomes such as

dropping out of school, but less important for cognitive outcomes, such as academic achievement.

2.6.2.3 Cultural Resource.

Intellectual pursuits are strongly related to the cultural resources and atmosphere at home (Yang & Gustafsson, 2004). The latent variable focuses on the cultural aspect of home background, which according to previous research is most significantly related to school achievement (e.g., Areepattamannil et al., 2015; Bloom, 1964, 1976; DiMaggio, 1982; DiMaggio & Mohr, 1985; Dumais, 2002; Keeves, 1972) and educational attainment, college attendance and college graduation (DiMaggio & Mohr, 1985; Wildhagen, 2009). In other words, cultural resources accounted for sizeable proportions of the effect of socio-economic background on students' educational performance. Thus, cultural differences between families with high and low cultural status are likely to reflect most of the inequalities in students' academic performance. Bourdieu's theory of cultural capital (1973, 1984) is the best-known theory that provides a cultural explanation for differences in educational outcomes. He argues that children from families with high cultural capital are advantaged since they have similar cultural understandings to those that underlie the education system, so are judged very favourably by the system's gatekeepers, such as teachers, schools and assessment authorities (Wildhagen, 2009).

The often-used term "cultural capital" (Bourdieu, 1973; Coleman et al., 1966; DiMaggio, 1982; Lareau, 1987) is expressed by educational credentials, linguistic ability, cultural knowledge and cultural possessions such as books, newspapers, periodicals, telephone, radio, musical instruments, sheet music, phonographic records, phonograph, works of art, etc. (Barone, 2006; Chapin, 1928; Sullivan, 2001; Wildhagen, 2009), or by specific cultural interests, behaviour and activities such as reading, visiting a museum and appreciating cultural goods (De Graaf et al., 2000; Katsillis & Rubinson, 1990; Tunmer et al., 2006). Focusing on parents rather than students, their participation in cultural activities affects a range of their children's educational outcomes (Crook, 1997; De Graaf, 1988; De Graaf et al., 2000). De Graaf et al. (1989) found that the cultural dimension of parents' occupational status also had a strong effect on their children's education. Nevertheless, additional analyses suggested that "the number of books in the home" is a more important component of cultural resources in regard to student achievement than other cultural possessions at home (Comber & Keeves, 1973; Keeves & Saha, 1992). A "literary" or "bookish" home environment is likely to be a

crude indicator of the intellectual environment of the home, and the extent to which parents participate in and value learning. Just as highly academic environments in schools enhance educational success, so do highly academic home environments. This explains why cultural resources are just as important in accounting for socio-economic inequalities in education outcomes (Marks et al., 2006).

In sum, family socio-economic status (SES) is the position that a family occupies with reference to the prevailing average standards of cultural resources, effective income, material possessions and participation in group activity of the community (Chapin, 1928). Several international comparative studies have confirmed that the ownership of a set of home possession items can be used to indicate the multifaceted feature of family SES (Yang, 2003). For a majority of the countries, two dimensions are identified at the individual level. One dimension clearly represents possessions related to academic and cultural activities (e.g., many books, newspapers, encyclopaedias, a piano, etc.), while the other represents the possession of economic and material resources at home (Bourdieu, 1986, 1989; Bourdieu & Passeron, 1977). This may also be due to the fact that the sociocultural context and economic situation vary across countries (Yang & Gustafsson, 2004). These possession items, together with parents' education and occupation, are commonly selected to measure family SES in numerous international large-scale studies (Areepattamannil et al., 2015; OECD, 2012; Perry & McConney, 2010; Sirin, 2005; Yang, 2003). With respect to studies using the TIMSS database in particular, the conventional way of measuring SES is to use a composite of parents' highest educational attainment, parents' highest occupational status and home possessions as a proxy.

2.6.3 Family Socio-economic Status (SES) as a Determinant of School Performance

The important role of family socio-economic status (SES) in determining student school performance has always been an area of considerable attention in the sociology of education since the mid-1960s (Battle, 1999, 1998; Battle & Lewis, 2002; Battle & Scott, 2000; Coleman, 1990; Coleman et al., 1966; Hedges & Nowell, 1999; Kalender & Berberoglu, 2009; Myrberg & Rosén, 2006, 2008; Okpala et al., 2001). A large body of research has established an empirical relationship between family socio-economic status (SES) and students' achievements (e.g., Baharudin & Tom, 1998; Barry, 2006; Coleman et al., 1966; Eamon, 2005; Hattie, 2009; Hochschild, 2003; Jencks et al., 1972; Jeynes, 2002; Keeves & Saha, 1997; Kim & Choi, 2008; Marjoribanks, 1979, 1996; Marks, 2006; McNeal, 2001; Noel & de Broucker, 2001; OECD, 2004; Okpala et al., 2001; Ream & Palardy, 2008; Seyfried, 1998; Sirin, 2005;

White, 1982; Yang, 2003; Yang & Gustafsson, 2004). The relationship is strong and positive; on average, the higher a student's family SES, the stronger his or her educational outcomes tend to be (Battle & Lewis, 2002; Caldas & Bankston, 1997; Hedges & Nowell, 1999; Kyriakides, 2006; Perry & McConney, 2010). Similarly, with respect to educational outcomes in science, previous findings have demonstrated a significant positive and enduring independent effect of socio-economic status (SES) on individual science performance as well (Akukwe & Schroeders, 2016; Areepattamannil et al., 2015; Caldas, 1993; Caldas & Bankston, 1997; Rumberger & Willms, 1992; Wiseman et al., 2008).

Empirical evidence of family influence on academic outcomes by and large shows that children raised in families with more financial, cultural and social resources and whose parents have higher levels of education and occupation tend to perform better academically (Areepattamannil, 2012; Areepattamannil et al., 2015; Areepattamannil et al., 2011; Caro et al., 2009; Duncan & Brooks-Gunn, 1997; Hattie, 2009; Magnuson, 2003; Marjoribanks, 2002; O'Dwyer, 2005; Perry & McConney, 2010; Sirin, 2005; Sousa et al., 2012; Yeung et al., 2002) and are more likely to complete secondary school and university than their peers from lower SES backgrounds (Blossfeld & Shavit, 1993; Willms, 1999). A frequently encountered explanation for this finding is that parents with a relatively high SES tend to create a favourable learning environment for their children (Akukwe & Schroeders, 2016; Becker & Tomes, 1979; Peng & Wright, 1994; Scott-Jones, 1995; Thompson et al., 1988) and invest their economic, cultural, social and occupational capital in ways that facilitate the well-being of their offspring from childhood into the adult years (Akukwe & Schroeders, 2016; Becker & Tomes, 1979; Conger & Donnellan, 2007; Yang & Gustafsson, 2004). Additionally, these academically qualified parents with high-prestige occupations are likely to intensively provide their children with educational support by, for example, demonstrating more personal involvement and communication with their children (Garg et al., 2002; Lee & Bowen, 2006), helping with their homework (Ho & Willms, 1996; Lee & Bowen, 2006) and participating in school (Garg et al., 2002; Hoover-Dempsey et al., 1987). These educational resources, along with the positive educational environment and the perception of future benefits based on achievement, are likely to create a strong motivation for high academic performance, which in turn increases the likelihood that their children will perform well in school (Kaplan et al., 2001; Kozol, 1991).

On the other hand, it is well established in the research literature that parents having a lower SES negatively affects their children's academic achievement (Eamon, 2005; Hochschild, 2003; Seyfried, 1998), because low family SES prevents access to vital resources

and creates additional stress at home (Eamon, 2005; Jeynes, 2002; Marjoribanks, 1996). In addition, children from socio-economically disadvantaged families with less educated parents are also disadvantaged in school learning (Battle & Lewis, 2002; Okpala et al., 2001; Perry & McConney, 2010; Zhou & Wang, 2015). For example, they may have more difficult starting conditions at school than their peers and may be faced with teachers who are less confident about their competence and perspectives (Westphal et al., 2016), which may not do justice to their actual achievement (Ready & Wright, 2011). Consequently, they tend to perform lower academically, their achievement growth may proceed at a slower rate (Caro et al., 2009) and they may be less likely to continue on to college (Cabrera & La Nasa, 2001) than their peers from high socio-economic backgrounds (Hattie, 2009; Lareau, 2002; Sirin, 2005; Wang, 2011).

2.6.4 Possible Interventions to Reduce Socio-economic Inequalities in Education

The extent to which schools influence educational outcomes has been the subject of a great deal of research (Marks et al., 2006). It is indeed important to obtain a better understanding of how school characteristics influence students' educational achievement (Battle & Lewis, 2002). There are a range of school characteristics – resources, academic and disciplinary climates, the quality of teachers, teaching practices, the curriculum and leadership by the principal – that, to varying degrees, influence students' educational outcomes (Greenwald et al., 1996; Lee & Bryk, 1989; Schreiber, 2002). Such an understanding may serve as the basis for social interventions that improve the well-being of those students from a low socio-economic background.

Schools may be involved in the socio-economic inequalities in education in a number of ways. For example, wealthy families can provide their children with a superior education by sending them to high-fee elite private schools or purchasing homes in the catchment areas of high-performing state schools. School systems may further increase social inequality by assisting less competent and less motivated students from advantaged family backgrounds and creating barriers for academically able students from lower socio-economic families. However, school factors are important in mediating the relationship between socio-economic background and student performance (Marks et al., 2006). Thus, educational inequalities due to low family SES can be improved and addressed directly through reallocation of school resources by government initiatives. For example, governments can provide financial support in the form of scholarships, stipends, allowances for textbooks and other educational materials, and tax deductions for educational expenses. Alternatively, they could increase the overall funding of

schools deemed as disadvantaged, and directly fund specific resources such as classrooms, libraries, laboratories and teachers. Furthermore, highly differentiated systems can magnify socio-economic inequalities in education. The policy responses are clear: be clear that the allocation of students to different academic locations should be based on objective measures of student performance; delay the allocation of students to different locations since the effects of socio-economic background tend to be stronger among younger students; allow movement between tracks and minimize differences in the learning environment between tracks. In some countries, one of the most common policy initiatives of governments has been to reduce or completely abolish tracking. Similarly, school systems that reward ability and effort rather than social origins may substantially reduce the extent of social reproduction between generations, especially in highly differentiated school systems. All the above-mentioned policy implications were established as a way of reducing socio-economic inequalities in educational outcomes.

From a social policy point of view, the finding of the crucial positive effect of socio-economic status (SES) on academic achievement adds to the chorus of research in the area of educational sociology (Battle & Lewis, 2002). Indeed, educational policies targeted at improving the economic circumstances of students from less economically privileged families may help foster not only equity in learning opportunities but also equity in learning outcomes (Areepattamannil et al., 2015; OECD, 2010). Therefore, if our society is interested in enhancing academic outcomes, policies that reduce socio-economic inequalities in education are unexpendable.

2.7 Teacher Expectations for Student Achievement

2.7.1 Self-fulfilling Prophecy

Self-fulfilling prophecies have generated a tremendous amount of empirical research and several theoretical reviews and have often been the focus of psychological, social and educational researchers. The ongoing interest in this area attests to both its theoretical and practical importance (Jussim, 1986). The concept of self-fulfilling prophecy refers to an originally false statement that is believed to be true and therefore becomes true in its consequences (Jussim, 1986; Merton, 1948; Nolkemper et al., 2019). For example, a person acts because of inaccurate expectations in such a way that the originally false assumptions become true (Deniz & Ersoy, 2016; Merton, 1948) or public definitions of a situation, prophecies, become an integral part of the situation and thus affect subsequent developments

(Merton, 1948; Rosenthal & Jacobson, 1968). The self-fulfilling process could occur on any occasion – for instance, in classrooms, in colleges, in workplaces or in government (Jussim & Harber, 2005). When applied to classrooms, the self-fulfilling prophecy refers to situations in which the expectancies of teachers affect their student’s behaviour in the direction of the expectancies (Jussim, 1986; Martin, 1977; Rosenthal & Jacobson, 1968). In this case, the expectations are not based on the students’ actual performance (Nolkemper et al., 2019). Nevertheless, these inaccurate expectations have a moderating effect not only on the achievement but also on the motivation of the students (Jussim, 1989).

2.7.2 The Pygmalion Effect

In the context of school, this phenomenon has been researched under the name “Pygmalion effect” or “Rosenthal effect” at the individual level (Friedrich et al., 2015; Nolkemper et al., 2019). Pygmalion effects have high scientific and practical relevance due to their potentially positive or negative effects on student outcomes (Friedrich et al., 2015). Furthermore, identifying this effect of expectancies on behaviour is clearly important in regard to understanding the interpersonal dynamics between teachers and students. Not surprisingly, Pygmalion effects have been the subject of many empirical studies (Jussim & Harber, 2005; Rosenthal & Rubin, 1978; Tenenbaum & Ruck, 2007), which have documented, by and large, the existence of expectancy effects.

Although Merton (1948) illustrated the concept of self-fulfilling prophecy and Clark (1965) identified low teacher expectation effects in ghetto schools, it was not until the publication of Rosenthal and Jacobson’s (1968) *Pygmalion in the Classroom* that the topic of teacher expectations arrived on the educational scene (Brophy, 1983). Despite its historical importance, the Oak School experiment is only one of a great number of studies of teacher expectation effects. Robert Rosenthal and his colleagues have performed psychological experiments, the philosophical importance of which has yet to be seriously considered (Martin, 1977). The Pygmalion effect refers to the effects of interpersonal expectancies, that is, the finding that what a person expects of another can come to serve as a self-fulfilling prophecy (Friedrich et al., 2015; Martin, 1977; Nolkemper et al., 2019; Rosenthal, 2010). In psychological research, the classic Pygmalion effect study dates back to the 1950s. What Rosenthal and Jacobson hoped to determine through this experiment was the degree to which changes in teacher expectation produce changes in student achievement (Rosenthal & Jacobson, 1968). In this Oak School experiment, the elementary school teachers were told that randomly

chosen children could be expected to be “bloomers” based on their results in the Harvard Test of Inflected Acquisition, which was not the case, and they would soon experience an enormous improvement in their intellectual development (Friedrich et al., 2015; Martin, 1977; Nolkemper et al., 2019; Rosenthal & Jacobson, 1968). By the end of the school year, these children had gained significantly in their intellectual achievement compared to the control group (Rosenthal & Jacobson, 1968). As a result, teachers’ false expectations had become true; that is, the expectations of teachers created a self-fulfilling prophecy (Jussim & Harber, 2005). This experiment not only showed that teacher expectations had a positive dramatic impact on the actual performance of “bloomers” (Gilbert, 1995), but also indicated that the more the children in the control group gained in IQ, the less well adjusted, interesting and affectionate they were seen to be by their teachers (Nolkemper et al., 2019). Teachers seemed actively hostile toward students showing unexpected intellectual growth.

The study of Rosenthal and Jacobson opened up new areas of research in education and psychology (Brophy, 1983; Brophy & Good, 1974; Jussim & Harber, 2005; Miller & Turnbull, 1986; Snyder, 1984). Research has found that implicit beliefs about individual students impact the judgements of teachers, especially under high cognitive and emotional loads or if only a little diagnostic information is available (Fiske, 1998; Jussim & Harber, 2005; Nolkemper et al., 2019). Teachers form their expectancies of their students’ achievements on the basis of the knowledge they have about their students early in the school year, such as previous grades and initial perceptions of in-class performance, but also based on teachers’ prejudices or stereotypes (Friedrich et al., 2015; Good, 1987; Jussim et al., 1996; Reyna, 2000, 2008). Teachers’ consideration of their students strongly influences the individual student’s academic progress (Nolkemper et al., 2019; Rosenthal, 2010) and therefore his or her future opportunities (Damgaci & Aydin, 2014; Friedrich et al., 2015). For instance, the probability of attending university for students whose abilities and potential have been overestimated by their teachers is higher than that of students with the same cognitive abilities who have been judged inaccurately (Birkelbach, 2011; Nolkemper et al., 2019). The message of the Pygmalion effect was clear and simple and it provided scientific credibility and strong rhetorical ammunition for pundits, policymakers, social activists and reformers (Jussim & Harber, 2005). In particular, social psychologists interpreted this study as a testament to the power of expectations to create social reality (Fiske & Taylor, 1991; Gilbert, 1995; Jones, 1986; Jussim & Harber, 2005; Miller & Turnbull, 1986).

Although many empirical studies have supported the predictions of the Pygmalion effect, the effect sizes have tended to be small to moderate (averaging about $r = .1$ to $.2$), certainly smaller than the effects of students' former achievement on teacher expectations (Brophy, 1983; Crano & Mellon, 1978; Friedrich et al., 2015; Jussim & Harber, 2005). Although the potential for teachers' expectations to function as self-fulfilling prophecies always exists, the extent to which they actually do so in typical classrooms is probably limited, averaging perhaps a 5–10 % effect per student (Brophy, 1983; Cooper, 1979; Friedrich et al., 2015; Jussim & Eccles, 1992, 1995; Madon et al., 1997); that is, on average, self-fulfilling prophecies typically change the achievement of about 5–10 % of all students. Thus, 90–95 % of the time, students are unaffected by teacher expectations (Jussim & Harber, 2005). One possible explanation for why teacher expectation effects may not be particularly powerful is that their expectations are generally accurate and open to corrective feedback (Brophy, 1983; Jussim & Harber, 2005). Accurate beliefs, by definition, do not create self-fulfilling prophecies (Merton, 1948). In short, accuracy limits self-fulfilling prophecies.

2.7.3 Teacher Expectancy Effects

The effects of teacher expectations are likely to be unintended and very subtle (Rosenthal & Jacobson, 1968). High correlations between teacher expectations and student achievement ($.5$ – $.9$) are found in many studies (Brophy & Good, 1974; Crano & Mellon, 1978; Friedrich et al., 2015; Humphreys & Stubbs, 1977; Jussim, 1986; Jussim & Harber, 2005). Some researchers even reported that teacher expectations modestly influence changes in intellectual status (Jussim & Harber, 2005; Raudenbush, 1984, 1994). According to the Pygmalion effect, teacher expectations create self-fulfilling prophecies. Early in the school year, teachers develop clear expectations for the performance of the entire class, groups of students or specific individuals (Brophy, 1983; Brophy & Good, 1974; Friedrich et al., 2015; Good, 1987; Jussim, 1989; Rist, 1970). Even when the expectations are initially erroneous, teachers may evoke expectancy-consistent performances from their students (Brophy & Good, 1974; Friedrich et al., 2015; Jussim, 1986; Rosenthal & Jacobson, 1968). Brophy and Good (1970) indicated that teacher expectations affect student outcomes indirectly by leading to differential teacher treatment of students that will condition their self-concept (Jussim, 1989), attitudes, expectations and behaviour (Brophy, 1983). Students perceive and react to their teachers' expectancies and most of them confirm these expectations— for example, students believed to be high achievers often perform at higher levels than students believed to be low achievers

(Brophy & Good, 1974; Crano & Mellon, 1978; Humphreys & Stubbs, 1977; Williams, 1976). The findings reviewed make it clear that teachers interact differentially with students, in ways that seem likely to maximize the achievement progress of high-expectation students but limit the progress of low-expectation students (Brophy, 1983).

In addition, a comprehensive conceptualization of the self-fulfilling prophecy effects of teacher expectations for student achievement requires attention not only to teachers' behaviour related to the communication of expectations with students but also to teachers' beliefs about an appropriate curriculum, effective instruction and student motivation, to the quality of the personal relationship between teachers and students, and to a variety of individual different variables of teachers and students – for example, the instructional strategies of teachers and their expectations differ according to ascribed personal categories (Brophy, 1983; Cartohers & Parfitt, 2017; Nolkemper et al., 2019). Thus, expectations interact with teachers' personal characteristics and beliefs to determine teachers' behaviour, so similar expectations may lead to different teachers' behaviour; similarly, students may also differ in their interpretation of, and response to, teachers' behaviour, so similar teachers' behaviour may produce different student outcomes. However, teacher expectations may also lead to perceptual biases, which refer to the tendency to interpret, perceive, remember or explain students' actions in ways that are consistent with their expectations. Last but not least, teacher expectations may accurately predict student achievement (Brophy, 1983; Hoge, 1984).

Scott (1962) indicated that the work of developmental and experimental psychologists and of ethologists is in agreement on the importance of age as a factor in determining the degree to which an organism can be shaped, moulded or influenced (Rosenthal & Jacobson, 1968). In general, the younger the organism, the greater is thought to be the degree of susceptibility to social influence. Coffin (1941) also concluded that the ability to influence increases from infancy to ages seven to nine but decreases after that. Similarly, the self-fulfilling prophecy is in evidence primarily at the lower grade levels (Rosenthal & Jacobson, 1968). In other words, younger children show greater gains associated with teacher expectancies because they are generally regarded as more malleable, less fixed, more capable of change and more subject to the effects of critical periods (Rosenthal & Jacobson, 1968). Consequently, younger children within a given school have less well-established reputations and they are more sensitive to, and more affected by, the particular processes whereby teachers communicate their expectations to children. Additionally, there is some evidence to suggest that teachers of the lower grades in fact differ from those of the upper grades (Rosenthal & Jacobson, 1968). The instructional

strategy is one example: in the upper elementary grades and the secondary grades, most teachers use a whole-class, public-presentation, recitation or discussion method, and the emphasis is on teaching and learning the content (Brophy, 1983). Thus, individualized dyadic interactions with students are infrequent. In the early grades, however, there is much use of small-group instruction and teachers spend a lot of time developing personal relationships with their students; as a result, young children are more susceptible to teacher expectation effects.

2.7.4 Conceptualizing Self-Fulfilling Prophecy Effects in the Classroom

Brophy and Good (1970) described a possible mechanism behind teacher expectancies in a comprehensive model (Friedrich et al., 2015): (a) teachers form differential expectations for their students; (b) Teachers' beliefs about those students begin to lead to differential treatment such as providing more attention and support, offering more challenging learning materials, interacting more often and longer, and being more responsive to the performance of the students for whom they hold high expectations (Rosenthal, 1974); (c) these students in turn recognize the high expectations and respond to them by working harder and consequently develop higher motivation and greater interest in schoolwork; (d) this more engaged behaviour of the students will, in the long run, improve their academic achievement and these changes may also affect their self-concept (Harris & Rosenthal, 1985); (e) after the teachers recognize the positive changes in these students, they feel supported by their own expectancies and the self-fulfilling cycle is finally complete and reinforced.

For conceptualizing expectancy effects in general social interaction, Darley and Fazio (1980) offered a complex model that includes explicit attention to causal attributions and other information-processing mechanisms that become involved when teachers and students interpret the meanings of each other's behaviour (Brophy, 1983). Paraphrased to refer specifically to teacher expectation effects on students, the model is as follows:

First of all, the teachers develop a set of expectations for student outcomes based on the students' status characteristics, reputations and prior accomplishments, as well as information obtained early in the school year. The impressions that the teachers form from interacting with their students at the beginning are based primarily on the students' participation in academic activities and performance in assignments. These impressions, or more accurately expectations, influence how the teachers interact with and treat the students differently.

Through those interactions and that differential treatment, the students interpret and respond to their teachers' actions or behaviour, to the extent that these actions are seen as

responsive to factors specific to the students who will come to expect similar treatment from the teachers in the future. Usually the students' behaviour will bear some reciprocal relationship with the teachers' actions, so as to confirm the teachers' expectations. This is especially likely if the expectations implied by the teachers' behaviour are congruent with the students' self-image or at least are acceptable to the students. Where this is not the case, the students may respond in ways that disconfirm the teachers' expectations.

Depending on the responses of the students, the teachers try to maintain or adjust those expectations. Most teachers are biased toward maintaining their expectations once they have been formed, so that students' responses that confirm expectations are likely to be attributed to the dispositional qualities of the students and thus taken as confirmation of expectations, whereas disconfirming responses are likely to be attributed to situational factors and thus not necessarily taken as evidence that expectations are incorrect. Nevertheless, repeated and salient disconfirmation may be necessary to change an entrenched expectation.

Finally, the students interpret their own responses to the teachers. These responses are self-revealing, which gives the students more information about what they are really like. To the extent that the students have understood the teachers' expectations or responded with behaviour that confirms those expectations, the students' self-image may change in the direction implied by the teachers' expectations.

Both the above-mentioned rather similar descriptive models of the stages occurring in classroom self-fulfilling prophecies (Brophy & Good, 1970; Darley & Fazio, 1980) agree on three broad and general stages: teachers develop expectations; teachers treat students differently depending on their expectations; and students react to this differential treatment in ways that confirm the expectations (Jussim, 1986). An overview of the three stages of self-fulfilling prophecies is presented in Table 2.2.

Table 2.2

Self-fulfilling Prophecies

STAGE ONE TEACHER EXPECTATION	Initial Expectation: Stereotypes Reputation Standardized tests Early Performance Native Prediction Processes	→	Maintenance and Change of Expectation: Confirmatory Biases Flexibility of Expectations Strength of Disconfirming Evidence
STAGE TWO DIFFERENTIAL TREATMENT	Psychological Mediators: Perceptions of Control Perceptions of Similarity		Treatment of Students: Feedback Emotional Support

	Dissonance Attributions Effect Situational Mediators: Tracking Ability Grouping Grade Level	→	Types of Assignments Attention Opportunities to Learn Amount and Difficulty of Material Taught
STAGE THREE STUDENTS' REACTION	Psychological Mediators: Skill Development Perceptions of Control Values Self-schemas Self-esteem	→	Behavioural Reactions: Effort Persistence Attention Participation Cooperation

2.7.4.1 Stage One: Teacher Expectation.

A necessary first step in the self-fulfilling prophecy process is for teachers to develop expectations for students' future achievement. Most education theorists agree that teachers do form impressions quite early in the year (Braun, 1976; Brophy, 1983; Brophy & Good, 1974; Dusek, 1975; West & Anderson, 1976). Initial expectations are the predictions that teachers develop on the basis of currently available evidence obtained prior to any interaction with the students as well as extensive observation of student performance, superficial student characteristics and achievement-related information obtained in initial interactions at the beginning of the school year. Indeed, research has shown that a host of factors are capable of evoking initial expectations, including physical appearance, race, social class, early performance, track or group placement, classroom conduct, ethnicity, gender, speech style, various diagnostic labels and so on (Braun, 1976; Brophy, 1983; Brophy & Good, 1974; Cooper et al., 1975; Dusek & Joseph, 1983; Persell, 1977; Rist, 1970; Seligman et al., 1972). Often, expectations based on characteristics associated with stereotyping and prejudice, or on more direct indicators of achievement, may exaggerate the differences between students that lead to naive predictions. As the school year progresses, teachers either revise or maintain these expectations in response to students' performances. This model presents the psychological processes involved in teacher expectancy development and change. For example, consistent performances will maintain or strengthen expectations because they confirm for teachers the validity and accuracy of their expectations. Any inaccuracy, however, is unlikely to bias students' achievement if teachers alter their impressions in response to corrective feedback when more dependable information becomes available (Borko et al., 1979; Brophy, 1983; Brophy & Good, 1974; Shavelson et al., 1977; Willis, 1972).

2.7.4.2 Stage Two: Differential Treatment.

The second stage of the model describes the relationships between teachers' expectations and their treatment of students. The types of differential treatment included in this model correspond to Rosenthal's (1974) four-factor theory: teachers provide different amounts and types of feedback to highs and lows; are more emotionally supportive of highs; spend more time and effort with highs; and provide highs with greater opportunities to perform and learn. Several psychological and situational processes are presumed to mediate the link between expectations and these sorts of treatment. Psychological mediators refer to teachers' perceptions of control over students' behaviour, teachers' perceptions of similarity between themselves and the students, and how teachers attribute the situation of dissonance. The grade level of the class and whether students are tracked or grouped by ability level are the situational factors especially relevant to understanding patterns of teachers' differential treatment.

Often, teachers have greater control over high-expectancy students' behaviour than over low-expectancy students' behaviour (Cooper, 1979). Because teachers perceive high-expectancy students as having a greater comprehension of a broader range of topics, they also feel more able to direct, control and reach understandings with these students. Consequently, the relationship between similarity and liking may provide insights into teachers' differing emotional responses to different students. Because most teachers are of the same race as most of their students, middle class and relatively articulate, in many classrooms, students with similar characteristics will be liked more. Race, socio-economic class and speech style are three immediately available and salient cues in most social encounters (Jussim & Harber, 2005). These factors are likely to have a substantial impact on liking, at least in initial interactions, and they may continue to influence liking beyond first impressions owing to their assumed relation with values. The factor that probably has the strongest relationship with liking, however, is teachers' perceptions of students' beliefs and values. Perceptions of similarity may mediate the links between expectations and differential treatment in the following way: (a) expectations lead teachers to perceive themselves as more similar to highs; (b) perceived similarity leads teachers to like highs more than lows; and (c) teachers provide a warmer and more supportive environment for those students whom they like more. Consequently, perceived similarity is probably most useful for understanding the warmer socio-emotional climate that teachers sometimes provide for their high achievers and why some teachers spend more time with highs. Additionally, cognitive dissonance theory provides the framework for understanding teachers' reactions to expectancy-disconfirming performances. Dissonance

occurs when students unexpectedly exceed teachers' expectations (Jussim & Harber, 2005), or more accurately, highs fail and lows succeed, which seems to trigger oppressive teacher responses toward these students. In other words, teachers will be more likely to feel and express negative affect to low-performing highs and high-performing lows (Rosenthal & Jacobson, 1968; Rubovits & Maehr, 1973). Those negative reactions to lows' successes are clearly inappropriate and could be damaging to lows' motivation and learning. Specifically, expectancy-consistent performances, highs' successes and lows' failures are often attributed to individuals' performance-related personal characteristics, whereas the importance of expectancy-disconfirming performances, highs' failures and lows' successes can be discounted by attributing them to situational factors (Deaux & Emswiller, 1974; Regan et al., 1974).

Students differ in intelligence, achievement motivation, classroom conduct and all of the other cognitive and personality variables relevant to teaching and learning, and these differences evoke teachers' differential expectations and condition their behaviour in part (Brophy, 1983). Differences in expectations lead to differences in what is taught, which in turn lead to differences in what is ultimately learned (Brophy, 1983). Self-fulfilling prophecies may occur because teachers behave differently toward high- and low-expectancy students and these differences are evident in the quality, not the quantity, of the interaction (Brophy & Good, 1970; Jussim & Harber, 2005). Some of the general ways in which differential treatment commonly observed in the classroom and laboratory may affect high- and low-expectancy students include its impact on students' opportunity to learn (Brophy, 1983), their development of scholastic skills and their motivation to achieve; these important motivational factors may then affect students' performance (Jussim, 1986).

A positive discrimination exists towards students for whom teachers hold higher expectations (Brophy & Good, 1970; Nolkemper et al., 2019). Research on classroom interactions shows that compared to low-expectancy students, teachers give high-expectancy students more opportunities to demonstrate mastery (Brophy, 1983; Harris & Rosenthal, 1985; Jussim, 1986; Jussim & Harber, 2005; Nolkemper et al., 2019; Rosenthal, 1974), provide clearer and more favourable feedback (Brophy & Good, 1970; Cooper, 1977, 1979; Finn, 1972; Rosenthal, 1974; Weinstein, 1976) as well as more positive emotional support to highs (Chaikin et al., 1974; Rist, 1970; Rubovits & Maehr, 1973), pay more attention and teach more material to highs (Beez, 1968; Cooper & Good, 1983; Rist, 1970; Rosenthal, 1974; Rubovits & Maehr, 1971), motivate and interact with highs more often, and give highs more opportunities to learn difficult material (Allington, 1980; Brophy, 1983; Brophy & Good, 1970;

Nolkemper et al., 2019; Rubovits & Maehr, 1971). However, teachers, on the other hand, provide lows with fewer opportunities to perform and less favourable feedback (Jussim, 1986). Lows are called on less frequently and have their answers cut off or provided for them more quickly. As a result of having fewer performance opportunities, lows have less experience and practice at developing important intellectual skills. Being called on less and having their attempts at classroom participation terminated more quickly are ways in which teachers give lows less feedback regarding the quality of their work. It also gives them less chance to think spontaneously, to attempt to articulate their ideas, to become aware of their own mistakes and to make their own corrections. These students are, therefore, less motivated and less emotionally involved in class (Nolkemper et al., 2019; Urhahne, 2015), so they do not expect to be successful, are more worried about exams and perceive difficulties in getting in touch with their teachers. These results can be interpreted as the product of the differential treatment of teachers toward their students based on a categorization of those students (Nolkemper et al., 2019). Overall, then, teachers' perceptions of students' performance affect the feedback they provide. The clarity of the feedback and the nature and frequency of performance opportunities provided for high- and low-expectancy students can impact on the skills and knowledge they glean from their classroom experiences and their achievement motivation (Braun, 1976; Cooper, 1979; Weinstein, 1985).

2.7.4.3 Stage Three: Students' Reaction.

People respond not only to the objective features of a situation, but also, and at times primarily, to the meaning this situation has for them (Merton, 1948). And once they have assigned some meaning to the situation, their consequent behaviour and some of the consequences of that behaviour are determined by the ascribed meaning. When applied to classrooms, teacher expectation effects are mediated not only by teacher behaviour but by student reaction to that behaviour (Brophy, 1983). In the third stage of the model, students react to the differential treatment. Students' performance is also assumed to be mediated by cognitive, affective and motivational factors. The mediating factors addressed in this model include students' perceived control over outcomes, the value that students place on learning and achievement, and their intrinsic interest in school. These different cognitive, affective and motivational reactions, as well as differences in skill development, affect scholastic behaviours such as effort, participation, cooperation, attendance and so forth, so that ultimately, high-expectancy students often perform at levels superior to those of low-expectancy students.

Different approaches to skill development are a critical way in which differential treatment enhances highs' and inhibits lows' achievement. Some forms of differential treatment may lead directly to differences in skill development without much mediation by social, cognitive or affective processes. For example, feedback provides students with information regarding right and wrong answers. Positive feedback for success and negative feedback for failure, such as that provided for high-expectancy students, convey clear information distinguishing between high- and low-quality work. As discussed previously, however, some teachers do not provide lows with appropriate feedback. When teachers react negatively or with muted praise to lows' successes, they fail to provide the necessary information enabling lows to discriminate between high- and poor-quality scholastic performances. Also, due to this non-contingent feedback, teachers may lead many lows to believe that performance is not contingent on effort. As a consequence, lows may not try as hard, persist as long or, more generally, understand which behaviour leads to scholastic success, so that they are not able to control their own outcomes. Ultimately, this leads to lower levels of performance. Such differential teacher treatment would likely increase, and not merely maintain, existing student differences, thus producing self-fulfilling prophecy effects of teacher expectations on student achievement (Brophy, 1983).

Values, which generally refer to the desirability or importance of an activity or outcome, play a major role in most theoretical approaches to motivation (Atkinson, 1964; Deci, 1975; Dweck & Elliott, 1984; Eccles & Wigfield, 1985; Jussim, 1986; Nicholls, 1979; Parsons et al., 1983). The more valuable the reward of an activity is to a person, the more likely he or she is to perform the activity. Similarly, students who are heavily dependent on teachers for information are more likely to confirm teachers' expectations (West & Anderson, 1976). These students either have fewer alternative sources of rewards and information or feel that teachers' reactions are especially important to them. They generally value the teachers' reactions more highly than those who care less about the teachers' evaluations, and will be more likely to behave in ways designed to evoke favourable reactions from the teachers. Social exchange theory accounts for these findings and goes further by suggesting that anything leading to a lowering of the value placed on the teachers' reactions would lead to lowered susceptibility to expectancy effects.

Additionally, social exchange theory suggests that more punishing activities are less likely to be performed by students and punishment renders any activity that results in avoiding punishment more likely. Thus, studying and working hard not only avoid punishment, they

lead to rewards in the form of teacher praise, positive affect and high grades. Consequently, working hard for school should become a relatively highly valued activity for high-expectancy students. In contrast, lows may be criticized more for failure, praised less for success and face a less supportive emotional atmosphere. For them, school may come to be perceived as a punishing situation. Lows who are treated in this way may come to value any activity that avoids the punishment they receive in school. Because lows receive fewer positive rewards for success and effort, the achievement behaviours that lead to high performance will not become highly valued. Other methods of avoiding the classroom's punishing atmosphere, such as missing classes and withdrawing from classroom activities, become more appealing alternatives. Thus, a cycle of low academic performance is perpetuated.

Furthermore, a particular type of value may be an especially likely mediator of the effects of differential treatment on motivation (Jussim, 1986). *Intrinsic value* refers to the pleasure one receives from simply engaging in an activity and has been incorporated into many approaches to motivation (Deci, 1975; Harter, 1981; Lepper et al., 1973; Nicholls, 1979; Parsons et al., 1983). For instance, some students may simply enjoy certain scholastic experiences and these students will be more motivated to perform these activities frequently and to develop expertise in them. Cognitive evaluation theory (Deci, 1975) may be most directly applicable to understanding how some types of differential treatment affect students' intrinsic interest in school. The feedback patterns found to lead to low intrinsic motivation correspond very closely to the pattern confronting at least some low-expectancy students. Intrinsic motivation decreases in response to three types of feedback patterns, namely those that are primarily designed to control the behaviour of the reward, feedback that is not contingent on effort or performance and negative feedback. The controlling aspect of rewards conveys the message that the student is urged to engage in activities in order to satisfy the demands of others such as teachers or parents. As a result, the student's intrinsic interest in the activity declines (Ryan et al., 1985). Research on elementary school classrooms has shown that when teachers are more concerned with issues of control, their students are less intrinsically interested in school (Deci et al., 1981). Similarly, cognitive evaluation theory proposes that intrinsic motivation is increased by feelings of mastery. Because excessive negative feedback and feedback that is not contingent on performance are likely to lead to feelings of incompetence (Abramson et al., 1978; Cooper, 1977, 1979; Murray & Jackson, 1983; Ryan et al., 1985), these reward patterns also undermine intrinsic interest in school. Consequently,

when lows receive this sort of treatment, they are likely to decrease their intrinsic interest in learning. In contrast, intrinsic motivation is likely to be enhanced among highs.

2.7.5 Role of Self

A great deal of research specifically addresses the role of the self in motivation and achievement. The self may be the primary mediator of one's perceptions and interactions with the environment (Coombs & Snygg, 1959; Epstein, 1973; Jussim, 1986). Similarly, one of the most important factors mediating the impact of teacher expectations may be students' sense of self, because the self may mediate students' reactions to the teachers and further mediate the impact of the teachers' behaviour. In addition, the nature and strength of students' self-concept may be viewed as a primary mediator of the degree of susceptibility, which may be an especially useful way to understand students' likely reactions to the treatment they receive in the classroom (Friedrich et al., 2015; Jussim, 1986). The perspective taken here is that the self has two conceptually distinguishable aspects – one primarily cognitive and the other primarily affective. The cognitive aspect of the self can be viewed as self-schemas, or the individual's self-theory, highly organized, internally consistent, relatively stable but also open to change, which means understanding oneself and one's relationship with the environment (Epstein, 1973), whereas the affective aspect of the self corresponds to self-esteem and refers to how individuals feel about, or evaluate, themselves.

Self-schemas (Markus, 1977) can be considered self-hypotheses, that is, generalizations and predictions about the self in more restricted domains (Jussim, 1986). Research has demonstrated that people may hold schemas related to their degree of independence (Markus, 1977), sex roles (Markus et al., 1982) creativity and body weight (Markus, 1980). Indeed, a whole host of trait-related schemas may exist, including characteristics such as being friendly, smart, sensitive and so forth. These characteristics of self-schemas are important because they provide insight into why different students may react differently to similar treatment by teachers. Schemas most relevant to classroom achievement situations include aspects such as being smart, competent and motivated (Jussim, 1986). For example, students may hold schemas that they are smart or that they are stupid. High-expectancy students who are also smart schematically have the optimal situation. Both the treatment they receive and their own cognitive biases will act to maximize their confidence and self-esteem in school situations. Such students are likely to maintain high levels of motivation for school and may be more likely to be perceived as pleasant, competent and successful by their teachers. Low-expectancy

students who are also unintelligent schematically experience school very differently. For these students, the emotional impact of success and failure may be somewhat mitigated. They may respond less intensely to success, because they would either tend to diminish its importance or derogate their role in attaining it. They might also respond less intensely to lower performance than highs because they would expect to do less well. Unfortunately, because these students react less intensely to school performance, the teachers may infer that they do not care much about school, thereby reinforcing the teachers' original expectancies (Jussim, 1986).

Strong self-schematics usually lead to self-verification (Swann & Ely, 1984), however either students' self-schemas or teachers' expectations will eventually change. Indeed, some researchers have supported the general proposition that students' self-schematics change as a function of teachers' expectations (Parsons et al., 1982). People will change their self-ratings only when they receive self-discrepant feedback in highly structured situations in which they have little opportunity to influence or resist the treatment they receive (Swann, 1983). This description may fit many classrooms quite well, explaining why some students, especially those with strong self-schematics, would find it difficult to resist internalizing a self-definition implicit in the way they are treated by teachers. On the other hand, individuals without strong self-schematics are more likely to believe others' descriptions of them (Markus, 1977) and more likely to confirm another's expectations; likewise, students who do not hold a particularly strong view of their intelligence or ability may be most susceptible to expectancy effects. Consistently favourable or unfavourable treatment by teachers, however, may be one of the dominant factors leading to the development of self-schemas regarding academic competence (Jussim, 1986).

Self-esteem may be an important factor in self-fulfilling prophecies because it plays a major role in determining students' susceptibility to teacher expectation effects (Jussim, 1986). One of the most influential sources of self-esteem, especially among children, is the evaluations provided by powerful others (Harter, 1984). Apparently, then, teachers' evaluations of students may have quite a strong impact on their development of self-esteem. Thus, teacher expectations, by leading to differential evaluation and treatment, may be one factor leading to the development of high or low self-esteem among students. Some research shows a direct connection between self-esteem and achievement. For instance, high self-esteem leads to certain behavioural orientations associated with higher performance, including intrinsic motivation, task orientation and preference for challenge (Harter, 1984). Additionally, students who are high in self-esteem generally evaluate themselves quite favourably, therefore it may

be much easier for them to discount the effects of teachers' unfavourable treatment and negative feedback. In contrast, students low in self-esteem cannot readily discount failures, because these outcomes are consistent with their own generally unfavourable self-evaluations, consequently failure should be much more affectively and motivationally damaging to them. In line with this perspective, research has revealed that after failure, students with lower self-esteem decrease their self-evaluations more (Shrauger & Rosenberg, 1970), persist less and perform worse (Brockner, 1979; Shrauger & Sorman, 1977), especially if the failure is prolonged (Brockner et al., 1983).

2.7.6 Differences of Opinion Concerning the Generality and Strength of the Self-fulfilling Prophecy

A great deal of evidence supports the notion that expectations can function as self-fulfilling prophecies with relatively moderate effect sizes (Brophy, 1983; Brophy & Good, 1974; Jussim & Harber, 2005; Merton, 1948; Rosenthal & Jacobson, 1968), whereas some data imply that teacher expectations do not always automatically function as self-fulfilling prophecies (Dusek, 1975; West & Anderson, 1976). This description suggests that although self-fulfilling prophecies do occur, students confirm teachers' expectations mostly and primarily because of the accuracy of those expectations (Jussim, 1989; Jussim & Harber, 2005). West and Anderson (1976) and Dusek (1975) count as evidence supporting self-fulfilling prophecy effects only those studies in which expectations based on false information assigned randomly to individual students were induced in teachers, before teachers had an opportunity to form their own expectations naturally in the process of observing and interacting with their students. In other words, only when inaccurate expectations, i.e., over- or underestimates of students' actual achievement potential, are rigidly maintained and consistently projected to the students may they lead to self-fulfilling prophecies (Brophy, 1983; Jussim, 1989; Nolkemper et al., 2019).

More and more educational psychology reviews support the general proposition that teacher expectancies exist and that they are quite accurate (Jussim & Harber, 2005). Accuracy narrowly refers to teacher expectations successfully predicting, but not causing or influencing, student achievement. Some researchers consider self-fulfilling prophecy a type of accuracy (Alwin & Hauser, 1975; Jost & Banaji, 1994; Jussim & Harber, 2005; Swann, 1984). More commonly, teacher expectations collected early in the year predict student achievement at the end of the year, but these correlations mostly reflect accurate teacher expectations based on the

most reliable information about students and the interaction with students, and that most of the inaccurate perceptions are corrected when more dependable information becomes available (Borko et al., 1979; Brophy, 1983; Brophy & Good, 1974; Jussim & Harber, 2005; Shavelson et al., 1977; Willis, 1972). Similarly, although there are relationships between teacher expectations, teacher-student interaction and student achievement, most of these are more accurately construed as student effects on teachers than as the effects of teacher expectations on students (Brophy & Good, 1970; Miller & Turnbull, 1986). Overall, then, teacher expectations generally predict student performance more because they are accurate than because they create self-fulfilling prophecies (Brophy, 1983; Cooper, 1979; Dusek, 1975; Jussim, 1989; Jussim & Harber, 2005; Meyer, 1985; West & Anderson, 1976). In short, predictive validity can come from only two sources, which are both mutually exclusive and exhaustive (Jussim & Harber, 2005): (a) teacher expectations cause student achievement (e.g., through self-fulfilling prophecies); and (b) teacher expectations predict, but do not cause, student achievement. About 75% of the overall predictive validity of teacher expectations for standardized test scores reflects accuracy and the remaining 25% reflects the self-fulfilling prophecy. In addition, as accuracy increases, the potential for self-fulfilling prophecies declines; as accuracy decreases, the potential for self-fulfilling prophecies increases (Jussim & Harber, 2005). As a result, these results provide more support for perspectives emphasizing limitations on self-fulfilling prophecy effects than for perspectives emphasizing the power of expectancy effects to create students' future achievement (Jussim, 1989).

2.8 Teacher Quality

Equality of Educational Opportunity – widely known as the “Coleman Report” – established school as an important influence on student outcomes (Ambussaidi & Yang, 2019). In particular, researchers agree that teachers are one of the most important school-based resources in determining students' future academic success and lifetime outcomes (Chetty et al., 2014; Rivkin et al., 2005; Rockoff, 2004). Also, for policymakers looking at ways to improve compulsory education, one approach has been to focus on teachers as they continue to be the school system's principal resource (Wayne & Youngs, 2003). An OECD study (2005) concluded, “of those variables which are potentially open to policy influence, factors to do with teachers and teaching are the most important influences on student learning”.

A large literature has investigated the contribution of teachers to educational achievements of students (Hanushek & Rivkin, 2006; Staiger & Rockoff, 2010). Most of the

studies have illustrated the positive and cumulative effects of teachers as they relate to student achievement (e.g., Hanushek, 1992; Hanushek & Rivkin, 2006; Kane et al., 2008; Nye et al., 2004; Rivkin et al., 2005; Rowan et al., 2002; Sanders & Rivers, 1996; Staiger & Rockoff, 2010). Similarly, the important role of teachers has also been emphasized as an essential element in structuring and facilitating student learning of science (Reiser et al., 2001; Thomas & Strunk, 2017). For example, their role in classroom instruction situates teachers as direct arbiters of children's experience with science, and their role in the early formation of children's attitudes toward science suggests that elementary science teachers wield heavy influence on boys' and girls' interests, expectations and achievement in science (Thomas & Strunk, 2017).

Multiple studies further point to teacher effectiveness as the dominant factor affecting the academic growth of a student (Burroughs et al., 2019b; Ceglie & Settlage, 2016; Darling-Hammond & Hudson, 1988; George & Kaplan, 1998; Nye et al., 2004; Sanders & Horn, 1998; Sanders et al., 1997). Goe (2007), among others, defined teacher effectiveness in terms of growth in student learning, typically measured by students' standardized assessment results. Chetty et al. (2014) found that students taught by highly effective teachers were more likely to attend college, earn more, live in higher-income neighbourhoods and save more money for retirement. This potential of a highly effective teacher to significantly enhance the lives of their students makes it essential that researchers and policymakers properly understand the factors that contribute to a teacher's effectiveness (Burroughs et al., 2019b). The question of which factors contribute to teacher effectiveness, however, has been a subject of debate among researchers (Ambussaidi & Yang, 2019; Huang & Moon, 2009).

Teacher quality has therefore garnered a great deal of attention (Zhang & Campbell, 2015). A large body of literature exists that examines teacher quality characteristics and the relationship between indicators of those characteristics and teacher effectiveness (Bolyard & Moyer-Packenham, 2008). A consistent finding in the literature suggests that these specific characteristics referring to teacher quality are strongly related to teacher effectiveness, which in turn is associated with student achievement (Gerritsen et al., 2017). As a consequence, these empirical researches identified differences in the quality of teachers as explaining more of the variation in student achievement than any other school-based factor (Goldhaber & Brewer, 1997; Sanders & Rivers, 1996; Strauss & Sawyer, 1986). Hence, there has been a strong emphasis on improving science teacher quality as a way to enhance student science achievement.

2.8.1 The Significance of Teacher Quality

It is generally acknowledged that promoting teacher quality is a key element in improving primary and secondary education (Harris & Sass, 2011). The Coleman Report emphasized the importance of teacher quality standing the test of time (Goldhaber, 2016). New empirical work, using better data and more sophisticated statistical techniques, has, in broad terms, reinforced the Coleman Report's conclusion that the quality of teachers is the most important schooling variable (Goldhaber, 2016). Most of these findings have long regarded teacher quality as a driving force and the most powerful school-related factor responsible for student achievement (e.g., Akiba et al., 2007; Baumert et al., 2010; Blömeke & Delaney, 2014; Blömeke et al., 2016; Burroughs et al., 2019c; Darling-Hammond, 2002; Goldhaber, 2016; Greenberg et al., 2004; Greenwald et al., 1996; Hedges et al., 1994; Moyer-Packenham et al., 2008). Further, several studies indicated that disadvantaged students benefit significantly more from increased teacher quality than those students who represent the larger groups (Bird, 2017; Goldhaber, 2016; Heck, 2007; Nye et al., 2004). In more specific terms, for any groups, the effect of good teachers is greatest upon the children who suffer the most educational disadvantage in their background, and a given investment in upgrading teacher quality will have most effect on achievement, especially in underprivileged areas or nations. Thus, raising the quality of teachers in schools “may well be the single best opportunity to reduce racial and socio-economic achievement gaps” (Boyd et al., 2008, p. 535).

A consistent finding in the literature is that the quality of teachers does matter, but also, importantly, these are resources over which policymakers have direct control (Goldhaber, 2016). Considerable involvement and efforts by governments and policymakers around the world have therefore continually increased the demand to improve and reward teachers based on qualifications (Luschei & Chudgar, 2011; OECD, 2005; Zhang & Campbell, 2015). Many international non-profit organizations have also devoted ambitious and costly efforts to upgrading the quality of teachers (USAID, 2009a, 2009b). In sum, the quality of a teacher is considered to be a crucial factor for the production of human capital. Understanding the determinants of teacher quality is important for improving the quality of education and therefore a key issue for educational policy (Goldhaber, 2016). It is thus more important than ever to explore exactly what characteristics define a qualified science teacher and how best to prepare an individual to fill that role.

2.8.2 Definition of Teacher Quality

Over the last several decades, educators, researchers and policymakers have attempted to improve the capacity of the teacher labour force, spawning a voluminous research literature exploring the relationship between teacher attributes and student educational development in the process (e.g., Bird, 2017; Darling-Hammond, 2002; Hanushek, 1992; Kane et al., 2008; Nye et al., 2004; Rowan et al., 2002; Sanders & Rivers, 1996). The wide variety of research has identified and examined various variables of teacher characteristics believed to be indicators of teacher quality and the relationship between these variables and teacher effectiveness (Rice, 2003; Wayne & Youngs, 2003), which in turn is associated with enhanced student achievement (Huang & Moon, 2009). These characteristics are considered to be measurable, manageable and controllable (Goldhaber, 2004; Lushei & Chudgar, 2011; Rice, 2003). Although there is a large body of research literature on the question of teacher quality, evidence on the impact of teacher characteristics on student outcomes has remained quite limited (Burroughs et al., 2019b). In addition, there has been no consensus on what factors enhance, or even signal, teacher quality (Goldhaber, 2016; Harris & Sass, 2011). Hence the literature has not yet provided clear policy advice about the types of teachers that are most effective, and therefore should be hired and kept in the education profession based on their observed characteristics (Goldhaber, 2016). Identifying the determinants of teacher quality in promoting student achievement, therefore, has been less clear and continues to be an important area of focus in educational research (Huang & Moon, 2009).

Teacher quality is a complex phenomenon for which no general and absolute agreement exists concerning an appropriate and comprehensive definition (Ambussaidi & Yang, 2019; Zhang & Campbell, 2015). Researchers, policymakers and educators have historically viewed teacher quality from differing perspectives (Bolyard & Moyer-Packenham, 2008). From a researcher's point of view, teacher quality is operationalized as a construct and variables, which are identified and examined in relation to outcome measures. For a policymaker, teacher quality provides a benchmark against which individuals can be identified as meeting or not meeting a given standard of quality (Blank & Langeson, 1999). School administrators view teacher quality as a means of finding the right educator for the job. For educators in different positions within the educational system, teacher quality takes on different meanings. For the classroom teacher, teacher quality may be viewed as a continuous process of self-renewal and professional development where one works to impact and improve the quality of one's own teaching. A teacher educator may view a high-quality teacher as one who has a strong foundational knowledge of content and pedagogy that can be built upon and strengthened throughout one's

career. With these perspectives in mind, it is easy to see how different views have emerged within the construct of teacher quality.

There were hence many different interpretations of what teacher quality means. The existing body of literature on teacher quality includes a wide range of formal qualifications, which are indicated by educational level, major field of study, years of teaching experience and certification, sense of preparedness to teach specific subjects (Blömeke et al., 2016; Gustafsson & Nilsen, 2016), instructional practices and participation in professional development activities, as well as teacher evaluation scores as direct predictors of student educational outcomes (Ambussaidi & Yang, 2019; Blömeke et al., 2016; Burroughs et al., 2019c; Darling-Hammond, 2004; Greenwald et al., 1996; Hanushek, 1997; Rice, 2003; Wayne & Youngs, 2003).

For example, Kennedy (2008) defined teacher quality as attributes teachers possess that enable them to effectively impact student achievement. These include characteristics teachers bring with them to the job, performance on a daily basis, and their ability to build relationships and make connections with their students. Burroughs et al. (2019a) explored factors associated with teacher quality including both teacher characteristics (experience, self-efficacy, formal preparation, gender) and teacher behaviours (instructional time and content). Burroughs et al. (2019b, 2019c, 2009e) identified three main categories of teacher quality that may be associated with higher student achievement, namely teacher experience, teacher professional knowledge (measured by education and self-reported preparation to teach specific subjects) and teacher behaviour, such as teacher provision of opportunity to learn (measured by time spent on particular subjects and content coverage). Blömeke et al. (2016) concluded that the variables indicative of teacher quality include measures of teacher qualifications, particular characteristics of teachers' educational background, amount of experience in teaching and participation in professional development activities, as well as personality characteristics such as teachers' self-efficacy (Thomas & Strunk, 2017). Strong (2011) grouped the definitions according to the perspectives of former researchers: the qualifications of the teacher as a reflection of competence (e.g., degree, quality of college, exam scores, certification, subject matter credential, experience); the personal or psychological qualities of a teacher, such as love of children, honesty, compassion and fairness; the pedagogical standards that a teacher exhibits (use of certain teaching strategies, classroom management skills, establishment of a positive classroom climate); and the teacher's demonstrated ability to raise student learning (successful or effective teaching). Bird (2017) indicated that the areas of teacher quality that have been most commonly studied and scrutinized in regard to the relationship with student achievement

included teacher effects, teacher experience, teacher qualifications, teacher certification, teacher education (degree level), teacher preparation programmes and teacher evaluation scores. Heck (2007) defined teacher quality as the percentage of teachers who were certified, passed knowledge tests in their content area and met performance standards. According to Bolyard and Moyer-Packenham (2008), there were six primary characteristics commonly identified by researchers in studies examining the quality of science teachers, namely general ability, experience, pedagogical knowledge, subject matter knowledge, certification status and teacher behaviours, practices and beliefs. These categories of individual teacher quality were chosen based on their frequent use in large-scale meta-analyses and reviews of the literature on general teacher quality (Cochran-Smith & Zeichner, 2009; Darling-Hammond, 2000; Rice, 2003; Wayne & Youngs, 2003; Wilson et al., 2001; Wilson & Floden, 2003). Although teacher quality measures vary from study to study (Hanushek, 1989; Heck, 2007; Rockoff, 2004), these quality measurements are often framed around teaching experience, teacher certification, educational degree level, academic major and professional development. The results of these studies, however, have been mixed and inconclusive.

In summary, educators, researchers and policymakers have sought to identify the characteristics of a well-qualified teacher (Moyer-Packenham et al., 2008). In general, a highly qualified teacher is commonly identified as fully certified, experienced, possessing an advanced degree, demonstrating competence in both subject matter knowledge and subject-specific knowledge for teaching (Akiba et al., 2007), and participating in professional development activities. Further, findings from international studies using the TIMSS data set provide additional insights regarding teacher attributes and student achievement (Burroughs et al., 2019d; Zhang & Campbell, 2015). Since 1995, successive cycles of TIMSS have randomly selected a group of representative schools as well as intact classrooms and collected extensive information about teacher background and practices across countries; such data are ideally suited to addressing important questions about the role of teachers in influencing student outcomes (Burroughs et al., 2019c, 2019e). As a consequence, TIMSS data provide a unique opportunity to examine the impact of teachers on a representative sample of students in multiple countries across time. In the present study, this advantage of the design of TIMSS is thus taken to examine the relationship between the key characteristics of teacher quality and science achievement (Blömeke et al., 2016).

2.8.3 The Relationship between Teacher Quality and Student Achievement

More recent studies investigating the relationship between specific characteristics of teacher quality and student achievement have continued to provide mixed results (Ferguson, 1991; Ferguson & Ladd, 1996; Goldhaber, 2004; Greenwald et al., 1996; Hanushek, 1997; Rivkin et al., 2005; Wayne & Youngs, 2003; Wenglinsky, 2002). Particularly in the subject of science, because of the limited number of studies, findings in this area have been inconclusive (Zhang & Campbell, 2015).

Many empirical studies and contemporary research have consistently identified several teacher characteristics selected on the basis of teacher quality that are associated with student achievement (Croninger et al., 2007; Rockoff, 2004). For example, Goldhaber (2016) and Blömeke et al. (2016) suggested that teacher quality is one of the few school characteristics that significantly affect student performance. Hedge et al. (1994), Greenwald et al. (1996) and Darling-Hammond (2000) revealed that variables that attempt to describe the quality of teachers show very strong relations with academic performance. Further, there are several studies that have indicated that the collective attributes of teacher quality have a positive relationship with student achievement (e.g., Ambussaidi & Yang, 2019; Clotfelter et al., 2007; Greenwald et al., 1996; Heck, 2007; Nye et al., 2004; Rockoff, 2004; Sanders et al., 1997; Zhang & Campbell, 2015). These studies have clearly supported the relevance of teacher quality for higher educational outcomes (Nye et al., 2004; Sanders et al., 1997). In other words, high-quality teachers are considered to play an essential role in promoting student achievement (Burroughs et al., 2019c; Harris & Sass, 2011; Zhang & Campbell, 2015). On the other hand, unqualified teachers are likely the most important factor contributing to poor student achievement (Goldhaber, 2004). Additionally, the research shows the important variation in teacher quality within schools and its connection not only to achievement scores but also to other important outcomes (Goldhaber, 2016). For example, Chetty et al. (2014) found that teacher quality predicted students' outcomes long into the future. Students assigned to high-value-added teachers are more likely to graduate from high school, go to college, be employed and earn higher wages. Nonetheless, teacher quality indicators that influence student achievement in different countries may vary depending on the educational context, student characteristics and school factors (Ambussaidi & Yang, 2019).

On the other hand, a series of analyses attempted to identify potential trends in teacher quality over time and its relationship with student achievement, but found no strong evidence of consistent predictable relationships between commonly employed indicators of teacher effectiveness and student outcomes (Burroughs et al., 2019d, 2019f; Wayne & Youngs, 2003).

In short, these studies suggested that the relationship between teacher quality measures and student outcomes across countries and grade levels appears to be generally weak and inconsistent (Hanushek, 1989; Hanushek & Rivkin, 2010).

The following section sheds light on characteristics believed to be indicators of teacher quality and the relationship between variables of these characteristics and student achievement. Primary attributes studied frequently as indicators of individual teacher quality are teachers' years of experience, teachers' professional knowledge and teachers' participation in professional development.

2.8.3.1 Informal On-the-Job Training: Teacher Experience.

Teacher experience refers to the total number of years that a teacher has taught (Bird, 2017; Bolyard & Moyer-Packenham, 2008; Burroughs et al., 2019b, 2019e). Overall teaching experience has been investigated in several studies (e.g., Croninger et al., 2007; Link & Ratledge, 1979; Murnane & Phillips, 1981; Summers & Wolfe, 1977). Teachers' years of experience is found to be an observed characteristic that matters for enhanced effectiveness and productivity in teaching (Ehrenberg & Brewer, 1995; Ferguson, 1991; Fetler, 1999; Greenwald et al., 1996; Hanushek, 1992, 1996; Noell & Burns, 2006; Staiger & Rockoff, 2010). Further, teacher experience is often considered an important attribute in relation to student achievement (Chetty et al., 2011; Hanushek, 2011; Harris & Sass, 2011; Hawkins et al., 1998; Kane et al., 2008; Krueger, 1999; Moyer-Packenham et al., 2008; Staiger & Rockoff, 2010; Wiswall, 2013). However, the impact of teacher experience on educational development depends on the different grade levels as well as particular subject areas (Nye et al., 2004; Rowan et al., 2002). Krueger (1999) and Chetty et al. (2011) found a larger effect of experienced teachers for children of early grades than for higher grades. In other words, teacher experience raises test scores, especially for younger pupils. Hence, more focused policies that keep experienced teachers in the classroom appear to be beneficial mostly for younger students.

A wide variety of research has been conducted on the relationship between teacher experience and student achievement over several decades (Ehrenberg & Brewer, 1994; Hanushek, 1989). In general, the results of these studies have been quite mixed with no consistent relationship (Bird, 2017; Bolyard & Moyer-Packenham, 2008; Hanushek, 1989), with some results indicating enhanced student outcomes as teachers gained experience (e.g., Akiba et al., 2007; Bolyard & Moyer-Packenham, 2008; Clotfelter et al., 2007; Ehrenberg & Brewer, 1995; Ferguson, 1991; Fetler, 1999; Goldhaber & Brewer, 1997; Greenwald et al.,

1996; Hanushek, 1996; Murnane & Phillips, 1981; Rice, 2003), other results showing teacher experience having a positive impact within the first three to five years of the teaching career but with little impact thereafter (e.g., Clotfelter et al., 2010; Croninger et al., 2007), and yet more studies finding little to no correlation whatsoever (e.g., Gallagher, 2004).

Many studies showed a statistically significant positive relationship between experienced teachers and student achievement gains (e.g., Ambussaidi & Yang, 2019; Chidolue, 1996; Ferguson, 1991; Fetler, 1999; Nye et al., 2004). In other words, students' test scores improved with teachers who had more years of teaching experience. In Greenwald et al.'s (1996) meta-analysis, teaching experience was found to be a strong positive predictor of student academic outcomes, with 30% of the studies showing statistically significant positive effects and with only 3% showing small or statistically significant negative effects. Goldhaber (2016) indicated that students who were allocated to classes with more experienced teachers performed better than students assigned to classes with less experienced teachers. Similarly, Clotfelter et al. (2007) clearly reported that teachers with more experience were more successful at raising student achievement scores than their less experienced colleagues. Rivkin et al. (2005) and Croninger et al. (2007) reported that students of inexperienced teachers performed significantly worse than those of experienced teachers. These results were possibly attributed to experienced teachers learning their craft through experience and thus being more capable of meeting the affective needs of their students than less experienced teachers (Chidolue, 1996).

Nevertheless, although teachers' years of experience had a positive relationship with student learning, it was not always significant or linear (Goldhaber & Brewer, 1997; Murnane & Phillips, 1981). Until recently there was a consensus in the literature that the experience of teachers only matters for their effectiveness (Ambussaidi & Yang, 2019) and student achievement gains during the first several years of their teaching career (e.g., Clotfelter et al., 2007; Croninger et al., 2007; Goldhaber, 2008; Harris & Sass, 2011; Rivkin et al., 2005; Rockoff, 2004; Staiger & Rockoff, 2010) but tended to show limited gains in subsequent years (Wiswall, 2013). Clotfelter et al. (2010) further indicated that both beginning teachers and more experienced teachers were no more effective than those with three to five years of experience. Nonetheless, in contrast to previous literature mentioned above, recent studies indicated that gains from teacher experience were also found after the initial years in teachers' profession (Harris & Sass, 2011; Wiswall, 2013). For example, Harris and Sass (2011) illustrated that the largest gains from experience did indeed occur in the first few years, but found continuing

gains beyond the first five years of teachers' career in some subjects and grades. Krueger (1999) and Chetty et al. (2011) therefore concluded that teacher experience matters for student performance not only in the initial stages but also in later stages of the teaching career.

Meanwhile, other studies have failed to identify consistent, statistically significant or even any association between student achievement and teacher experience (e.g., Archibald, 2006; Blömeke et al., 2016; Borman & Kimball, 2005; Croninger et al., 2007; Gallagher, 2004; Gustafsson & Nilsen, 2016; Hanushek & Luque, 2003; Hawk et al., 1985; Heck, 2007; Huang & Moon, 2009; Kimball et al., 2004; Link & Ratledge, 1979; Luschei & Chudgar, 2011; Summers & Wolfe, 1977; Wilson & Floden, 2003). Some studies have even shown teacher experience to have negative effects on student outcomes (Bird, 2017; Huang & Moon, 2009). According to these literatures, little of the variation in teacher quality is explained by the average number of years of teaching experience (Rivkin et al., 2005). Therefore, less experienced teachers could be more effective than veteran teachers (Bird, 2017). Rice (2010) asserted that this could be attributed to seasoned teachers not keeping up to date with the most recent instructional strategies and curricular advances.

In sum, the results of the studies investigating the relationship between teacher experience and student achievement were mixed and inconsistent, with most of the studies showing statistically significant positive effects and some showing small, negative or even no effects. Nonetheless, teacher experience is essential, and the first years of teaching experience are especially important for teacher development (Harris & Sass, 2011; Leigh, 2010). However, research has also found that teachers continue to develop after five years of experience, and that this development can positively affect student achievement (Harris & Sass, 2011).

2.8.3.2 Teacher Professional Knowledge.

A teacher's professional knowledge refers to pedagogical knowledge, subject matter knowledge and curricular knowledge (Collinson, 1999). This professional knowledge is mainly influenced by their formal educational background – for example, undergraduate qualifications earned by a teacher, graduate studies undertaken, the major academic disciplines studied (subject specializations), specific coursework taken, college attended (competitive level of the undergraduate institution) and opportunities to engage with professional development (Collinson, 1999; Rice, 2003; Wayne & Youngs, 2003). Several areas have been studied using these indicators of teacher professional knowledge to reveal the relationship between teacher preparation and student achievement gain (Bird, 2017).

Teachers' Formal Education Degree Level: Possession of an undergraduate degree or an advanced degree.

In order to be successful in any profession, most people would argue that the proper level of training and education is necessary (Bird, 2017). Nonetheless, when considering the relationship between a teacher's level of education and student achievement, the findings presented in the literature are often inconsistent (Wilson & Floden, 2003) – sometimes positive, but sometimes conflicting, or they proved to be small, negative or not statistically significant (Clotfelter et al., 2007, 2010; Hanushek, 1989; Hawk et al., 1985; Kimball et al., 2004; Rivkin et al., 2005).

Several international studies have reported that teachers' degree levels are related to student outcomes (Akiba et al., 2007; Gustafsson & Nilsen, 2016; Montt, 2011; Wößmann, 2003). Blömeke et al. (2016) even indicated that the level of teacher education is on average the strongest predictor of student achievement across all countries. According to the NCLB's definition, a highly qualified teacher should have, as a minimum, a bachelor's degree. Some studies further revealed that students assigned to teachers with an advanced degree performed better than those assigned to teachers with only a bachelor's degree (Betts et al., 2003; Harris & Sass, 2011; Nye et al., 2004). On the other hand, there is also evidence indicating either insignificant or in some cases even negative associations between the possession of an advanced degree by a teacher and their effectiveness (Harris & Sass, 2011) or student achievement gains (Croninger et al., 2007; Dee, 2004; Nye et al., 2004; Rivkin et al., 2005). For example, Hanushek (1986) reviewed numerous studies that used teacher education level as a variable and found no strong evidence supporting the idea that teachers with advanced degrees perform any differently from those that have only a bachelor's degree. Clotfelter et al. (2007, 2010) reported that teachers who earned a master's degree appear to be somewhat less effective on average than those who do not have a graduate degree, and they even found a large negative effect for teachers who have earned a Ph.D. Harris and Sass (2011) did not find any significant relationships between advanced degrees and student achievement in any other subject area except mathematics. However, these findings regarding advanced degree attainment may be misleading since these degrees are often earned over an extended period of time and the impact of those courses may take effect over a number of years.

2.8.3.2.1 The Competitive Level of the Undergraduate Institution.

In addition to teachers' education degree level, some studies further took the competitiveness of undergraduate institutions into account while detecting the predictors of teacher quality. Several results showed a positive and significant relationship between the prestige of the undergraduate institution and later effectiveness as a teacher (Clotfelter et al., 2010; Kane et al., 2008), which in turn leads to differences in students' test scores. For example, Ehrenberg and Brewer (1994, 1995) and Summers and Wolfe (1977) found that having a teacher who had attended a higher-rated undergraduate institution is statistically significantly associated with higher gains in the average student performance in several areas. Clotfelter et al. (2010) also reported a positive and statistically significant relationship between student achievement and whether or not their teachers attended a very competitive college. However, other studies suggested that the reputation and quality of an undergraduate institution do not make a statistically significant contribution to student outcomes (Cavalluzzo, 2004; Kane et al., 2008).

2.8.3.2.2 Pedagogical Knowledge.

Teacher education research often considers measures of teachers' pedagogical knowledge as an indicator of teacher quality (Ambussaidi & Yang, 2019; Bolyard & Moyer-Packenham, 2008; Moyer-Packenham et al., 2008). These studies use measures such as a major in pedagogy, degrees in education or educational coursework to examine the impact of teacher preparation on the development of teaching-related knowledge, and subsequently to explore the connection between teachers' pedagogical knowledge, or so-called "knowledge of teaching", and student academic outcomes. Researchers have reported positive effects of education training on teachers' pedagogical knowledge and practice (Adams & Krockover, 1997; Ferguson & Womack, 1993; Gess-Newsome & Lederman, 1993; Grossman & Richert, 1988; Grossman et al., 2000; Guyton & Farokhi, 1987; Hansen & Feldhusen, 1994; Valli & Agostinelli, 1993). However, studies examining the relationship between degrees or coursework in education as a measure of teachers' pedagogical knowledge and student outcomes have been more mixed (Bolyard & Moyer-Packenham, 2008). Most of these studies found a positive effect of pedagogical knowledge on student learning (Adams & Krockover, 1997; Ashton & Crocker, 1987; Ferguson & Womack, 1993), especially at the elementary level. Hawkins et al. (1998) also indicated that students of teachers who had a major in education or subject-specific pedagogy significantly outperformed students of teachers with a major in a field other than education or subject matter pedagogy. On the other hand, a few studies showed

that teachers with education degrees have no impact on students' science achievement and even have a statistically significant negative influence on students' mathematics achievement at the high school level (Goldhaber & Brewer, 2000).

2.8.3.2.3 Teacher Content Knowledge/Subject Matter Knowledge.

There is a growing body of work suggesting that teacher content knowledge may be associated with student learning (Burroughs et al., 2019b). It should be noted that there is an important distinction between general content knowledge about a subject (i.e., science knowledge) and pedagogical content knowledge (i.e., science education) specifically related to teaching that subject, each of which may be independently related to student outcomes (Baumert et al., 2010).

Subject matter knowledge, which refers to knowledge of subject-specific content, is another highly valued teacher characteristic presumed to be indicative of teacher quality (Bolyard & Moyer-Packenham, 2008; Goldhaber & Brewer, 1998; Moyer-Packenham et al., 2008; Rowan et al., 1997). Common variables used to measure teacher content knowledge include an undergraduate or graduate subject-specific major, a degree and coursework (Bolyard & Moyer-Packenham, 2008). Reviews of research indicated links between teachers' subject matter preparation and student achievement, although these results are inconclusive (Darling-Hammond, 2000; Darling-Hammond & Youngs, 2002; Hawkins et al., 1998; Monk, 1994; Rowan et al., 2002; Wilson et al., 2001; Wilson & Floden, 2003). However, more studies reported a trend toward positive associations between teachers' subject specializations and their student academic outcomes (e.g., Baumert et al., 2010; Chaney, 1995; Chingos & Peterson, 2011; Clotfelter et al., 2006; Constantine et al., 2009; Croninger et al., 2007; Druva & Anderson, 1983; Goldhaber & Brewer, 2000; Harris & Sass, 2011; Hawk et al., 1985; Hawkins et al., 1998; Hill et al., 2005; Metzler & Woessmann, 2012; Monk, 1994; Monk & King, 1994; Rowan et al., 1997; Shuls & Trivitt, 2015). Only a few studies considering teachers' major academic disciplines, subject-specific degrees or coursework as teacher content knowledge found neither a positive nor a significant relationship between this subject matter preparation and student achievement in science (Goldhaber & Brewer, 2000), mathematics (Eisenberg, 1977; Rowan et al., 2002) and reading (Rowan et al., 2002).

2.8.3.2.4 Pedagogical Content Knowledge/Subject-Specific Knowledge for Teaching.

The intersection of subject-specific knowledge and pedagogy is defined as pedagogical content knowledge (Shulman, 1986) or subject matter knowledge for teaching (Hill & Ball, 2004). Shulman (1986) referred to pedagogical content knowledge as knowledge that “goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching” (p. 9). This knowledge includes ways of representing a topic in a way that makes it accessible to learners and enhances understanding of what facilitates or hinders the learning of a topic. Although the evidence supported the idea that teachers’ specialization in a particular subject is essential for students’ educational development, there were indications that preparation in subject-specific pedagogy is beneficial as well (Blömeke et al., 2016; Bolyard & Moyer-Packenham, 2008; Clotfelter et al., 2007). This discussion stemmed from a perspective that knowing a subject for oneself is not adequate to effectively carry out the work of teaching. Rather, teachers must have an understanding of content as well as knowledge of how students think and understand the content. Hence, Ball (1991, 2003) argued that teachers must not only know the subject matter for themselves but also understand the subject in a way that enables them to effectively use it in instruction. Correspondingly, both teachers’ pedagogical content knowledge and content knowledge about a subject are of great importance for instructional quality and student learning (Blömeke et al., 2016).

The impact of pedagogical content knowledge, as measured mostly by majors or courses taken in subject-specific pedagogy (Burroughs et al., 2019e) (i.e., a major or degrees in science education, or science education methods courses), on student achievement has also been examined (Bolyard & Moyer-Packenham, 2008). Several results showed evidence of a positive relationship between subject matter knowledge for teaching and student achievement (Goldhaber & Brewer, 1997; Hawk et al., 1985). Hawkins et al. (1998) found that students of fourth-grade teachers who had a college major in education or mathematics education significantly outperformed students of teachers with a major in a field other than education, mathematics education or mathematics. Courses taken in subject-specific pedagogy also appear to have a positive relation with student achievement (Chaney, 1995; Monk, 1994). For example, Chaney (1995) found that students whose teachers had taken coursework in both advanced mathematics and mathematics education had higher scores in mathematics tests than students of teachers who had taken neither class of course. Druva and Anderson’s (1983) meta-analysis indicated positive correlations between student outcomes and teachers’ background in science and education courses. In sum, the preparation and competence of teachers to teach a specific subject is critical. Prospective science teachers therefore need to gain knowledge in science

that they will teach and to understand about how students learn, as well as to learn about effective pedagogy in teaching science (Hooper et al., 2013).

2.8.3.3 Professional Development.

Another predictor of teacher quality is one of the main forms of teacher training, in-service professional development. Several findings that less experienced teachers are more effective than veteran teachers (Rice, 2010) can be attributed to the seasoned teachers not keeping up to date with the most recent instructional strategies and curricular advances (Clotfelter et al., 2010). Additional research therefore pointed to the importance of attending effective professional development activities (National Science Board, 2014). For example, Harris and Sass (2011) claimed that implementing content-oriented professional development exposes teachers to recent developments within the field, which in turn leads to positive gains in overall teacher productivity as well as fostering student achievement in the specific subject. Rice (2010) contended that schools should focus their professional development on current best practices and provide incentives in order to ensure that teachers are capable of delivering instruction that best meets the needs of their students.

In almost all countries, a variety of professional development activities exist, from very short classes to comprehensive programmes (Goldsmith et al., 2014; Guskey, 2000). These include school-based programmes and coaching, seminars, workshops, conferences, professional journals or other types of out- and in-service training with the aim of supporting the development of teacher competencies, increasing their effectiveness and broadening their knowledge (Blank & de las Alas, 2009; Hooper et al., 2013; Yoon et al., 2007). Overall, meta-analyses have suggested that professional development is positively related to instructional quality and student achievement only if the activities meet certain quality features (Timperley et al., 2007), which are classified into a focus on content, active learning, coherence, and a certain minimum length of the professional development course to be sustainable and collaborative activities (Desimone, 2011). Collaboration in terms of joint work on cases and practising under supervision of colleagues seems to be particularly relevant (Boyle et al., 2005). Discussions, reflection and continuous feedback seem to stimulate real changes in beliefs and routines (Goldsmith et al., 2014). TIMSS included several scales that assessed both teachers' participation in formal professional development activities and their involvement in continuous and collaborative professional development activities with colleagues in the school (Blömeke et al., 2016).

However, some researchers found that teachers' professional development experiences fail to yield changes in teacher effectiveness that are detectable in student test scores (Burroughs et al., 2019b; Goldhaber, 2016). These findings commonly indicated that in-service professional development showed only little or even no effect on the ability of teachers to improve student achievement (Garet et al., 2008, 2010; Jacob & Lefgren, 2004; Wallace, 2009), especially at the elementary level (Harris & Sass, 2011). However, Cavalluzzo (2004) claimed that professional development is positively related to teacher effectiveness. Blank and de las Alas (2009) and Blömeke et al. (2016) even reported significant and positive relationships between teachers' continuous professional development and student achievement.

2.8.4 The Relationship between Science Teacher Quality and Student Science Achievement

Over the past three decades, only a limited amount of studies have been conducted investigating the relationship between characteristics of teacher quality and student achievement in the area of science (Goldhaber & Brewer, 2000; Monk, 1994; Ye, 2000). The relationship between science teacher quality and student science performance has produced mixed and inconsistent results (Bolyard & Moyer-Packenham, 2008; Chaney, 1995; Goldhaber & Brewer, 2000; Monk, 1994; Zhang & Campbell, 2015).

In terms of science teacher experience, Druva and Anderson (1983) found that student outcomes in science were positively related to teachers' experience, whereas Goldhaber and Brewer (2000), Monk (1994) and Ye (2000) indicated that there was no relationship between teacher experience and student science achievement, which implied that science teachers with more years of teaching experience were no more effective than those with less experience.

Research on the relationship between teachers' knowledge for teaching and student achievement has also been limited and generally in the area of mathematics (Bolyard & Moyer-Packenham, 2008). In the case of science teachers, previous studies commonly produced mixed results regarding the effects of science teachers' educational background – as measured by teacher educational level and professional knowledge in science and/or education – on student science achievement (Zhang & Campbell, 2015). Teachers with a major or degrees in science delivered the body of content knowledge necessary to present science to learners in a meaningful way and to connect scientific ideas and topics to one another, as well as to the learner's prior knowledge and future learning objectives (Cochran-Smith & Zeichner, 2009; Wilson et al., 2001). Although the impact of teacher education on student achievement in science has been inconclusive, there has remained evidence of a positive trend (Bolyard &

Moyer-Packenham, 2008). For example, Goldhaber and Brewer (2000) reported that students taught by teachers with bachelor's degrees in science had significantly higher science achievement scores than those taught by teachers without any degree or only with a bachelor's degree in a non-science subject. Monk (1994) indicated a significant positive relationship between teachers with a science major and their students' science achievement. Druva and Anderson (1983) found student achievement to be positively related to the number of science courses taken by teachers. Chaney (1995) revealed positive associations between students' science achievement and teachers holding graduate degrees in science. Bolyard and Moyer-Packenham (2008) suggested that teachers who held a bachelor's or master's degree in science appeared to have positive impacts on student science outcomes. Further, some research indicated that the relationship between science teachers' subject matter preparation and student achievement often depended upon the area of science, i.e., physical science, life science, earth science, etc. (Chaney, 1995; Druva & Anderson, 1983; Monk & King, 1994). For example, Bolyard and Moyer-Packenham (2008) suggested that the number of credits in earth and physical science earned by a teacher was positively related to student achievement. Monk and King (1994) found that coursework in physical sciences had a positive impact on higher-ability students.

On the other hand, several studies have failed to identify consistent, positive, significant or even any association between predictors of teacher quality and student science performance. For example, Goldhaber and Brewer (2000) and Ye (2000) found that a teacher with a master's degree in science or education was not a significant predictor of student achievement in science. A few studies focused explicitly on cross-national large-scale data revealed limited evidence that teacher characteristics were systematically related to student science achievement (Luschei & Chudgar, 2011; Zhang & Campbell, 2015). In Monk's study (1994), the findings were also mixed, with a teaching degree in science influencing juniors but having no effect on sophomores.

In sum, as one of the most significant school-based resources in determining students' academic success and lifetime outcomes, teachers have attracted a great deal of attention, especially the important role of teacher quality as an essential element in structuring and facilitating student learning in science. The importance of teacher quality has stood the test of time (Goldhaber, 2016). The quality of a teacher has been considered a crucial factor for the production of human capital. Further, it has been generally acknowledged that raising the quality of teachers is a key element in enhancing teacher effectiveness, which in turn can

increase student academic outcomes, and is the best chance of reducing racial and socio-economic achievement gaps in schools. Therefore, understanding the determinants of teacher quality is considered key for improving the quality of education. Although studies examining the relationship between specific characteristics selected on the basis of teacher quality and student science achievement have provided mixed results, there has remained evidence of a positive trend. In other words, high-quality science teachers are still considered to have an essential role in promoting student science achievement (Burroughs et al., 2019c; Harris & Sass, 2011; Zhang & Campbell, 2015). Such findings have the potential to provide insights into the importance of hiring and developing qualified teachers, who are more capable of helping students achieve in science, and to provide direction for ongoing teacher training (Wayne & Youngs, 2003). It is therefore necessary to explore the relationship between teacher quality and student science achievement in this study.

Chapter 3: Theoretical Framework

3.1 Introduction

This chapter focuses on theories used in this study to explain the components of personal psychological characteristics and contextual factors that influence student science achievement. Using an ecological model and expectancy-value theory as a guide, this study investigated: (1) the gender differences in science achievement; (2) the associations between students' attitudes toward science and their science achievement; (3) the associations between teachers' expectations and student science achievement; (4) the associations between parental expectations and student science achievement; (5) the role of teachers' and parents' expectations in the relationships between student gender, student attitudes toward science and student science achievement. The hypotheses and the conceptual models are formulated at the end of this chapter.

3.2 Bronfenbrenner's Ecological Model

The best-known model, Bronfenbrenner's ecological theory of development (Bronfenbrenner, 1977, 1979), posits a series of overlapping systems to illustrate the potential impact of both immediate and indirect contextual factors on human behaviour (Cross et al., 2015). These systems, namely microsystem, mesosystem, exosystem and macrosystem, are nested hierarchically from proximal to distal and centre on an individual (Bronfenbrenner, 1979; Bronfenbrenner & Ceci, 1994). In the case of students' learning, the ecological model suggests that students' developmental outcomes are the product of the interaction between the student and his or her multiple environmental systems (Bronfenbrenner, 1979). This ecological model can therefore help explain the effect of contextual factors on parental educational expectations, teachers' academic expectations, students' academic characteristics, such as attitudes towards learning science, and their science achievement.

The proximal environment, also referred to as the "microsystem" – the layer closest to the student – includes family or home, school and peer groups, to which children are commonly exposed (Bronfenbrenner & Ceci, 1994). At this most immediate level, children have direct interactions with their parents, teachers and peers, who influence and reinforce their particular attitudes and behaviours (Cross et al., 2015). For example, within the family environment, parents may be involved in children's education by expecting their children to perform well academically (Benner et al., 2016; Wilder, 2014). Such practice may provide specific direction and guidance for children with respect to their education (Hou & Leung, 2011). Through an

ecological lens, parents' educational practices offer children an education-oriented proximal environment, which, in theory, influences their educational outcomes. Bronfenbrenner (1979) further theorized that this proximal environment differs depending on family background characteristics, such as family socio-economic status, parents' educational attainment and family structure. Similarly, the interaction between students and teachers at school also plays a substantial role in the formation of students' motivation for learning and their educational achievement. Teachers have expectations and hold values for their students to grow in various developmental aspects. They subsequently guide their students' academic development by interacting with them in specific ways to convey and emphasize the importance of those expectations and values to their students (Zhang, 2018).

Further, the social concept of gender role influences the expectations of both teachers and parents as well as their interactions with children because they treat boys and girls differently (Eccles et al., 1990). In addition, teachers' and parents' beliefs about the role of gender in STEM fields are found to be associated with boys' and girls' interest, values and self-efficacy in learning science (Zhang, 2018). Therefore, the ecological model also provides insight from a socialization perspective in understanding the influential role of gender in parents' and teachers' expectations as well as children's academic beliefs and behaviours. Additionally, ecological theory states that the proximal environment contributes to an individual's academic achievement, depending on personal characteristics, such as gender, motivation and attitudes. In other words, the theory also underscores the role of personal characteristics in one's academic achievement (Bronfenbrenner & Morris, 2006).

The environments from the microsystem also affect children's development by influencing each other at the level known as the "mesosystem" (Cross et al., 2015). For example, the home and family interact with the school and class teachers, and these two settings can have a joint impact on the child. More distant systems also affect the child. The exosystem includes contexts with which the child does not have immediate contact but which still affect their lives, such as a parent's workplace, school administrators and institutional infrastructures (Cross et al., 2015). Moreover, the most distal environment, also referred to as the "macrosystem", consists of broader social, cultural, political and economic ideologies, in which all other lower-order systems are embedded (Cala & Soriano, 2014). The macrosystem shapes the institutions and social trends that ultimately affect the child's environment (Bronfenbrenner, 1977, 1979). Therefore, the social and cultural context plays an influential role in teachers' academic

expectations, parents' educational expectations and children's learning process overall (Thomas & Strunk, 2017).

In summary, Bronfenbrenner provided a theory for analysing the different levels that influence the construction of children's behavioural development, emphasizing how important the environment is for it (Esteban & Ratner, 2010). The model envisages the existence of a number of environments or contexts that may be analysed from four levels, which are all part of the same reality (Cala & Soriano, 2014). Accordingly, this study examined parents' educational expectations and teachers' academic expectations as two important educational involvement practices of social agents that construct a proximal environment that influences children's science achievement. Further, the key role of children's characteristics, including gender, and their academic characteristics of attitudes towards learning science that contribute to their science achievement were considered, as were contextual family factors, such as family socio-economic background, as well as the distal factor of cultural background.

3.3 Expectancy-value Theory

Individual differences in cognitive ability predict educational attainment and achievement (Deary et al., 2007; Kuncel et al., 2004; Rohde & Thompson, 2007). However, psychological constructs capturing individual differences in motivation (e.g., self-concept, interest and values) have been shown to explain an additional amount of variance in these outcomes (Chamorro-Premuzic et al., 2010; Duckworth & Seligman, 2005; Kuncel et al., 2010; Steinmayr & Spinath, 2009). In other words, motivation predicts academic achievement beyond cognitive ability. Motivation is a set of beliefs, values and emotions that influences how an individual tackles an activity or a goal (Pintrich & Schunk, 2002). In the case of students' learning, generally, motivated students invest more time in educational tasks, expend greater effort, ask for help and persist in the face of difficulty (Eccles et al., 1998; Wang et al., 2013). Scholars even point to motivation as a viable explanation for racial-ethnic disparities in students' academic outcomes (Fuligni et al., 2009). One of the most elaborate and influential frameworks to conceptualize achievement motivation is expectancy-value theory (Atkinson, 1957; Eccles, 2009; Eccles et al., 1983; Wigfield & Eccles, 2000). Expectancy-value theory is also a widely accepted and powerful approach explaining academic achievement as well as educational choices and attainment (Meyer et al., 2019). This framework proposes that motivation is a function of expectancy and task value components (Flake et al., 2015). Recently,

attention to the multiplicative term of “expectancy and value beliefs” has increased (Meyer et al., 2019).

A developmental perspective expectancy-value theory has been one of the most important views on the nature of achievement motivation (Flake et al., 2015; Meyer et al., 2019; Safavian & Conley, 2016; Wigfield, 1994), beginning with Atkinson's (1957) seminal work and continuing through the work of Battle (1965, 1966), Crandall et al. (e.g., Crandall, 1969; Crandall et al., 1962) and more recently Feather (1982, 1988, 1992) and Eccles, Wigfield, et al. (e.g., Eccles, 1984; Eccles et al., 1983; Eccles et al., 1984; Wigfield & Eccles, 1992). Theorists adopting this perspective posit that individuals' expectancies for success and the value they have for succeeding are important determinants of their motivation to perform different achievement tasks (Wigfield, 1994). Atkinson (1957) originally defined expectancies as individuals' anticipations that their performance will be followed by either success or failure, and defined value as the relative attractiveness of succeeding or failing in a task. More recent researchers in the expectancy-value tradition (e.g., Eccles et al., 1983; Wigfield & Eccles, 1992) have expanded these definitions, and further discussed how individuals' expectancies for success, subjective task values and other achievement beliefs mediate their motivation and achievement in educational settings. In this study, the expectancy-value theory proposed by Eccles, Wigfield, et al. served as an overarching framework.

3.3.1 Eccles et al.'s Expectancy-value Model

Over 30 years ago, Eccles et al. (1983) were the first to translate expectancy-value models of motivation into educational research (Flake et al., 2015). Their expectancy-value theory has been widely used to explain and predict students' learning persistence (e.g., Dietrich et al., 2017; Levpušček et al., 2013; Trautwein et al., 2009; Trautwein et al., 2006), aspirations (e.g., Eccles & Wang, 2016; Nagy et al., 2006; Updegraff et al., 1996) and performance in various domains and contexts, including academic achievement (Eccles et al., 1993; Trautwein & Lüdtke, 2007; Wigfield et al., 2006; Wigfield & Guthrie, 1997), on different educational levels (e.g., Denissen et al., 2007). The expectancy-value theory acknowledges socio-psychological influences on individuals' choices and persistence, and posits that achievement motivation, educational engagement, academic performance and educational or occupational decisions are motivated by a combination of individuals' expectations for success and subjective task values in particular domains (Atkinson, 1957; Eccles et al., 1983; Wigfield, 1994; Wigfield & Eccles, 1992, 2000). For example, children are more likely to pursue an

activity if they expect to do well and they value the activity (Leaper, 2011). These two basic components of the expectancy-value theory, therefore, inform the ways in which children are motivated toward a subject, and thus how they achieve and persist in that area.

3.3.2 Expectancy of Success

Expectancy refers to an individual's expectations for success and involves perceptions of one's competence and also confidence regarding future success, or self-concept (Eccles & Wigfield, 2002). Expectancy beliefs and self-concept are theoretically distinct, however they are not separable empirically (Eccles & Wigfield, 2002). Therefore, expectancy of success has been measured with a self-concept instrument in many studies (e.g., Guo et al., 2017; Trautwein et al., 2012). Further, expectations for success differ across racial-ethnic groups and develop over childhood and adolescence (Petersen & Hyde, 2014). Students' current self-perceptions of their ability and their self-efficacy are related positively to indicators of motivation, learning-related behaviours and academic outcomes (Patrick et al., 2004). In sum, children's beliefs about their expectations of future success and their current competencies load onto the same factor (Eccles & Wigfield, 1995), which has been associated with achievement motivation (Kim et al., 2017).

3.3.3 Subjective Task Values

In the achievement motivation literature, subjective task values have been defined more specifically as how a task meets different needs of individuals (Eccles et al., 1983; Wigfield & Eccles, 1992). One important aspect of the Eccles et al. (1983) model is that subjective task values are conceptualized as a multidimensional construct (Kim et al., 2017), which can be further differentiated into four major subcomponents: attainment value or importance, intrinsic value, utility value or usefulness of the task, and cost (Conley, 2012; Eccles et al., 1983; Eccles & Wigfield, 2002; Flake et al., 2015; Gaspard et al., 2015; Guo et al., 2015; Leaper, 2011; Trautwein et al., 2012; Wigfield & Eccles, 1992). Building on Battle's (1965, 1966) work, Eccles et al. defined attainment value as the personal importance of doing well in a given task (Meyer et al., 2019; Patrick et al., 2004; Wigfield, 1994). Attainment value is also related to an individual's self-schema, confirming relevant aspects of their identity by succeeding in the task (Eccles & Wigfield, 2002). Intrinsic value refers to the subjective interest in a task or the inherent enjoyment one gains from doing the task; this component is similar in certain respects to notions of intrinsic motivation (Deci & Ryan, 1985; Eccles & Wigfield, 2002; Harter, 1981).

Utility value concerns the usefulness of the task for the individual in light of future goals. Because of the greater importance of extrinsic performance rewards, utility value can be conceptualized as similar to extrinsic motivation (Eccles, 2009; Trautwein et al., 2012). For instance, utility value includes the perceived extent to which succeeding in this task can impact a student's future life. Cost describes the anticipated effort one will need to put into completing the task, as well as one's perceptions of negative consequences of involvement with the task – for example, performance anxiety amounting to emotional stress or alternative opportunity costs of choosing this option (Eccles, 2005; Wigfield & Eccles, 1992). According to Wigfield and Eccles (2000), a goal is valued if the individual has a lot of interest in the domain, if the goal is viewed as useful and important, and the cost of achieving the goal is not prohibitive. There has been considerable research that has shown that students' evaluation of academic subjects is related to the choices they make (Wigfield & Eccles, 1992), to other motivational beliefs (Anderman et al., 2001) and to the achievement in that subject domain.

As a comprehensive sociocultural framework for understanding motivation, Eccles et al.'s expectancy-value theory situates beliefs of expectancy and value as the most proximal predictors of achievement-related outcomes while accounting for social, historical and cultural experiences as key determinants of those beliefs (Safavian & Conley, 2016). Eccles and colleagues (Eccles et al., 1983; Eccles & Wigfield, 2002; Wigfield & Eccles, 2000) argue that expectancy and value are shaped by a combination of factors, which are differentiated into two categories, namely individuals' characteristics, including personal past achievement experiences, goals, self-concepts, beliefs and aptitudes, and environmental influences, such as cultural milieu and socializers' beliefs, which are most directly determined by the broad cultural milieu (Leaper, 2011). Individuals' interpretations of previous performance and their perceptions of socializers' attitudes and expectations lead to the development of achievement-related beliefs, including individuals' goals and self-schema, as well as task-specific beliefs, such as beliefs about ability and the perceived difficulty of a task that, in turn, influence the formation of expectancy and value beliefs (Eccles et al., 1983, 1998; Wigfield et al., 2009). In addition, expectations for success and task values are positively correlated (Eccles & Wigfield, 2002; Wigfield et al., 2009); expectancies for success tend to predict children's later task values; that is, children tend to value the domains in which they feel competent (Eccles & Wigfield, 2002). Moreover, both factors predict children's achievement-related outcomes. It has been a relatively consistent finding that expectations for success (i.e., competence-related beliefs) are more strongly linked to performance, while task values are more strongly tied to achievement-

related persistence and choices (Eccles et al., 1983; Wigfield & Eccles, 1992, 2000; Wigfield et al., 2009).

3.3.4 Influences of Socializers on Boys' and Girls' Learning and Achievement

In the case of socialization processes, socialization by social agents such as parents, teachers and peers plays an essential role in shaping children's affective characteristics, which in turn influence different aspects of performance (Thomas & Strunk, 2017). For example, children's perceptions of socializers' beliefs, behaviours and expectations have direct and interactive effects on their own educationally relevant behaviours and beliefs, including perceptions of competencies, expectations, stereotypes, causal attributions and values (Eccles et al., 1983; Wigfield et al., 2009). In particular, as the significant others for young children, the important roles of parents and teachers are seen as key determinants of the early formation of children's attitudes in elementary science (Thomas & Strunk, 2017). In the field of elementary science teaching and learning, researchers have explored students' interest and persistence in science classes, and their interest and understanding of science careers. Expectancy-value theory guides the exploration of the independent roles of parents and teachers in influencing boys' and girls' motivation and achievement in science. Parents and teachers hold beliefs about the gender role in STEM fields and engage in behaviours that shape boys' and girls' attitudes towards science, which subsequently lead to gender disparities in science achievement. For example, LeGrand (2013) found that gender differences in expectancy and value exist in science across grade levels, beginning in elementary school and growing in high school, potentially offering an explanation for gender gaps in science majors and careers.

In summary, expectancy-value theory is a developmental theory (Petersen & Hyde, 2014), which can be seen an important contribution to the understanding of motivation in educational contexts (Meyer et al., 2019). Students' affective characteristics, including attitudes towards learning, as well as social environmental influences, such as socialization processes, are incorporated into the theory. Moreover, it also concerns the importance of the cultural milieu, such as cultural gender-role stereotypes or gender segregation of occupations, in shaping students' educational and future career choices. This theory especially highlights the dual importance of competence-related beliefs, or expectations for success, and task values in explaining children's motivation as well as predicting a wide range of their future outcomes (Leaper, 2011; Weiner, 2019). According to the expectancy-value theory, goal-directed actions

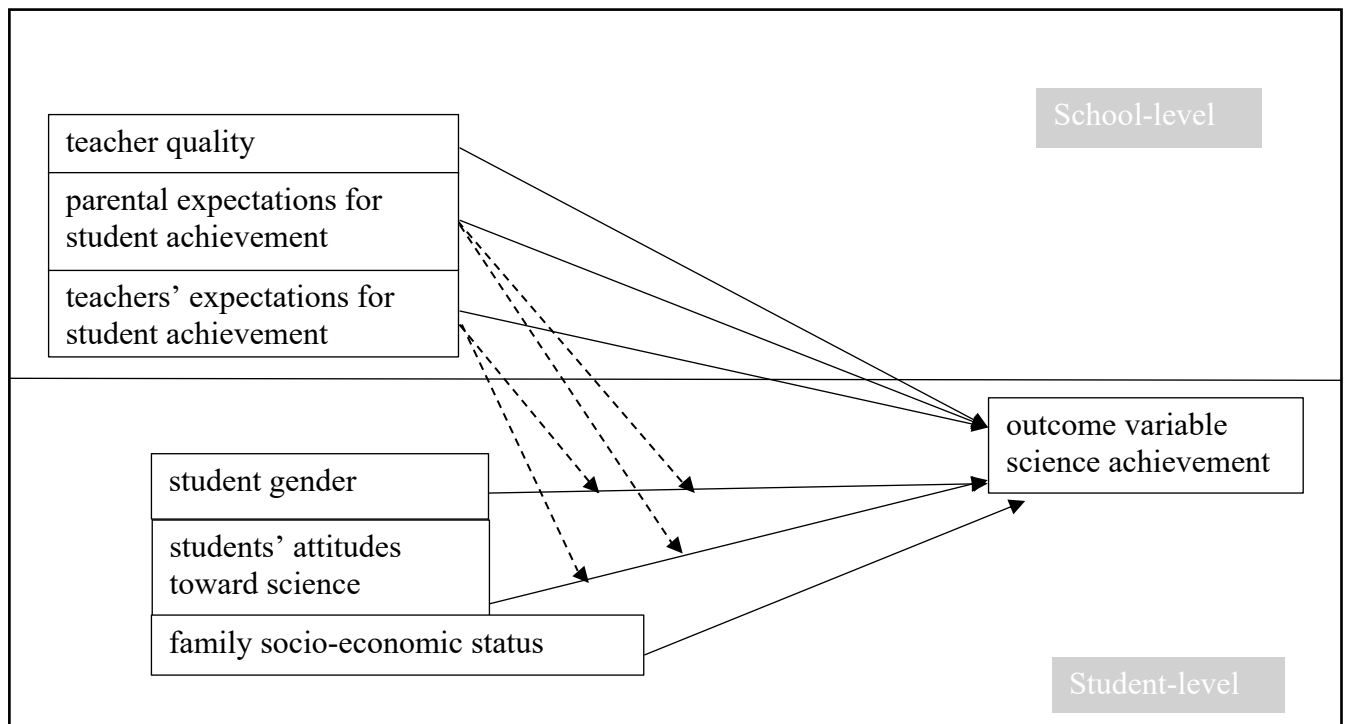
are guided by expectations that certain behaviours are likely to lead to a desired outcome and by the extent to which the outcome is valued (Fishbein & Ajzen, 2010; Wigfield & Eccles, 2000). Therefore, children are going to pursue a task when they believe in their mastery ability and when the task is highly valued by them.

Together, Bronfenbrenner’s ecological model and Eccles et al.’s expectancy-value theory were used in this study to explain the educational expectations of teachers and parents that influence children’s science achievement directly or indirectly through boys’ and girls’ academic affective characteristics, such as attitudes towards science, across families from diverse sociocultural backgrounds.

3.4 Hypotheses

The goal of this study is to examine the ways in which attributes of students, parents and teachers are related to students’ science achievement. The conceptual model presented in Figure 3.1 and the following hypotheses are meant to guide the study.

Figure 3.1
The Conceptual Model



At the first level, student gender, student attitudes toward science and family socio-economic status were entered to predict student science achievement. It was hypothesized that there would be gender differences in science outcomes, and higher levels of attitudes in learning science and family SES would predict higher levels of student science achievement.

At the second level, teachers' educational expectations, parental expectations and teacher quality were entered as predictors of student science performance. It was hypothesized that the more teachers and parents expect of student academic outcomes, the better students perform in science. Also, it was hypothesized that teacher quality would have a significant and positive impact on student science outcomes. Moreover, educational expectations of teachers and parents were further added as the interaction variables to examine the hypothesis that there would be significant interaction effects across different levels – or to be more precise, the relationships between student gender and science achievement, as well as the connections between student attitudes toward science and science performance, would be affected by the expectations of teachers and parents.

The hypotheses for the study are as follows:

Hypothesis 1. There is a significant variability in the average fourth-grade students' science achievement between schools in Germany and Taiwan.

Hypothesis 2a. Students' attitudes toward science are positively associated with students' higher science achievement in Germany and Taiwan.

Hypothesis 2b. Family socio-economic status (SES) is positively associated with students' higher science achievement in Germany and Taiwan.

Hypothesis 2c. There are gender differences in science achievement in Germany and Taiwan.

Hypothesis 3a. Teachers' expectations for student achievement are positively associated with students' higher science achievement in Germany and Taiwan.

Hypothesis 3b. Parental expectations for student achievement are positively associated with students' higher science achievement in Germany and Taiwan.

Hypothesis 3c. Teacher quality is positively associated with students' higher science achievement in Germany and Taiwan.

Hypothesis 4. There are significant interaction effects across the student level and the school level in Germany and Taiwan.

Chapter 4: Methods

4.1 Introduction

This chapter will firstly provide a description of data sources, participants, sampling, sampling weights, estimation methods, missing data and centring. Subsequently, measures including independent and dependent variables from different levels will be discussed. This will be followed by the main analysis methodology, where hierarchical linear modelling (HLM) is used to differentiate variation at the student and school level, and to test variables at these levels for each country simultaneously. Four typical sequences of HLM models will be presented to answer the research questions and corresponding hypotheses.

4.2 Data and Participants

The data are from the Trends in Mathematics and Science Study (TIMSS), which is a project of the International Association for the Evaluation of Educational Achievement (IEA). Entering its third decade and seventh cycle of data collection, TIMSS is a well-established international assessment of mathematics and science (Mullis, 2017). In addition to monitoring trends in achievement at the fourth and eighth grades, TIMSS provides information about relative progress across grades as the cohort of students assessed at the fourth grade in one cycle moves to the eighth grade four years later. Extensive information about participating countries' education systems in terms of their organization, curricula and instructional practices is also collected and reported, in order to understand the teaching and learning process and to improve education policymaking. In sum, TIMSS is a valuable resource for monitoring curricular implementation and identifying the most promising instructional practices from around the world. About 60 countries use TIMSS trend data for evaluating the effectiveness of their educational systems in a global context, and new countries join TIMSS in each cycle (Mullis, 2017). TIMSS 2019 is the most recent in the TIMSS trend series, which began with the first assessments in 1995 and continued every four years. About 64 countries and eight benchmarking entities participated in TIMSS 2019. Among them, 58 countries and six benchmarking entities participated in the TIMSS fourth-grade science assessment. The TIMSS 2019 database used in this study was downloaded from the official website of the 2019 TIMSS & PIRLS International Study Center.

Fourth-grade students and their science teachers from Germany and Taiwan are the population of this study. The Germany TIMSS 2019 sample consists of 3,437 students and their 218 science teachers in 203 schools, and the Taiwan sample consists of 3,765 students and their

179 science teachers in 162 schools. The number of students, their science teachers and schools of both participating countries are presented in Table 4.1.

Table 4.1

TIMSS 2019 Students, their Science Teachers and School Samples of Germany and Taiwan

Country (Common Name)	Number of Students	Number of Science Teachers	Number of Schools
Germany	3437	218	203
Chinese Taipei (Taiwan)	3765	179	162

4.3 Sampling

The TIMSS programme employs a rigorous two-stage school and classroom random sampling technique so that achievement in the student population as a whole may be estimated accurately by assessing just a sample of students from a sample of schools. This stratified two-stage cluster sample design for TIMSS is as follows: for the first sampling stage, schools are sampled with probability proportional to their size (PPS) from the list of all schools in the population that contain eligible students. The schools in this list may be stratified according to important demographic variables. Schools for the test and data collection are sampled simultaneously using a systematic random sampling approach. The second sampling stage consists of selecting one or more intact classes with equal probability from the target grade of each participating school, and all students in each sampled class participate in the assessment. Intact classes of students are sampled rather than individuals from across the grade level or of a certain age because TIMSS pays particular attention to students' curricular and instructional experiences, and these typically are organized on a classroom basis. Class sampling in each country is conducted by the National Research Coordinator using the Within-School Sampling Software (WinW3S) developed by IEA Hamburg and Statistics Canada (LaRoche et al., 2020). The main inferential statistical analysis used in this study was HLM, which is particularly relevant because TIMSS is a nested data set, with TIMSS 2019 student-level data nested within teacher/class-level data, which are then nested within school-level data. The data were collected via the TIMSS 2019 Student Questionnaire, Teacher Questionnaire, Home Questionnaire and student tests in science.

4.4 Sampling Weights

For analyses based on the TIMSS data sample to accurately reflect population attributes, it is necessary to take the design of the sample into account. This is accomplished in part by assigning a sampling weight to each respondent in the sample, and weighting the respondents by the sampling weight in all analyses (Foy & Olson, 2009; Liou, 2010). The sampling weights properly account for the sample design, pay special attention to any stratification or disproportional sampling of subgroups and include adjustments for non-response (Foy & Olson, 2009; Joncas, 2008). The overall sampling weight for each student is the product of the three weighting components: school, class (within school) and student (within class) (LaRoche et al., 2020). At each level, the weighting component consists of a basic weight that is the inverse of the probability of selection at that level, together with an adjustment for non-participation. The weighting variables – SENWGT (student senate weight – sums to 500 in each country) and SCHWGT (school weight) – were applied to this study. The weight variable SENWGT is designed for use in student-level analyses from all student-level files, and SCHWGT is designed for use in school-level analyses where the schools are the units of analysis.

4.5 Estimation Methods

Estimation methods typically produce point estimates of each parameter in the multilevel model and these estimates are often valuable in addressing particular research questions. Common methods of estimation for multilevel models include maximum likelihood (ML), restricted maximum likelihood (REML) and Bayesian (Kreft & Leeuw, 1998; Raudenbush & Bryk, 2002). These methods of estimation can be carried out using many different algorithms, thus underscoring the need for definitive information regarding the estimation methods and algorithms employed. The algorithms have been programmed into many different software programs – for instance, one researcher may accomplish REML estimation using the EM algorithm programmed into HLM (Raudenbush et al., 2004), another may accomplish REML estimation using restricted iterative generalized least squares (RIGLS) in MLwiN, while a third may accomplish REML using the Newton-Raphson algorithm programmed in SAS PROC MIXED (Ferron et al., 2008). In this study, HLM 8.01 was chosen as the appropriate software program to effectively analyse the data of German and Taiwanese participants. Further, REML produces the same results as FML when sample sizes are large, and produces preferable results to FML for small samples because it adjusts for the degree of freedom, and it is helpful when convergence is a problem (Chepete, 2010). Therefore, the models in this study were estimated using the default estimation method restricted maximum

likelihood (REML) instead of the alternative full maximum likelihood (FML) that is mainly used if models to be compared contain different fixed parts (Snijders & Bosker, 1999).

4.6 Missing Data

Missing data can be assigned a value of omitted/invalid, not administered, logically not applicable or not reached during data capture (Kowolik et al., 2020). Mean imputation involves replacing the missing value with the mean of the variable or with the subgroup mean in cases where stratified sampling is used (Allison, 2000; Tabachnick & Fidell, 2001). The rationale for using the mean as a substitute value is that the mean is the best guess about the value of a variable (Tabachnick & Fidell, 2001). In the current study, the missing data of the scale variables were replaced by the series mean, and the missing data of the nominal variables were handled by mode.

4.7 Centring

It is important to point out that certain centring options can produce a mismatch between the paradigm from which the researcher is operating and the implicit paradigm operationalized analytically (Hofmann & Gavin, 1998). Under grand mean centring, the variance in the intercept term represents the between-group variance in the outcome variable adjusted for the level-1 variables. Kreft et al. (1995) concluded that grand mean centring and raw metric approaches produce equivalent models (Hofmann, 1997); however, it is noted that even though these two models are equivalent, grand mean centred models provide a computational advantage (Raudenbush, 1989), because, in most cases, grand mean centring reduces the correlation between the intercept and slope estimates across groups. This reduction of the covariation between the random intercepts and slopes can help to alleviate potential level-2 estimation problems due to multicollinearity (Hofmann, 1997). Grand mean centring was thus adopted in both level 1 and level 2 of the models in this study.

4.8 Measures

In this study, fourth-grade student science achievement measures serve as the dependent variable. Independent variables exist in two levels: the student level and the school level. Three selected variables at the student level, namely student gender (GNDR), students' attitudes toward science (ATT) and family socio-economic status (SES), and three selected variables at the school level, i.e., teachers' expectations for student achievement (TCHEXP),

parental expectations for student achievement (PAREXP) and teacher quality (TCHQLTY), are used in HLM analyses. The rationale for selecting these variables is based on previous literature suggesting that these variables are closely related to student science achievement. Table 4.2 provides descriptive information on all the variables across two levels for Germany and Taiwan.

Table 4.2

Descriptive Statistics for Student Science Achievement and Characteristics of Students, Parents and Teachers between Germany and Taiwan (TIMSS, 2019)

Variable	Germany				Taiwan			
	Mean	SD	Min	Max	Mean	SD	Min	Max
<i>Level 1 student-level statistics</i>								
Student Science Achievement	518.35	76.99	220.04	736.57	558.05	65.43	307.90	759.64
Student Gender (GNDR)	0.43	0.50	0.00	1.00	0.52	0.50	0.00	1.00
Students' Attitudes toward Science (ATT)	2.70	0.54	1.00	3.00	2.64	0.56	1.00	3.00
Family Socio-economic Status (SES)	2.15	0.58	1.00	3.00	2.19	0.74	1.00	3.00
<i>Level 2 school-level statistics</i>								
Teachers' Expectations for Student Achievement (TCHEXP)	3.49	0.72	1.00	5.00	3.99	0.60	2.00	5.00
Parental Expectations for Student Achievement (PAREXP)	3.84	0.71	1.00	5.00	3.81	0.70	2.00	5.00
Teacher Quality (TCHQLTY)	2.97	0.40	1.75	3.75	3.01	0.56	1.75	4.25

4.8.1 Dependent Variables

Student Science Achievement. The TIMSS 2019 science achievement scores are used as the outcome variable at the student level in this study. In order to provide unbiased estimates

of student achievement and its relationship with contextual variables, the TIMSS scaling approach uses a conditioning model with subsequent multiple imputation to obtain five plausible values representing proficiency in mathematics and science for all students across two grade levels (Foy et al., 2020). All of these five plausible values were used when considering student weights in the analyses to ensure the accurate representation of student science achievement (Germany: $\bar{X} = 518.35$, $SD = 76.99$; Taiwan: $\bar{X} = 558.05$, $SD = 65.43$).

4.8.2 Independent Variables

4.8.2.1 Student-level Predictor Variables.

Student Gender (GNDR). It is a dichotomous variable coded as 1 = boy and 0 = girl (Germany: $\bar{X} = 0.43$, $SD = 0.50$; Taiwan: $\bar{X} = 0.52$, $SD = 0.50$).

Students' Attitudes toward Science (ATT). The index is based on students' responses to 16 statements about their science ability and how they feel about science. It is a continuous variable derived from the TIMSS 2019 student context data with a range from 1 to 3 (Germany: $\bar{X} = 2.70$, $SD = 0.54$; Taiwan: $\bar{X} = 2.64$, $SD = 0.56$).

Family Socio-economic Status (SES). Students were scored according to their own and their parents' reports regarding the availability of four resources on home resources for learning, namely the number of books in the home, the number of home possessions, which indicate family wealth as well as cultural, martial and educational resources, the highest level of education of either parent and the highest level of occupation of either parent. It is a continuous variable derived from 16 items in the student and home questionnaires with a range from 1 to 3 (Germany: $\bar{X} = 2.15$, $SD = 0.58$; Taiwan: $\bar{X} = 2.19$, $SD = 0.74$).

4.8.2.2 School-level Predictor Variables.

Teachers' and Parents' Expectations for Student Achievement. Teachers' expectations for student achievement (TCHEXP) is a continuous variable represented by an item asking teachers about the level of student achievement they expect (Germany: $\bar{X} = 3.49$, $SD = 0.72$; Taiwan: $\bar{X} = 3.99$, $SD = 0.60$). Another continuous variable, parental expectations for student achievement (PAREXP), was derived from an item measuring teachers' perceptions of the level of children's achievement that parents expect (Germany: $\bar{X} = 3.84$, $SD = 0.71$; Taiwan:

$\bar{X} = 3.81$, $SD = 0.70$). Both indicators of expectations for student achievement were derived from the TIMSS 2019 teacher context data with a range from 1 to 5.

Teacher Quality (TCHQLTY). The index is based on teachers' responses to five questions about years of teaching experience, a major in education and science, the highest level of formal education and hours spent in formal in-service/professional development for science. Higher values in this index indicate better teacher quality (Germany: $\bar{X} = 2.97$, $SD = 0.40$; Taiwan: $\bar{X} = 3.01$, $SD = 0.56$).

All the independent variables across two levels were recoded, inverted, computed or categorized in accordance with the TIMSS User Guide for international databases. A summary of these variables and their corresponding items are listed in Table 4.3 (see Appendix A).

4.9 Analytical Approach

Hierarchical linear modelling (HLM) was used as the main statistical analysis in this study. In the educational field, organizations and data structures are often hierarchical, or nested, which means individual units are grouped into larger groups; these groups of individuals are grouped into higher-order organizations, and the organizations may be grouped at still higher levels (Raudenbush & Bryk, 2002). In other words, student achievement is a phenomenon of students and schools, meaning students are nested within classrooms, and classrooms are nested within schools. Ignoring the influences from any level of the hierarchical structure may cause statistical and interpretative problems (Burstein, 1980; Hox, 1994; Robinson, 1950). To solve these problems, a multilevel analytic approach is required (Hox, 2002; Muthén, 1990, 1991, 1994). Further, HLM can not only investigate the relationships within and between hierarchical levels of grouped data, but differentiate the total variances at different levels (Braun et al., 2006; Raudenbush & Bryk, 2002; Woltman et al., 2012). Therefore, HLM is a suitable means to examine educational data, and a multilevel analytic approach was employed to explore the two-level relationships between the hypothesized predictors and science achievement.

The HLM analysis process was composed of several models corresponding to the research questions. First, the one-way ANOVA model with random effects (null model), which contained no predictors, was conducted with student science achievement as the dependent variable and considering student senate weights of the five plausible values for science performance. The purpose of this preliminary model was to examine whether the variance at level 2 was significantly different to zero and to estimate how much variance in the outcome

variables was accounted for at different levels, which addresses the first research question (RQ1). Next, the random coefficients regression model (level-1 predictor model) tested the relationship between the level-1 independent variables and the outcome variables, which addresses the second research question (RQ2). Third, the means-as-outcomes regression model (level-2 predictor model) examined the relationship between the level-2 independent variables and the outcome variables, which addresses the third research question (RQ3). To address the final research question (RQ4), the intercepts-and-slopes-as-outcomes model (full random coefficients model) was conducted to detect the interaction effects across levels. This typical sequence of four models allows one to assess the viability of each of the necessary conditions (Hofmann, 1997; Raudenbush & Bryk, 2002).

4.9.1 The One-way ANOVA Model with Random Effects (Null Model)

For Research Question 1 (Is there a significant variability in the average fourth-grade student science achievement among schools in each selected country? How much of the variance in the fourth-grade student science achievement can be accounted for at the student and the school level?), the one-way ANOVA with random effects model was applied for Germany and Taiwan. This preliminary model is also known as the null, empty or unconditional model since there are no independent variables included in any of the levels (Chepete, 2010). The unconditional model was employed to determine whether there were differences in student science achievement between schools. If there was no variance in science achievement at the school level, multilevel modelling would be unnecessary. The null model is also capable of differentiating the variance in the student science score due to different levels (Liou, 2010; Sabah & Hammouri, 2010). The intraclass correlation coefficient (ICC), the ratio of between-group variance to the total variance, was then calculated to estimate how much overall variance in science achievement could be accounted for at the school level ($ICC = \rho = \tau_{00} / \tau_{00} + \sigma^2$) (Hofmann, 1997), and the proportions of variance accounted for at each level will be presented in the result section. To accomplish the variance partitioning in hierarchical linear models, the following set of equations are estimated (Hofmann, 1997):

Level 1 (student): *Science Achievement* $_{ij} = \beta_{0j} + r_{ij}$

Level 2 (school): $\beta_{0j} = \gamma_{00} + u_{0j}$

Mixed model: *Science Achievement* $_{ij} = \gamma_{00} + u_{0j} + r_{ij}$

where *Science Achievement*_{ij} represents the dependent variable at level 1 for the *i*th student within school *j*. β_{0j} is an estimate of the adjusted mean science achievement for school *j*. γ_{00} is equal to the grand mean science achievement. Variance (r_{ij}) = σ_2 represents within-group variance in science achievement and Variance (u_{0j}) = τ_{00} refers to between-group variance in science achievement.

4.9.2 The Random Coefficients Regression Model (Level-1 Predictor Model)

For Research Question 2 (What are the relationships between the student predictors and science achievement in each selected country?), the random coefficients regression model was applied for Germany and Taiwan. After assessing the degree of within- and between-group variance in science achievement, one can now investigate whether there is significant variance in the intercepts and slope across groups (Hofmann, 1997). Basically, the model is comprised of student-level variables with a random intercept and random slopes, and the slope coefficients will be tested for variation across schools (Chepete, 2010). This model was also utilized to estimate the influence of student gender (β_{1j}), students' attitudes toward science (β_{2j}) and family socio-economic status (β_{3j}) on student science achievement. Grand mean centring was adopted in scale variables including ATT and SES. However, the nominal variable refers to raw metric scaling where no centring occurs (Hofmann & Gavin, 1998), and student gender (GNDR) was thus used in its original metric. An effect size (R^2) was calculated and reported to explain the amount of variance in student science achievement that could be explained by the student-level independent variables ($R^2 = \sigma^2_{\text{null}} - \sigma^2_{\text{new}} / \sigma^2_{\text{null}}$).

Level-1 predictor model equations are as follows:

$$\text{Level 1 (student): } \textit{Science Achievement}_{ij} = \beta_{0j} + \beta_{1j}(\text{GNDR}) + \beta_{2j}(\textit{ATT}) + \beta_{3j}(\textit{SES}) + r_{ij}$$

$$\text{Level 2 (school): } \beta_{0j} = \gamma_{00} + u_{0j}$$

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

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

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

$$\text{Mixed model: } \textit{Science Achievement}_{ij} = \gamma_{00} + \gamma_{10}*\text{GNDR} + \gamma_{20}*\textit{ATT} + \gamma_{30}*\textit{SES} + u_{0j} + u_{1j} \\ * \text{GNDR} + u_{2j}*\textit{ATT} + u_{3j}*\textit{SES} + r_{ij}$$

Note. ***Bold italic***: grand-mean centring.

where *Science Achievement*_{ij} is the dependent variable for the *i*th student within school *j*. β_{0j} is an estimate of the adjusted mean dependent variable for school *j*, γ_{00} is the average science score across schools and r_{ij} is a student-level residual. The error terms in the set of school-level equations are u_{0j} through u_{3j} . By assumption, $E(r_{ij}) = 0$ and $\text{Var}(r_{ij}) = \sigma^2$.

4.9.3 Means-as-outcomes Regression Model (Level-2 Predictor Model)

For Research Question 3 (Which factors are associated with science achievement at the school level and how are they associated in each selected country?), a conditional HLM model was used for Germany and Taiwan. This variant of the random intercept model predicts level-1 intercept on the basis of the level-2 grouping variable and also on the basis of one or more level-2 random effect predictors (Garson, 2012). With only school-level variables, this model assesses whether this variance is significantly related to the proximity of group members (Hofmann, 1997). An effect size (R^2) was calculated and reported to explain the amount of variance in science achievement that could be accounted for by the school-level independent variables ($R^2 = \tau_{00\text{-null}} - \tau_{00\text{-new}} / \tau_{00\text{-null}}$). Scale variables at the second level, namely TCHEXP, PAREXP and TCHQLTY, were grand mean centred. The level-2 predictor model estimates the influence of teachers' expectations for student achievement (γ_{01}), parental expectations for student achievement (γ_{02}) and teacher quality (γ_{03}) on student science achievement, as follows:

Level 1 (student): *Science Achievement*_{ij} = $\beta_{0j} + r_{ij}$

Level 2 (school): $\beta_{0j} = \gamma_{00} + \gamma_{01}(\text{TCHEXP}) + \gamma_{02}(\text{PAREXP}) + \gamma_{03}(\text{TCHQLTY}) + u_{0j}$

Mixed model: *Science Achievement*_{ij} = $\gamma_{00} + \gamma_{01}^* \text{TCHEXP} + \gamma_{02}^* \text{PAREXP} + \gamma_{03}^* \text{TCHQLTY} + u_{0j} + r_{ij}$

Note. Bold italic: grand-mean centring.

where *Science Achievement*_{ij} is the dependent variable for the *i*th student within school *j*. β_{0j} is an estimate of the adjusted mean dependent variable for school *j*. γ_{00} is the average science score across schools. r_{ij} is a student-level residual and u_{0j} is a school-level residual. By assumption, $E(u_{0j}) = 0$ and $\text{Var}(u_{0j}) = \tau_{00}$.

4.9.4 The Intercepts-and-Slopes-as-Outcomes Model (Full Random Coefficients Model)

For Research Question 4 (Is there any significant interaction effect across the student level and the school level in each selected country?), a conditional HLM with both school-level

and student-level predictors, was employed to give the final explanation of the investigation (Chepete, 2010). The current model is a type of random coefficients (RC) models in which level-1 slopes and intercepts are modelled not only by the level-2 grouping variable as a random factor, but also by one or more other level-2 variables (Garson, 2012). Further, this final model added the cross-level interaction effects of expectations of teachers and parents at level 2 to determine their potential impact on the relationships between student gender and science achievement, as well as on the connections between student attitudes toward science and science outcomes. In other words, the interaction effects were modelled on the slopes between the particular student variables and student science outcome. Two effect sizes (R^2) were calculated and will be presented in the next chapter to explain the amount of variance in student science achievement accounted for by student-level and school-level variables, respectively (R^2 for level-1 model = $\sigma^2_{\text{null}} - \sigma^2_{\text{new}} / \sigma^2_{\text{null}}$; R^2 for level-2 model = $\tau_{00-\text{null}} - \tau_{00-\text{new}} / \tau_{00-\text{null}}$). All the continuous variables from both levels were grand mean centred, except that student gender as a dichotomous variable was not centred in HLM. The two-level hierarchical linear model is as follows:

Level 1 (student): *Science Achievement* $_{ij} = \beta_{0j} + \beta_{1j}(\text{GNDR}) + \beta_{2j}(\text{ATT}) + \beta_{3j}(\text{SES}) + r_{ij}$

Level 2 (school): $\beta_{0j} = \gamma_{00} + \gamma_{01}(\text{TCHEXP}) + \gamma_{02}(\text{PAREXP}) + \gamma_{03}(\text{TCHQLTY}) + u_{0j}$

$\beta_{1j} = \gamma_{10} + \gamma_{11}(\text{TCHEXP}) + \gamma_{12}(\text{PAREXP}) + u_{1j}$

$\beta_{2j} = \gamma_{20} + \gamma_{21}(\text{TCHEXP}) + \gamma_{22}(\text{PAREXP}) + u_{2j}$

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

Mixed model: *Science Achievement* $_{ij} = \gamma_{00} + \gamma_{01}*\text{TCHEXP} + \gamma_{02}*\text{PAREXP} + \gamma_{03}*\text{TCHQLTY} + \gamma_{10}*\text{GNDR} + \gamma_{11}*\text{TCHEXP}*\text{GNDR} + \gamma_{12}*\text{PAREXP}*\text{GNDR} + \gamma_{20}*\text{ATT} + \gamma_{21}*\text{TCHEXP}*\text{ATT} + \gamma_{22}*\text{PAREXP}*\text{ATT} + \gamma_{30}*\text{SES} + u_{0j} + u_{1j}*\text{GNDR} + u_{2j}*\text{ATT} + r_{ij}$

Note. ***Bold italic***: grand-mean centring.

where *Science Achievement* $_{ij}$ is the expected outcome for the i^{th} student within school j . β_{0j} is the intercept for each j^{th} school. β_{1j} , β_{2j} and β_{3j} are the level-1 regression coefficients on student science achievement, and r_{ij} is the student-level residual. γ_{00} is the average science score across schools. γ_{01} , γ_{02} and γ_{03} are the level-2 coefficients on student science achievement. Two additional fixed effects are included in the level-2 model. γ_{11} represents the effect of teachers' expectations on the slopes between student gender and science achievement. γ_{12} stands for the impact of parental expectations on the slopes between student gender and science

achievement. γ_{21} means the influence of teachers' expectations on the slopes between student attitudes toward science and science achievement. γ_{22} is equal to the effect of parental expectations on the slopes between student attitudes toward science and science achievement. The error terms in the level-2 model are u_{0j} through u_{3j} .

Chapter 5: Results

5.1 Introduction

Results for the HLM models regarding each research question and hypothesis are presented in this chapter. Firstly, the results from the null models are presented indicating the proportion of variance in science achievement at each level. Next, results of the level-1 predictor models, which examine the relationship between student characteristics and science outcomes, are shown. Subsequently, the results from the level-2 predictor models are shown to confirm whether the school characteristics have any significant influence on student science performance. Finally, results of the full random coefficients model are presented to show if there is any cross-level interaction effect.

5.2 Null Model

In order to answer the first research question (Is there a significant variability in the average fourth-grade student science achievement among schools in each selected country? How much of the variance in the fourth-grade student science achievement can be accounted for at the student and school level?), and to verify Hypothesis 1 (There is a significant variability in the average fourth-grade students' science achievement between schools in Germany and Taiwan), the null model was conducted for each nation. As the first step in the multilevel analysis, this one-way ANOVA with random effects model provides useful preliminary information about how much variation in science achievement lies within and between schools and about the reliability of each school's sample mean as an estimate of its true population mean (Clogg & Shihadeh, 2002). Results from the fully unconditional models in Table 5.1 indicate that there is a significant variability in means among schools in science achievement in Germany ($\tau_{00} = 1581.47$, $\chi^2 = 1247.99$, $p < .05$) and in Taiwan ($\tau_{00} = 1245.46$, $\chi^2 = 1272.22$, $p < .05$). Further, the intraclass correlation (ICC) was calculated as $\tau_{00} / (\tau_{00} + \sigma_2)$ to estimate the percentage of overall variance in achievement accounted for at the school level. Generally, studies of academic achievement using HLM have found more than 5.9% of the variance between groups, and if the proportion is higher than 13.8% it indicates that there is strongly significant variability between groups (Cohen, 1988). A significant proportion of variance in science achievement occurred between schools in both countries. In Germany, 25.3% of the overall model variance could be attributed to differences between schools, while 74.7% was due to differences among students. Similarly, approximately 75.0% of the variance in science outcomes was accounted for at the student level, and about 25.0% was accounted

for at the school level in Taiwan. In summary, Hypothesis 1 was confirmed. These results from the null models concluded that schools differed significantly in terms of their average science achievement; thus, multilevel analyses are desirable in analysing the data of both countries.

Table 5.1

Results of Variability in Science Achievement between Schools for Germany and Taiwan

Germany				
	<i>Fixed Effect</i>			
	Coefficient	SE	<i>t-ratio</i>	<i>p</i>
Intercept (science achievement) γ_{00}	516.56	3.10	166.74	<0.001
	<i>Random Effect</i>			
	Variance	<i>df</i>	χ^2	<i>p</i>
Between-school variability (intercept) u_{0j}	1581.47	202	1247.99	<0.001
Within-school variability r_{ij}	4662.28			
Taiwan				
	<i>Fixed Effect</i>			
	Coefficient	SE	<i>t-ratio</i>	<i>p</i>
Intercept (science achievement) γ_{00}	542.65	3.03	178.88	<0.001
	<i>Random Effect</i>			
	Variance	<i>df</i>	χ^2	<i>p</i>
Between-school variability (intercept) u_{0j}	1245.46	161	1272.22	<0.001
Within-school variability r_{ij}	3734.26			

5.3 Level-1 Predictor Model

To answer Research Question 2 (What are the relationships between the student predictors and science achievement in each selected country?), as well as to test Hypothesis 2 (a. Students' attitudes toward science are positively associated with students' higher science achievement in Germany and Taiwan; b. Family SES is positively associated with students' higher science achievement in Germany and Taiwan; c. There are gender differences in science achievement in Germany and Taiwan), the level-1 predictor model was conducted for both countries. As the second step in the multilevel analyses, this random coefficient regression model using only student-level variables, student gender (GNDR), attitudes toward science (ATT) and family socio-economic status (SES) as predictors of science achievement was built to examine the relationships between student characteristics and their achievement in science. Tables 5.2 and 5.3 present the results of the level-1 predictor models of student-level predictors on science achievement for Germany and Taiwan, respectively.

In Germany, all three student-level variables were positive predictors of student achievement in science. As expected, student gender (GNDR, $\gamma_{10} = 8.43$, $p < .05$) was positive and significantly associated with science achievement, meaning that boys performed better than girls in science. Similarly, student attitudes toward science (ATT, $\gamma_{20} = 29.87$, $p < .05$) and family socio-economic status (SES, $\gamma_{30} = 39.26$, $p < .05$) had a significant positive effect on student science outcomes. The proportion of reduction in variance at the first level in this model compared with the null model is $(4662.28 - 3916.17) / 4662.28 = 16.0\%$ (Hofmann, 1997; Hox, 2010). In other words, the student-level predictors accounted for approximately 16% of the variance in science achievement within schools ($R^2 = \sigma^2_{\text{null}} - \sigma^2_{\text{new}} / \sigma^2_{\text{null}}$).

Table 5.2

Summary of Level-1 Predictor Model of Student Characteristics on Science Achievement for Germany

Germany				
	<i>Fixed Effect</i>			
	Coefficient	SE	<i>t</i> -ratio	<i>p</i>
Intercept (science achievement) γ_{00}	513.33	2.82	181.71	<0.001
Student-level variables				
GNDR γ_{10}	8.43	3.22	2.62	0.016
ATT γ_{20}	29.87	3.11	9.61	<0.001
SES γ_{30}	39.26	2.31	16.97	<0.001
	<i>Random Effect</i>			
	Variance	<i>df</i>	χ^2	<i>p</i>
Between-school variability				
(intercept) u_{0j}	933.53	182	344.44	<0.001
GNDR u_{1j}	132.10	182	184.45	0.436
ATT u_{2j}	137.77	182	226.68	0.014
SES u_{3j}	129.41	182	229.01	0.010
Within-school variability r_{ij}	3916.17			
Proportion of variance explained				
At the student level (within schools)	0.16			

In Taiwan, significant and positive predictors for achievement in science included student attitudes toward science (ATT, $\gamma_{20} = 20.92$, $p < .05$) and family socio-economic status (SES, $\gamma_{30} = 34.77$, $p < .05$). However, student gender (GNDR, $\gamma_{10} = 2.52$, $p > .05$) had no significant impact on science performance. Overall, the two significant student-level predictors explained about 25.4% of the variance in science achievement within schools ($R^2 = \sigma^2_{\text{null}} - \sigma^2_{\text{new}} / \sigma^2_{\text{null}}$).

Table 5.3

Summary of Level-1 Predictor Model of Student Characteristics on Science Achievement for Taiwan

Taiwan				
	<i>Fixed Effect</i>			
	Coefficient	SE	<i>t</i> -ratio	<i>p</i>
Intercept (science achievement) γ_{00}	547.09	3.35	163.48	<0.001
Student-level variables				
GNDR γ_{10}	2.52	3.37	0.75	0.470
ATT γ_{20}	20.92	4.78	4.37	0.003
SES γ_{30}	34.77	1.89	18.37	<0.001
	<i>Random Effect</i>			
	Variance	<i>df</i>	χ^2	<i>p</i>
Between-school variability				
(intercept) u_{0j}	700.58	159	402.67	<0.001
GNDR u_{1j}	232.78	159	227.32	<0.001
ATT u_{2j}	309.75	159	311.58	<0.001
SES u_{3j}	253.30	159	261.80	<0.001
Within-school variability r_{ij}	2786.58			
Proportion of variance explained				
At the student level (within schools)		0.25		

In summary, Hypothesis 2 was partially confirmed. Germany and Taiwan had almost the same pattern for significant variables. Two of the three student-level predictors, students' attitudes toward science (ATT) and family socio-economic status (SES), had a significant positive relationship with science outcomes in both countries. In other words, students who expressed more positive attitudes toward science and whose family had higher socio-economic status were more likely to show higher science achievements. In terms of the gender gap in science, there were significant gender disparities in science outcomes favouring boys in Germany, whereas there was no clear advantage in science to either gender in Taiwan.

5.4 Level-2 Predictor Model

Next, the level-2 predictor model was used to answer the third research question asking about the effect of school characteristics on student science achievement in each selected country, and to verify the following hypothesis: Teachers' expectations for student achievement, parental expectations and teacher quality are all associated positively with higher science achievement in Germany and Taiwan. In this means-as-outcomes regression model,

only level-2 variables are added to the model; there is no predictor placed at the first level. Three main predictors of student academic achievement, namely teachers' expectations for student achievement (TCHEXP), parental expectations for student achievement (PAREXP) and teacher quality (TCHQLTY), were entered at the school level to determine whether these characteristics of teachers and parents impacted student science outcomes. Results from the level-2 predictor models for the school effects on science achievement for Germany and Taiwan are presented in Tables 5.4 and 5.5, respectively.

In Germany, teachers' expectations for student achievement (TCHEXP, $\gamma_{01} = 13.28, p < .05$) and parental expectations for student achievement (PAREXP, $\gamma_{02} = 20.80, p < 0.05$) were both significant and positive predictors of science achievement. Teacher quality (TCHQLTY, $\gamma_{03} = 3.38, p > .05$), however, was a non-significant predictor of student science outcomes. In terms of the effect size, the proportion of reduction in variance at the second level in this model compared with the null model is $(1581.47 - 1185.07) / 1581.47 = 25.1\%$ (Hox, 2010). Thus, these two significant level-2 predictors accounted for about 25% of the variance in student science achievement between schools ($R^2 = \tau_{00-\text{null}} - \tau_{00-\text{new}} / \tau_{00-\text{null}}$).

Table 5.4

Summary of Level-2 Predictor Model of School Characteristics on Science Achievement for Germany

Germany				
	<i>Fixed Effect</i>			
	Coefficient	SE	<i>t-ratio</i>	<i>p</i>
Intercept (science achievement) γ_{00}	516.26	2.78	185.61	<0.001
School-level variables				
TCHEXP γ_{01}	13.28	4.18	3.18	0.002
PAREXP γ_{02}	20.80	4.31	4.83	<0.001
TCHQLTY γ_{03}	3.38	6.52	0.52	>.500
	<i>Random Effect</i>			
	Variance	<i>df</i>	χ^2	<i>p</i>
Between-school variability (intercept) u_{0j}	1185.07	199	1011.29	<0.001
Within-school variability r_{ij}	4661.82			
Proportion of variance explained				
At the school level (between schools)		0.25		

In Taiwan, only parental expectations for student achievement (PAREXP, $\gamma_{02} = 12.97, p < .05$) had a significant positive association with student science achievement, while teachers'

expectations for student achievement (TCHEXP, $\gamma_{01} = -7.50$, $p > .05$) and teacher quality (TCHQLTY, $\gamma_{03} = -9.74$, $p > .05$) had no significant impact on student science outcomes. Overall, the significant school-level predictor explained about 7.8% of the variance in science achievement between schools ($R^2 = \tau_{00\text{-null}} - \tau_{00\text{-new}} / \tau_{00\text{-null}}$).

Table 5.5

Summary of Level-2 Predictor Model of School Characteristics on Science Achievement for Taiwan

Taiwan				
	<i>Fixed Effect</i>			
	Coefficient	SE	<i>t-ratio</i>	<i>p</i>
Intercept (science achievement) γ_{00}	543.52	3.40	159.76	<0.001
School-level variables				
TCHEXP γ_{01}	-7.50	5.70	-1.32	0.192
PAREXP γ_{02}	12.97	4.82	2.69	0.008
TCHQLTY γ_{03}	-9.74	6.18	-1.58	0.125
	<i>Random Effect</i>			
	Variance	<i>df</i>	χ^2	<i>p</i>
Between-school variability (intercept) u_{0j}	1148.00	158	1166.03	<0.001
Within-school variability r_{ij}	3735.02			
Proportion of variance explained				
At the school level (between schools)	0.08			

In summary, Hypothesis 3 was partially confirmed. In Germany, teachers' expectations for student achievement (TCHEXP) and parental expectations for student achievement (PAREXP) were important predictors, since they both had a strong, positive and significant impact on student science achievement. In other words, as the educational expectations of teachers and parents rose, student science achievement also significantly improved. Similarly, parental expectations for student achievement (PAREXP) also played a significant role in Taiwanese student science achievement. The significant and positive connection between Taiwanese parents' educational expectations and their children's science achievement suggested that higher parental expectations led to higher science scores. However, teacher quality (TCHQLTY) was a statistically non-significant predictor of science achievement in both countries.

5.5 Full Random Coefficients Model

Finally, a full random coefficients model was utilized for each selected nation to give an answer to the last research question about whether there is any significant interaction effect across levels. This intercepts-and-slopes-as-outcomes model includes both level-1 and level-2 predictor models, therefore the variations in average levels of student science achievement are explained by the joint effects of the level-1 and level-2 variables. Further, to verify the final hypothesis, teachers' expectations and parental expectations for student achievement were added as the interaction effects to determine their potential impacts on the relationships between student gender and science achievement, as well as on the associations between student attitudes toward science and science outcomes. Results of the full random coefficients models for the cross-level interaction effects of educational expectations of teachers or parents on the relationships between student gender or science attitudes and science outcomes for Germany and Taiwan are listed in Tables 5.6 and 5.7, respectively.

The results in Table 5.6 indicate that there is no interaction effect of school-level predictors on the relationships between student-level predictors and science achievement in Germany. For example, teachers' expectations for student achievement were not a significant predictor of the slopes for student gender and science achievement (GNDR *TCHEXP, $\gamma_{11} = 4.03$, $p > .05$), or student attitudes toward science (ATT *TCHEXP, $\gamma_{21} = 2.70$, $p > .05$). Similarly, parental expectations for student achievement were not a significant predictor of the slopes for student gender and science achievement (GNDR *PAREXP, $\gamma_{12} = -4.93$, $p > .05$), or student attitudes toward science (ATT *PAREXP, $\gamma_{22} = 3.02$, $p > .05$). After entering all the variables of both levels in this final model, level-1 predictors explained about 15.7% of the variance in science achievement within schools ($R^2 = \sigma_{\text{null}}^2 - \sigma_{\text{new}}^2 / \sigma_{\text{null}}^2$), whereas level-2 predictors accounted for approximately 50.1% of the variance in science scores between schools ($R^2 = \tau_{00-\text{null}} - \tau_{00-\text{new}} / \tau_{00-\text{null}}$).

Table 5.6

Results from the Full Random Coefficients Model for the Cross-level Interaction Effects for Germany

Germany				
	<i>Fixed Effect</i>			
	Coefficient	SE	<i>t-ratio</i>	<i>p</i>
Intercept (science achievement) γ_{00}	512.33	2.69	190.43	<0.001
Student-level variables				
GNDR γ_{10}	8.71	3.12	2.80	0.010
GNDR *TCHEXP γ_{11}	4.03	5.07	0.80	0.438

GNDR *PAREXP γ_{12}	-4.93	4.21	-1.17	0.243
ATT γ_{20}	29.85	3.07	9.73	<0.001
ATT *TCHEXP γ_{21}	2.70	4.03	0.67	>.500
ATT *PAREXP γ_{22}	3.02	4.20	0.72	0.473
SES γ_{30}	37.59	2.15	17.47	<0.001
School-level variables				
TCHEXP γ_{01}	8.87	3.94	2.25	0.026
PAREXP γ_{02}	17.78	3.92	4.54	<0.001
TCHQLTY γ_{03}	5.82	5.88	0.99	0.323
<i>Random Effect</i>				
	Variance	df	χ^2	p
Between-school variability				
(intercept) u_{0j}	789.06	182	369.11	<0.001
GNDR u_{1j}	103.54	183	207.84	0.101
ATT u_{2j}	140.42	183	238.85	0.004
Within-school variability r_{ij}	3931.54			
Proportion of variance explained				
At the student level (within schools)		0.16		
At the school level (between schools)		0.50		

On the other hand, in Taiwan, there were significant interaction effects of school-level predictors on the relationships between student attitudes toward science and science achievement. Parental expectations for student achievement had a strongly, positively and statistically significant effect on the relationship between student attitudes toward science and science achievement (ATT *PAREXP, $\gamma_{22} = 10.83$, $p = 0.011$), which means that it strengthens the positive relationship between student attitudes toward science and science achievement. It is clear that students who expressed more positive attitudes toward science had higher science scores, and that the difference was larger with higher parental expectations. Teachers' expectations for student achievement were, however, a significant and negative predictor for the slope between student attitudes toward science and their science outcomes (ATT *TCHEXP $\gamma_{21} = -10.89$, $p = 0.047$), which means that teacher expectations reduce the positive effect that student attitudes toward science have on student achievement in science. Nonetheless, neither educational expectations of teachers nor parental expectations significantly influenced the relationships between student gender and science performance (GNDR *TCHEXP, $\gamma_{11} = 3.05$, $p > .500$; GNDR *PAREXP $\gamma_{12} = -1.52$, $p > .500$). Overall, student-level predictors accounted for approximately 23.5% of the variance in science performance within schools ($R^2 = \sigma_{\text{null}}^2 - \sigma_{\text{new}}^2 / \sigma_{\text{null}}^2$), and school-level predictors explained about 29.0% of the variance in science achievement between schools ($R^2 = \tau_{00\text{-null}} - \tau_{00\text{-new}} / \tau_{00\text{-null}}$).

Table 5.7

Results from the Full Random Coefficients Model for the Cross-level Interaction Effects for Taiwan

Taiwan				
	<i>Fixed Effect</i>			
	Coefficient	SE	<i>t</i> -ratio	<i>p</i>
Intercept (science achievement) γ_{00}	546.88	3.30	165.62	<0.001
Student-level variables				
GNDR γ_{10}	2.53	3.42	0.74	0.471
GNDR *TCHEXP γ_{11}	3.05	5.23	0.58	>.500
GNDR *PAREXP γ_{12}	-1.52	3.92	-0.39	>.500
ATT γ_{20}	23.09	5.06	4.56	0.003
ATT *TCHEXP γ_{21}	-10.89	5.25	-2.07	0.047
ATT *PAREXP γ_{22}	10.83	4.18	2.59	0.011
SES γ_{30}	33.61	1.35	24.94	<0.001
School-level variables				
TCHEXP γ_{01}	-5.79	6.12	-0.95	0.353
PAREXP γ_{02}	9.43	4.40	2.15	0.033
TCHQLTY γ_{03}	-6.06	5.27	-1.15	0.262
	<i>Random Effect</i>			
	Variance	<i>df</i>	χ^2	<i>p</i>
Between-school variability				
(intercept) u_{0j}	884.54	156	555.79	<0.001
GNDR u_{1j}	271.89	157	236.30	<0.001
ATT u_{2j}	352.95	157	310.19	<0.001
Within-school variability r_{ij}	2855.05			
Proportion of variance explained				
At the student level (within schools)			0.24	
At the school level (between schools)			0.29	

Table 5.8 shows the results of the final HLM analyses of both student and school characteristics' effects on science achievement, as well as the cross-level interaction effects of teachers' or parents' expectations on the relationships between student gender or attitudes and science scores. As a result, Hypothesis 4 was partially confirmed. Unexpectedly, there was not any significant interaction effect across levels in Germany. However, in Taiwan, parental expectations for student achievement were a significant, positive and strong predictor of the relationships between student attitudes toward science and student science achievement, whereas teachers' expectations significantly but negatively impacted the relationships between student attitudes to learning science and science performance.

Table 5.8*The Effects of Student- and school-level Variables on Science Achievement within Nations*

Type of effect	Germany		Taiwan	
	Coefficient	SE	Coefficient	SE
<i>Fixed effects</i>				
Intercept γ_{00}	512.33***	2.69	546.88***	3.30
Student-level				
GNDR γ_{10}	8.71*	3.12	2.53	3.42
GNDR *TCHEXP γ_{11}	4.03	5.07	3.05	5.23
GNDR *PAREXP γ_{12}	-4.93	4.21	-1.52	3.92
ATT γ_{20}	29.85***	3.07	23.09**	5.06
ATT *TCHEXP γ_{21}	2.70	4.03	-10.89*	5.25
ATT *PAREXP γ_{22}	3.02	4.20	10.83*	4.18
SES γ_{30}	37.59***	2.15	33.61***	1.35
School-level				
TCHEXP γ_{01}	8.87*	6.54	-5.79	6.12
PAREXP γ_{02}	17.78***	3.92	9.43*	4.40
TCHQLTY γ_{03}	5.82	5.88	-6.06	5.27
<i>Random effects</i>				
	Variance	SD	Variance	SD
	component		component	
Between-school u_{0j}	789.06***	28.09	884.54***	29.74
GNDR u_{1j}	103.54	10.18	271.89***	16.49
ATT u_{2j}	140.42	11.85	352.95***	18.79
Within-school r_{ij}	3931.54	62.70	2855.05	53.43
Level 1 variance explained (%)	16%		24%	
Level 2 variance explained (%)	50%		29%	

*p<.05, **<.01, ***p<.001

Results from the amount of variance in science achievement within schools explained by student-level predictors indicated 16% for Germany and 24% for Taiwan, and the proportion of variance in science performance between schools accounted for by school-level predictors showed 50% for Germany and 29% for Taiwan. Further, in Germany, level-1 predictors explained about 12.0% ($0.747 \times 16\%$) of the total variance [$R^2 \times (1-ICC)$], whereas level-2 predictors accounted for a total of 12.7% ($0.253 \times 50\%$) in science scores ($R^2 \times ICC$). In Taiwan, the significant student-level predictors explained about 18.0% ($0.75 \times 24\%$) of the total variance [$R^2 \times (1-ICC)$], whereas the school-level predictors accounted for a total of 7.3% ($0.25 \times 29\%$) in the TIMSS 2019 fourth-grade science outcomes ($R^2 \times ICC$).

Chapter 6: Discussion

6.1 Introduction

As greater emphasis is placed on science education globally as a means of generating a high rate of return to national growth, there has been an increasing focus on regular monitoring of science performance and its antecedents. Although numerous studies have provided valuable insights showing that psychological characteristics and contextual factors are strongly and significantly related to children's achievement, relatively less research has focused on the subject area of science. This study, therefore, seeks to add to the understanding of these issues. Guided by an ecological model (Bronfenbrenner, 1977, 1979) and expectancy-value theory (Eccles et al., 1983), this cross-national comparative study aims to gain a clearer understanding of how psychological and contextual factors benefit or hinder children's science outcomes by comparing the phenomena in two contrasting country contexts. Particular attention is given to teachers' and parents' expectations, children's motivational beliefs in learning science, student gender and family circumstances that might magnify or reduce the gap in science achievement between Germany and Taiwan, specifically. Using TIMSS 2019 data and applying several HLM analyses, this quantitative study empirically and comparatively examines the ways in which both student and school attributes are related to science achievement.

In this chapter, the main findings related to the research questions are summarized. Subsequently, results are contextualized within the existing literature and discussed in relation to the theoretical framework of the study, and relevant implications are identified. In the final sections, several limitations of the study are addressed, suggestions for future research are provided and conclusions are drawn.

6.2 Summary of Results

Based on previous literature and the perspective of the ecological model (Bronfenbrenner, 1977, 1979) and the expectancy-value theory (Eccles et al., 1983), psychological factors such as educational expectations, attitudes toward science and gender identity, as well as contextual factors including teacher quality and family SES, are examined in the study to explore the two-level relationships between these hypothesized predictors and science outcomes that might further explain the gap in science outcomes between Germany and Taiwan. Overall, this study expects to find variables from both student and school levels to be significant and positive predictors of science achievement. It also expects to find that teachers' and parents' expectations would moderate the impact of student gender or students'

attitudes toward science on student science performance. The following sections provide a summary of the main findings related to the four research questions.

6.2.1 The Variability in Science Achievement between Schools

The first research question asks whether there is a significant variability in student science achievement between schools in Germany and Taiwan, and how much of the variance in science achievement can be accounted for at different levels. Results of this study confirm Hypothesis 1, indicating that a significant proportion of variance in science achievement occurs between schools in each selected country. Approximately 75% of the variance in science outcomes is accounted for at the student level, while about 25% is accounted for at the school level in both Germany and Taiwan. In other words, schools differ significantly in terms of the average science achievement, and multilevel modelling is, therefore, appropriate to analyse the two-level structure of the TIMSS 2019 data of both countries.

As the second step in the multilevel analyses, student variables are entered at the first level to examine the relationships between student characteristics and their science achievement. The ways in which student attributes are related to science achievement are described in the next section.

6.2.2 Student Characteristics and Student Science Achievement

The goal of the second research question is to determine how the three student attributes impact science achievement. In the level-1 analyses for science achievement, student gender is a significant and positive predictor for science outcomes only in Germany, and not in Taiwan. Boys in Germany score higher than girls in science, whereas no significant differences in science achievement are found between genders in Taiwan. Student attitudes toward science and family SES, however, are significant and positive predictors in both Germany and Taiwan. Students with positive attitudes toward science and whose family are designated as having high SES perform better in science. In summary, the hypothesized relationships between student characteristics and science achievement are partially confirmed. Within Germany and Taiwan, higher levels of student attitudes toward science, and family SES are related to higher reported science achievement, whereas student gender only significantly predicts science outcomes in Germany.

In addition to student characteristics, the psychological and contextual factors in school are also considered important predictors for science achievement in this study. Findings on the

relationships between school characteristics and science outcomes are reported in the next section.

6.2.3 School Characteristics and Student Science Achievement

The third research question examines whether school characteristics have effects on student achievement in science. Two of the three school-level variables are positively and significantly related to science outcomes. Parental expectations predict higher levels of science achievement in both selected countries. Nevertheless, teachers' expectations are a significant and positive predictor of science achievement only in Germany, and not in Taiwan. Conversely, teacher quality is not a significant predictor in either of the nations. Although the non-significant effect of teacher quality on student achievement is surprising given past research (Ambussaidi & Yang, 2019; Blömeke et al., 2016; Burroughs et al., 2019c; Goldhaber, 2016), it makes sense in the context of extremely similar quality between teachers within each selected country. In TIMSS 2019, almost all the science teachers within Germany and Taiwan are designated as being highly qualified, and thus the attributes between teachers are too similar to have an effect on student science achievement. Therefore, the third hypothesis is partially confirmed. Increased levels of parents' expectations are associated with higher science outcomes within countries. Teachers' expectations, however, contribute to science achievement only in Germany, and teacher quality does not impact on science performance in either Germany or Taiwan.

Finally, after examining the impact of student-level and school-level variables on science achievement, respectively, this study further explores the interaction effects of school-level predictors on the relationships between student-level predictors and science achievement. The results of the cross-level interaction effects are summarized in the final section.

6.2.4 The Cross-level Interaction Effects and Student Science Achievement

The fourth research question assesses whether teachers' or parents' expectations impact the relationship between students' characteristics and science achievement. In the case of Germany, teachers' and parents' expectations do not have a significant impact on the slopes between student gender and science outcomes, or between students' attitudes toward science and science achievement. For the model of Taiwan, only the relationship between students' attitudes toward science and science achievement is significantly impacted by teachers' and parents' expectations. Although parental expectations have a positive effect on the slope

between students' attitudes toward science and science achievement, teachers' expectations are a negative predictor of the relationship. In other words, the strength of the relationship is reinforced for schools with greater parental expectations but is diminished for schools with higher teachers' expectations in Taiwan. In summary, the hypothesized significant impact of teachers' and parents' expectations on the relationships between students' gender, attitudes toward science and science outcomes is partially confirmed. Only two significant effects of educational expectations on the relationship between students' characteristics and science achievement are found, with Taiwanese parents' expectations positively predicting the slope between students' attitudes toward science and science achievement, whereas Taiwanese teachers' expectations negatively impact this relationship.

6.3 Conclusions and Implications

One result of the growing recognition of the centrality of science education has been the recognition, worldwide, of the importance of regular monitoring of science performance and its antecedents. To improve science education, policymakers often benchmark themselves against the policies of their high-performing peers. Reform efforts have accordingly become institutionalized in the global sphere, making it possible for school systems across countries to adopt similar models to advance the quality of science teaching and learning. However, few international comparative studies have empirically examined the influence of psychological and contextual factors on student science achievement between Germany and Taiwan. A comparison between these two nations might not only help themselves but those Eastern and Western countries with similar sociocultural contexts and education systems to evaluate the effectiveness of their policies for improving science education. This study attempts to fill this gap in the literature by exploring the impact of the psychological characteristics of teachers, parents and students as well as the contextual attributes of home and school on children's science outcomes in an international setting between Germany and Taiwan.

Findings show that several affective and contextual characteristics are related positively to children's science achievement, both at the student and school levels. From the perspective of the ecological model, all those significant predictors of science achievement found in this study are variables in the proximal environment, where children are exposed commonly. The results, in line with expectancy-value theory, suggest that the educational expectations of those social agents from family or school play a role in forming children's motivational beliefs in learning science or shaping boys' and girls' gender identity in STEM fields that, in turn,

determine children's science achievement. Also, through an ecological lens, some evidence confirms that the interactions between home and school, or between parents and teachers, have a joint impact on children. Nevertheless, these variables in the contexts closest to children are embedded in, and influenced by, the most distal environment, which consists of the broader social norms, cultural values and educational ideologies. Thus, the distinct social and cultural background across countries results in the differences observed in the ways that children are raised, taught and expected between Germany and Taiwan, which ultimately explains the gap in student science outcomes between these two nations. In sum, the findings of this study are in line with Bronfenbrenner's ecological model as well as Eccles et al.'s expectancy-value theory, concluding that children's developmental and educational outcomes are the product of the interaction between them and their significant others from multiple environmental systems.

The next section examines the impact of student and school characteristics on student science achievement. It highlights significant findings, contextualizes these findings within the existing literature and offers practical implications for policy and practice.

6.3.1 Contextual Variables in the Study

As the contextual variable at the student level, family SES accounts for some variation in student science achievement. Students with an advanced family background perform better in science, confirming that higher-SES families are likely to help increase students' academic success by providing a favourable learning environment with sufficient educational resources and academic support for their child (Akukwe & Schroeders, 2016; Areepattamannil et al., 2015; Stubbe et al., 2020). For example, parents in Germany with a relatively high SES are commonly over-represented on school boards and fully exercise their substantial rights to effectively participate in children's learning in school (Hackling et al., 2017). Also, those children from lower-SES families are less likely to attend extra tutoring courses, to which most Taiwanese students are sent after school by their parents. Without the extra assistance from private tutoring lessons, these economically disadvantaged students are more likely to fall behind with their schoolwork, particularly in Taiwan's context full of competition. Overall, in line with the perspective of Bronfenbrenner's ecological model (1977, 1979), the findings show a close tie between home environment and student science achievement in Germany and Taiwan.

The school-level contextual variable is teacher quality. Although teacher quality typically has been found to have a positive association with student achievement (Ambussaidi

& Yang, 2019; Blömeke et al., 2016; Burroughs et al., 2019c; Goldhaber, 2016; Zhang & Campbell, 2015), there are no direct relationships in this study. Almost all science teachers within Germany and Taiwan are designated as being highly qualified in TIMSS 2019 data, and thus the attributes among teachers are too similar to have any significant effect on student science achievement. It is also possible that the specific teacher characteristics considered in this study are limiting, as they may not have captured the intended breadth of teacher quality. In addition to human capital of individual teachers, recent studies have expanded the conceptualizations of teacher quality to include dimensions related to teachers' social capital and affective attributes (Akiba & LeTendre, 2017; Brereton, 2018), indicating that variables such as organizational support, collaborative networks, job satisfaction and self-efficacy could potentially interpret some of the variance in student science outcomes, an area that should be explored in future studies. In sum, the strikingly similar characteristics between teachers as well as the exclusion of teachers' social capital and affective characteristics from the teacher quality conception could perhaps explain the non-significant effect of teacher quality on science achievement in this study.

The following sections provide a detailed discussion on the relevant findings and the implications for each variable in this study.

6.3.2 Students' Attitudes toward Science

Attitudes toward science encompass intrinsic motivation, academic self-concept and extrinsic motivation in the science domains (Mullis & Martin, 2017). At the student level in this analysis, as students' attitudes toward science improve, so too does their science achievement. This significant finding highlights the fact that students in both Germany and Taiwan who find science to be enjoyable, believe in their mastery ability and highly value the subject are more likely to persevere to achieve success in science, which confirms the expectancy-value theory underlying the notion that individual differences in motivational beliefs can lead to differences in academic outcomes (Eccles et al., 1983; Wang & Degol, 2013; Weiner, 2019). The importance of students' attitudes toward science for science achievement has also been reported in previous studies (e.g., Al-Mutawah & Fateel, 2018; Geesa et al., 2020; Jansen et al., 2014; Jiang, 2018; Juan et al., 2018; Liou, 2017; Mohammadpour et al., 2015; Steffensky et al., 2020). From the ecological perspective, the development of children' attitudes toward science, however, varies between countries due to their distinct contextual backgrounds. For instance, affective characteristics of children in Germany are highly regarded due to child-

focused and work-oriented pedagogy, whereas students' interests and self-concepts are generally overlooked in Taiwan's context, in which educational competition takes the lead over teaching and learning. Nevertheless, Taiwanese students are well aware of the great extrinsic value of science for a successful career, and through the lens of expectancy-value theory, the value determines students' task persistence in science and their science performance. Thus, the high subjective value in science could potentially explain Taiwanese students' higher achievement despite poorer attitudes. The fact that students lack self-confidence and affection in learning has, however, become a serious issue in Taiwan. To improve this situation and extend students' engagement with science, it is important for education policy and practice to value children's affective characteristics. Significant implications for school, educators and parents in terms of promoting children's motivational beliefs are proposed in the following section.

Implications for policy and practice. The positive link between attitudes toward science and science achievement highlights the influential role of affective characteristics in student academic outcomes. Therefore, policy and practices that promote students' interests, self-confidence and extrinsic motivation in science should be considered in both school and home contexts, especially in Taiwan, where test results carry more weight than students' motivational beliefs about learning. Expectations from the society, parental influences, teacher affective support, classroom climate and students' social origins, gender, age and early experiences with science are critical factors determining a child's view of science (Hooper et al., 2013). Based on the perspective of self-determination theory (Deci & Ryan, 1985), supportive learning environments that foster a sense of relatedness, competence and autonomy as well as opportunities for students to engage in science activities are considered powerful means to motivate students to put greater effort into STEM subjects. Thus, interventions such as creating a classroom environment that allows students to work autonomously (O'Mara et al., 2006; Reeve, 2002), encouraging students to pursue their personal goals, building a less competitive learning environment (Liem et al., 2013; Marsh & Craven, 2002), helping students to realize the connections between science content and their daily lives (Hulleman & Harackiewicz, 2009) and building supportive relationships among students, parents and teachers might help facilitate children's positive attitudes toward science in greater depth.

6.3.3 Gender Differences in Science Achievement

Gender is considered an important student characteristic influencing children's attitudes toward science, and the similarities or differences in attitudes toward science between boys and girls further determine the gap in science outcomes between sexes (Toma et al., 2019). In this study, there is a positive effect of being male on science achievement in Germany, whereas there is no clear advantage in science outcomes to either gender in Taiwan. It is possible that boys hold more positive attitudes and aspirations toward science than girls in Germany, whereas Taiwanese boys' and girls' motivational beliefs about learning science are more similar than different. The findings support previous studies concerning gender equity in science performance across countries that have found complex and mixed results (Jiang, 2018). The following sections discuss the findings regarding gender inequity, or more specifically gender equity in science outcome among fourth-grade students within Germany and Taiwan, respectively.

Boys outperform girls in science in Germany. It is an interesting finding that gender still accounts for some variation in elementary science in Germany, given that the gender gap in STEM fields has narrowed over the last few decades within many modern countries (Hyde et al., 2008; Leaper, 2015; Lindberg et al., 2010; Mullis et al., 2020; National Science Foundation, 2011) and that PISA 2018 also found no significant differences in science outcomes between boys and girls in Germany (Schiepe-Tiska et al., 2019). However, the student participants of TIMSS 2019 used in this study are fourth-grade pupils, who consider science a part of the interdisciplinary subject called "Sachunterricht" covering contents from the areas of natural science and social science (Wendt et al., 2020), whereas PISA assesses 15-year-old secondary students, who recognize science as a combination of separate subjects including physics, chemistry, biology, and earth and space sciences. Since science is not taught as an independent subject in elementary school, it cannot be assumed that primary students can clearly distinguish science content from the other content in Sachunterricht. Thus, different student populations measured in TIMSS and PISA and the distinct ways in which science is taught and learned in elementary and secondary schools might be the plausible reasons behind these contradictory findings. Nevertheless, these findings could also possibly mean that the gender gap in science is narrowing over grade levels in Germany. With respect to the gender gap found in this study, based on expectancy-value theory, it could be explained by boys' and girls' distinct motivational beliefs about learning science (Kessels et al., 2014; Lazarides & Lauermaun, 2019; Lühe et al., 2017; Spinath et al., 2014; Tsai et al., 2018). In a study that looked at subject-specific gender differences, Nonte et al. (2020) reported that boys in Germany

typically have more positive attitudes toward science domains, whereas girls are more confident in humanities, language and art, resulting in a gender gap favouring boys in science, despite girls outperforming them in almost all other academic areas. It is possible that some girls judge themselves as being less capable of, and less interested in, science than boys due to their gender-role identity (Kessels et al., 2014), regardless of their actual competencies (Nonte et al., 2020; Uunk et al., 2020), which in turn negatively influences girls' performance in science and their choice in STEM fields. It is therefore necessary to highlight that girls lack self-confidence in science when discussing the gender issue in Germany.

Through an ecological lens, some specific contextual factors within Germany might help explain the distinct attitudes toward science between boys and girls. To advance students' awareness of gender equality in science, a number of national initiatives, such as Science Days, Girls' Day and Boys' Day, Youth Research and the programme of the National Pact for Women in STEM Professions, are designed to motivate students, especially girls, to engage in learning science. However, some children still hold stereotypical views about gender roles, and in particular, those from disadvantaged social origins and underprivileged regions that promote gender inequity are likely to have different expectations of themselves regarding science (Jacobs & Eccles, 1992; Tiedemann, 2000). With respect to social origins, an immigrant background represents a dimension of inequality in Germany's education system. About 30% of students in Germany have a foreign nationality (Wendt et al., 2016) and a great number of them are Turkish and Syrian. Boys and girls with a Muslim background are educated to recognize the different roles and obligations for males and females (Bundesamt für Migration und Flüchtlinge, 2014; Diehl & Koenig, 2011; Salikutluk & Heyne, 2014), and they accordingly tend to internalize the gendered expectations promoted by their cultural environments and perform differently in science (Lühe, 2018). In addition to various home contexts, the internal diverse contexts within the country might also determine boys' and girls' different motivational beliefs about learning science. In Germany, demographic, economic, social and cultural heterogeneity differs among states due to its federalism, historical events and an increasing number of immigrants (Wendt et al., 2016). The extent of the gender gap in science outcomes accordingly varies with each federal state and is larger among those with a disadvantaged regional context, such as conservative social norms, devout religious beliefs, an aging population and a struggling economy (Wenzel, 2010).

Nevertheless, the gender disparities reported so far are exclusively differences in mean scores (Nonte et al., 2020). In addition to the mean values, it is also important to consider the distribution of girls and boys in different proficiency levels, as this can provide individual students with gender-specific support (Schiepe-Tiska et al., 2019). A few studies examining gender differences in the dispersion of elementary science scores in Germany suggest that although boys have slightly higher mean scores than girls in science on average, it appears that boys are over-represented at the higher proficiency levels, whereas no gender differences or a slight over-representation of girls are found at the middle and lower proficiency levels (Hedges & Nowell, 1995; Nowell & Hedges, 1998; Reilly et al., 2015). Similar findings are reported in PISA 2018, showing that there are significantly more males than females at proficiency levels V and VI in science-related subjects, despite female students being under-represented at the lower levels of proficiency. For a more differentiated insight, gender differences in different proficiency levels should therefore be explored in addition to the mean differences.

Gender gap in science achievement is closed in Taiwan. On the other hand, student gender is not a significant predictor for science outcomes in Taiwan. In other words, boys and girls perform more similarly than differently in science, which supports global trends in gender equality (Liou et al., 2021; Mullis et al., 2020; Reilly et al., 2019). It is possible that the inequality in attitudes toward science between sexes has been reduced to a negligible degree. This is an important finding, in that it suggests that males and females are more similar than different in most cognitive as well as psychological domains, which confirms the gender invariant and similarities model (Else-Quest et al., 2010; Hyde et al., 2008; Liu et al., 2010; Marsh et al., 2008; Tsai et al., 2015). The government's commitment to gender equality, social transitions of the low birth rate, parents' overemphasis on children's academic outcomes and the late tracking education system might be the plausible explanations for the narrowing gender gap in Taiwan, as described in the following paragraphs.

To advance social justice, the education system in Taiwan has made efforts to improve the advancement of minority groups by promoting equal educational opportunities, reducing educational resource discrepancies and narrowing the learning gap. Achieving gender equality is one of the goals of education equity. At all levels of schooling, curriculum, instruction and teaching materials are expected to model non-stereotypical gender roles to ensure a non-discriminative learning environment for students. In the society, as fertility rates have been dramatically decreasing, the primary family structure has been transferred from multi-generational households to dual-income nuclear households, in which child-rearing and

domestic responsibilities are commonly shared by fathers and mothers, which continues to influence society's ideas about gender equality. As a result, policies promoting gender equality and cultural media displaying gender role reversals have potentially instilled change among future generations (Lee, 2012). Contrary to Confucian philosophy of a patriarchal ideology, social roles have become less gender-bound in today's Taiwan, as children and adults alike have been encouraged to recognize the value of gender equality. This increased awareness of gender equality helps in socializing children to think flexibly about gender roles (Ho et al., 2013), and consequently reduces the gender gap in children's attitudes toward science and their science achievement.

Further, the state of contemporary parenthood in Taiwan might be another probable reason for the closing gap in science outcomes between genders. For cultural reasons as well as those of tradition, Taiwanese parents expect their children to succeed in school and want to ensure they receive the best education available. In recent years, children, regardless of their gender, have become equally important to their parents due to the sharp decline in birth rates, coupled with the increasing awareness of gender equality. In most families, sons and daughters are provided with the same amount of resources and are expected equally to excel in STEM domains – the key subjects to a successful career – which might result in the narrowing gender gap in science achievement.

Although the gender gap in student science achievement is closed in Taiwan, differences in science-related majors and workforce still remain between the sexes. It is possible that gender-stereotypical disparities in science are too early to be apparent among fourth-grade students (Hong & Lin, 2011). In contrast to the German school system with early tracking programmes in lower secondary level, students in Taiwan do not experience the transition until the entry into upper secondary schools. Boys' and girls' distinct attitudes toward specific subjects significantly increase during the transition, as they experience a shift in educational focus from learning to deciding future pathways (Liou et al., 2021), and their gender identities gradually develop along with the potential consequences of various practices of socialization for males and females over grade levels (Denissen et al., 2007; Liou et al., 2021). In the case of Taiwan, children in the fourth grade are not immediately facing this central status passage in their lives, and thus boys and girls tend to use less normative or social comparative judgements within the school context (Liou et al., 2021). The late tracking education system with less institutional differentiation might accordingly explain the negligible

gender differences in science achievement among the fourth-grade population in Taiwan (Tsai et al., 2018).

Overall, gender still plays a role in modern Germany and Taiwan. However, it should be noted that gender was only recorded in binary form, female/male, in TIMSS 2019. It would be meaningful if future assessments were to further investigate students' gender-role self-concept (Nonte et al., 2020). In addition, other potential characteristics, such as birth cohort and national welfare policies, could contribute to gender inequity (Lühe, 2018), which should be considered in future studies. For the purpose of improving science education and meeting the needs of the STEM workforce, reducing gender disparities in science is necessary for education programmes in both countries. Implications promoting gender equity are described in the next section.

Implications for policy and practice. In modern countries, diverse and vulnerable groups could be a reason behind gender inequality in educational outcomes (Bundesamt für Migration und Flüchtlinge, 2014; Diehl & Koenig, 2011; Lühe, 2018; Salikutluk & Heyne, 2014). As both Germany and Taiwan are composed of diverse groups and cultures, it is essential for their education systems not only to respect and care for students with different backgrounds, but to give them special support to promote more awareness of gender equality. Policies encouraging minority groups to recognize the value of gender equality via curricula, instruction, assessments and teacher training would therefore be necessary. Practical implications would include developing strategies aimed at eliminating gender discrimination, upholding human dignity, establishing a non-discriminative learning environment and reducing educational resource discrepancies between genders. A meaningful approach would be to reduce the salience of gender in the science classroom, which might offer pathways for girls to develop to their full individual potential, regardless of cultural gender stereotypes (Kessels et al., 2014), and thus make their engagement in science-related subjects or activities more likely (Kessels & Hannover, 2008). Extensive research also points to the potential benefits of intergroup contact in cooperative settings for reducing gender prejudice (Hong et al., 2008; Paluck & Green, 2009; Pettigrew & Tropp, 2006; Stake, 2003). In the classroom, girls and boys should be encouraged to collaborate in STEM activity settings. These mixed-gender cooperative learning groups offer children the opportunity to form a common in-group identity and sense of belonging that affirms their shared interest in STEM (Gaertner & Dovidio, 2000; Stake & Nickens, 2005).

In addition to building a non-discriminative environment, efforts should be put into developing girls' positive attitudes toward science as the next step (Rasinen et al., 2009), especially in Germany. It is therefore important for parents and teachers to work as partners to encourage girls to participate in STEM-oriented groups in class or extracurricular programmes that would help raise their interest in science (Rasinen et al., 2009). Those girls with an underprivileged background or conservative cultural values in particular need to experience appreciation of their science competences, which would strengthen their self-concepts in science. It is also crucial for female science teachers or mentors to act as positive role models for girls, which would help them gain a feeling of belongingness in STEM domains (Leaper, 2015). Finally, attention needs to be given to reframing girls' perception of the value affordances associated with certain science domains (Leaper, 2015). By viewing science as compatible with communal goals such as helping people or balancing work and family, female students would become more likely to engage in science (Diekman et al., 2011; Häussler & Hoffmann, 2002). Overall, as the key socializers in home and school contexts, parents and teachers play roles in determining children's, or boys' and girls' affective characteristics in learning science. It is therefore important for this study to further explore the impact of parents and teachers on children's motivational beliefs as well as on their science achievement. The findings about the ways parents' and teachers' expectations are related to student science outcome are discussed and compared in an international setting between Germany and Taiwan.

6.3.4 Parental Expectations for Student Achievement

Individual students score higher in science when they perceive their parents as having high expectations for their achievement. This is an important finding supporting Bronfenbrenner's ecological model (1977, 1979), in that it stresses that parents as the crucial socializers in the home environment could improve their children's learning through their expectations. As parents set their children high academic goals, the children are likely to perform as well as anticipated (Bandura et al., 2001; Grolnick & Slowiaczek, 1994). This finding also corroborates other studies that suggest that parental expectations exert a strong and positive influence on educational attainments (e.g., Benner et al., 2016; Bowen et al., 2012; Froiland & Davison, 2016; Ing, 2014; Vukovic et al., 2013; Wilder, 2014). Other results find that parents' educational expectations are related directly to student achievement, and indirectly through students' affective characteristics across gender and ethnicity groups (Jacobs & Harvey, 2005; Neuenschwander et al., 2007; Rice et al., 2013; Yeung et al., 2010; Zhang,

2018). Benner and Mistry (2007) show that parental expectations for student achievement not only predict student performance, but also promote students' positive academic characteristics.

Although high levels of parental expectations for student achievement are related positively to student science performance in both Germany and Taiwan, the gap in science outcomes between these two nations still remains. The distinct expectations German and Taiwanese parents generally have for their children might explain this gap. Due to child-focused and work-orientated pedagogy, the majority of German parents respect children's motivational beliefs about learning and expect more of learning itself than of test results (Hackling et al., 2017; Pepin & Moon, 1999), although there are still families, especially those with a relatively high SES, that pay a lot of attention to, and have high expectations of, children's academic achievement (Joshi & Shukla, 2019; Lareau, 2011). In contrast, with the social norm of credentialism, most Taiwanese parents highly value test scores over learning itself (Hackling et al., 2017). Many of them expect children to excel in school, but tend to overlook children's affective attributes (Ambussaidi & Yang, 2019; Chen, 2013), which explains Taiwanese students' higher science achievement despite their lower self-concept in science. From the perspective of the ecological model and expectancy-value theory, such differences in parents' expectations between Germany and Taiwan might be a reason behind the fact that Taiwanese students outperform their German counterparts in science. In sum, the findings highlight the significant role parents play in children's science outcome within each selected nation. To improve science education, it is necessary for education systems to take the powerful force of parental expectations into account. Effective cooperation between family and school is therefore considered a meaningful approach to benefit children's science learning, as described in the next section.

Implications for policy and practice. Parents' expectations for student achievement are found to determine not solely children's learning outcomes but, more importantly, children's motivational beliefs about learning (Rice et al., 2013; Yeung et al., 2010; Zhang, 2018). In general, parents who have high expectations regarding student achievement are more likely to effectively convey the value of education to children and provide them with a favourable learning environment as well as opportunities regarding academic engagement in family practices, which helps promote students' learning attitudes and educational outcomes (Jacobs & Harvey, 2005). Even in a financially impoverished context, parents' positive expectations still significantly contribute to their child's success in school (Brooks-Gunn et al., 2005; Davis-Kean et al., 2002; Furstenberg et al., 1999; Neuenschwander et al., 2007). In other words,

parental expectations can mitigate the effects of social and economic disadvantages on student achievement. To improve student science outcomes, it is therefore necessary for education programmes to increase parents' awareness of the significant influence of having positive educational expectations for their children. However, parents should not overemphasize science achievement over other accomplishments and expect extremely high test results that might lead to test-driven teaching and learning. This is especially evident in Taiwan, where most students have been under great stress, which undermines their motivation for learning. To be successful in competitive exams, these students have a tendency to memorize content knowledge and repeat the solving strategies continuously. Therefore, it is important for education programmes, particularly in Taiwan, to build a less competitive but more motivating learning environment and to work with parents to facilitate students' science learning by encouraging parents to set positive and reasonable expectations for individual students and considering ways in which parents can help their children develop positive attitudes toward science. In addition to parents, teachers, as other important social agents, could play an influential role in determining student achievement. In the next section, the relationships between teachers' expectations and student science outcomes found in this study are discussed in the context of Germany and Taiwan.

6.3.5 Teachers' Expectations for Student Achievement

Teachers' expectations are a positive predictor for student science achievement in Germany, but not in Taiwan. Through an ecological lens, the finding in the case of Germany highlights the fact that teachers continue to play a role in determining students' potential, opportunities and achievement through their expectations. The importance of teachers' expectations for student achievement has been reported in previous research (Friedrich et al., 2015; Hinnant et al., 2009; Jussim & Harber, 2005; McKown & Weinstein, 2008; Trouilloud et al., 2002; Zhu et al., 2018). Brophy (1983) found that teachers have different expectations of, and interact differently with, individual students, in ways that seem likely to maximize the progress of high-expectation students but limit that of low-expectation students. Brophy and Good (1970) indicated that teacher expectations affect student outcomes indirectly by forming students' self-concept, interest and values. Similarly, Urhahne (2015) suggested that through their behaviours, teachers communicate their expectations to students, which in turn affects students' motivation and thereby their achievement outcomes.

On the other hand, teachers' expectations do not impact student science achievement in Taiwan. This finding is surprising, given that Taiwanese teachers have relatively high SES and are highly respected in the society, which is very much influenced by Confucian values (Hackling et al., 2017). This unexpected outcome could be explained by the state of contemporary parenthood in Taiwan. With the declining fertility rate and the social norms of competitiveness, the tension over having children succeed is especially evident among Taiwanese parents, who regardless of their socio-economic status are eager to provide their child with the best possible upbringing. Many of them are confident in their child-rearing abilities and demand that their opinions on education be heard and followed. These so-called "monster parents" have placed great pressure on schoolteachers. Many teachers are already reporting being overwhelmed by today's parents, who persistently challenge their professionalism, intervene in teaching practices and show absolutely no respect to school staff (Jhu, 2017; Shu & Lin, 2021). These inappropriate behaviours and disrespectful attitudes toward teachers are eventually passed on to children, who in turn are also likely to look down on their teachers. The general disrespect of parents and students for teachers might be the reason behind the fact that teachers' expectations are not necessarily influential on Taiwanese students and their science achievement. It is therefore important for education programmes in Taiwan to improve the low influence of teachers' expectations on students' science learning. Relevant implications for Germany and Taiwan, respectively, are provided in the following section.

Implications for policy and practice. Although only significant in the case of Germany, teachers' expectations have been shown to make a substantial difference in student outcomes, as suggested by the growing number of studies finding that students have more positive attitudes toward learning, are more engaged in school and achieve at higher levels when their teachers have high expectations regarding their achievement (Boerma et al., 2016; Gilbert et al., 2014; Rubie-Davies, 2018; Urhahne, 2015). Dweck (2000) and Ladson-Billings (2009) found that teachers' expectations are mainly shaped by their perceptions of students. Unfortunately, implicit bias can colour teachers' expectations of their students. There is evidence that many teachers attribute inaccurate characterizations of academic ability and behaviour to students based on gender, race and economic background (Irvine, 2003; Kaplan et al., 2002), resulting in negative expectations, which often trigger a threat to social identity and thereby undesirable outcomes. The threat of stereotyping can nonetheless be mitigated by how teachers give constructive feedback to students about their work, noting that the feedback

reflects the teachers' high expectations and a conviction that the student can fulfil them (Cohen et al., 1999). Steele (2011) also reported that positive expectations, along with affirming attitudes, can counteract the threat of stereotyping and support academic outcomes. Based on these findings, teacher training programmes and educational interventions should increase teachers' awareness regarding the potential effects of their expectations on students. Strategies that raise teacher expectations and prevent low or biased expectations from having detrimental effects on student science achievement are necessary (de Boer et al., 2018), especially in culturally diverse countries such as Germany, where children with immigrant backgrounds are particularly over-represented in the lowest competency group and at risk of low educational attainment (Hackling et al., 2017). This could, for example, be done by encouraging teachers to exhibit high expectations for all students, to build positive relationships with students by respecting and showing them concern regardless of their background (Carter & Darling-Hammond, 2016), to promote cultural competence that helps them know their minority students well, to create an identity-safe classroom in which students are affirmed and enabled to belong, to provide a supportive science learning environment that motivates students to engage more in science, and more importantly to convey their confidence that students can excel at science.

With respect to the weak teacher influence on students in present-day Taiwan due to the phenomenon of monster parenting, Holloway et al. (2010) found that irrational parenting could have a positive effect on teaching and learning if the partnerships and communication channels between teachers and parents are well established. They suggested that school administrators, teachers and parents should engage in respectful and constructive dialogue, and most importantly clear boundaries need to be drawn for mutual benefit. Darling-Hammond et al. (2020) also showed that strong and respectful relationships between parents and teachers can create the resonance and coherence between home and school that provides aligned support for children and benefits students' learning. These findings suggest the need for policy and practices to build strong relationships between family and school, with an emphasis on strengthening relational trust among students, parents and teachers that might help teachers regain the respect of parents and increase their influence on students. Strategies that encourage parents and teachers to work together as partners to develop common rules, guidelines and expectations for children are therefore necessary for improving the negative effects of irrational parenting and increasing the impact of teachers' expectations on student achievement in Taiwan.

After discussing the impact of each variable of student and school levels on science achievement, respectively, this study also explores the interaction effects across student and school levels. Findings regarding teachers' and parents' expectations on the relationships between student gender and science achievement, or between students' attitudes toward science and science achievement, are reported and discussed in the next section.

6.3.6 The Cross-level Interaction Effects and Student Science Achievement

For the purposes of this study, teachers' and parents' expectations are not significant predictors for most relationships between students' attitudes toward science and science outcomes, or between student gender and science achievement. In fact, only teachers' expectations and parental expectations, respectively, have a significant impact on the slope between students' attitudes toward science and science achievement in Taiwan. The fact that the relationship is higher in schools with greater parental expectations but lower in schools with higher teachers' expectations could signal that children's motivational beliefs about learning science are mainly influenced by parents instead of teachers. In other words, parental influence is much more salient than teacher influence on today's children, which perhaps results from the universal phenomenon of irrational parenting in Taiwan. These findings support a study examining the current relationships among students, parents and teachers in Taiwan, which suggested that the influence of teachers has become relatively weak on the connections between students' motivational beliefs and learning outcomes due to the state of contemporary parenthood and the law on banning corporal punishment (Jhu, 2017).

In the case of Germany, neither teachers' expectations nor parental expectations have a significant impact on gender disparities in science outcomes, or on the positive relationship between students' attitudes toward science and science achievement. It is quite likely that teachers and parents in Germany are no longer key influencers on shaping fourth-graders' beliefs about gender role in science, as well as their attitudes toward science. Pupils in the fourth grade are entering early adolescence. Along with physical growth and sexual development, children start to question their gender identity and also begin to assert more independence but less supervision (Paulu, 2005). At this point, peer groups increasingly have more influence than parents and teachers on young teens' affective characteristics, as well as gender ideology (Leaper, 2015). In addition, most children of this age in Germany are at the end of their primary school years and experiencing the transition from elementary to secondary school. Peer influence could be particularly significant to these populations as they are

imminently facing separation from their friends and classmates. In sum, within an early tracking system in Germany, peers might become powerful influencers, or socializers, on early adolescents, which could explain the non-significant moderating roles of teachers' and parents' expectations in the influences of student gender and attitudes toward science on science achievement.

Although findings suggest that teachers, parents and peers might have different levels of influence on fourth-grade students' motivational beliefs or gender identity in science across nations due to distinct national circumstances, policy and practice, fostering trust and alignment among students, parents and teachers is equally important for both Germany and Taiwan. The need to maximize the positive impact of different groups of social agents on student science learning through effective cooperation between school and family is emphasized in the next section.

Implications for policy and practice. The findings of cross-level interaction effects are encouraging for both Germany and Taiwan to strengthen the connections among students, parents and teachers. In strong and respectful relationships, teachers, parents and children are likely to build trust between each other, which not only helps teachers and parents regain influence on young teens but creates resonance and coherence between home and school, which advances education and benefits children's learning (Bryk & Schneider, 2002; Darling-Hammond et al., 2020; Paulu, 2005). Policy and practices developing positive connections and alignment among individual students, home and school should therefore be seriously considered in Germany and Taiwan. Effective strategies include, for example, encouraging schools to create structures that enable teachers to know their students well and to develop strong relationships, ranging from smaller classes and school units to advisory systems, looping, teaching teams and longer grade spans. In the classroom, it is important for teachers to create a supportive environment, in which students are affirmed, enabled to belong and taught social responsibility. Authentic and effective parental engagement should also be stressed. Although fourth-grade pupils, or young adolescents, are increasingly affected by their peers, parents could still be a powerful influence in children's life when the bond between them is strong (Paulu, 2005). Staying effectively involved in children's school activities has been found to be a key strategy for parents to develop a close connection with their child. Further, studies have suggested that education works best when teachers and parents work closely with one another (Bryk & Schneider, 2002; Darling-Hammond et al., 2020). Based on these findings, schools should involve families as partners, aligning home and school practices, and capitalizing on

their cultural assets. Overall, these multiple approaches could foster strong relationships that promote the trust, safety and sense of belonging necessary for students' productive engagement in all aspects of school, including science learning.

6.4 Limitations

Despite the positive findings in this study, there are some apparent limitations. The study used the ecological model and expectancy-value theory to explain the national trends it found in the relationship between psychological characteristics, contextual factors and student science achievement within Germany and Taiwan. TIMSS 2019 surveyed elementary students, all of whom were mainly in their fourth year of school. Generalizability of the findings in the national model is, therefore, not completely possible, as participants are only fourth-grade students and their teachers. Similarly, it might not be appropriate to generalize the findings internationally in those countries sharing similar cultures or schooling systems with Germany or Taiwan due to the diversity in social and economic development within and across countries.

Additionally, TIMSS 2019 is a self-report survey and does not engage in direct observations in home and school contexts, so inferences about student and school characteristics are therefore limited due to potential differences between what a pupil or a teacher reports and what might actually occur at the family and classroom level. Thus, the reliance on self-reporting indicates that the validity of the predictor variable should still be interpreted with caution.

The study is also limited to the specific teacher characteristics considered teacher quality. Based on previous literature, the human capital of individual teachers, including experience, pedagogical and content expertise, and in-service training are identified as the components of teacher quality in this study. However, these collective characteristics might not be able to capture other important dimensions of teacher quality, such as teachers' social capital and affective characteristics, which are encompassed in the expanded conceptualizations of teacher quality in recent research. Therefore, teachers' social relationships, collaborative networks, job satisfaction and self-efficacy should have been considered in constructing teacher quality, but unfortunately are not included in the analyses partly due to data being unavailable in the TIMSS 2019 database.

With respect to parental expectations, the only relevant item in the TIMSS 2019 data is surveyed in the teacher questionnaire asking how individual teachers characterize the general parental expectations for student achievement within their classroom. Because teachers'

perceptions of a class's parental expectations are not a direct measure of an individual parent's actual anticipation for their child, inferences about parental expectations in this study are limited due to the diversity between parents and the potential disparities between what teachers observe in the classroom and what individual parents would report based on their family context.

6.5 Directions of Future Research

To improve the quality of science teaching and learning, education policymakers often benchmark themselves against the policies of their high-performing peers. Reform efforts have thus become institutionalized in the global sphere. Germany and Taiwan represent a wide range of geographic and contextual diversity between the West and the East. Although generalizability of the findings in nations with similar socio-economic backgrounds and school systems to Germany or Taiwan is possible, further comparisons for groups of countries across these regions would be more valid and reliable for institutionalization. Also, the methodology for this study could be replicated easily and applied to individual countries who also take part in international assessments. To generalize the results in a global model, similar studies could be conducted based on more nation states in future research.

In addition to TIMSS, another international large-scale database, namely the "Programme for International Student Achievement" (PISA), also provides a rich source for international comparative studies of science achievement. More potential items forming psychological constructs are especially investigated in PISA student questionnaires. It is suggested that the current study could be extended and deepened by cross-validating the results from different databases.

Further, school-level predictors in the study account for approximately 50% and 29% of the variance in science performance between schools in Germany and Taiwan, respectively, which means that additional variables could be added to future models to account for the variance. As well as the predictors collected from student, teacher and home data sets in this study, other contextual variables from school or curriculum questionnaires may further explain some of the variance in student science performance. Also, in the case of cross-level interaction effects, the findings suggest that teachers' and parents' expectations do not significantly impact most relationships between student characteristics and science outcomes. Results, however, indicate that there is still significant variance in those relationships that can be modelled, requiring the addition of potential interaction variables. Taking Germany as an example, gender

inequity in science outcomes and the relationships between pupils' science attitudes and science achievement may be affected by other social agents or contextual factors such as peers' influence or school treatment, which this study does not consider but could be an area to explore in future research. Therefore, additional potential predictors should be included in future research to obtain a fuller spectrum of student science achievement.

Finally, comparing the effects of the variables at different levels is an advantage for studies applying a multilevel analytic approach. In the case of socio-economic status, for instance, student-level SES could be aggregated to the school level to create a new school-level SES variable. Individual SES, however, is not the same as aggregated SES at the school level, meaning that the effect of student SES on their science achievement may be different from the effect of school SES. Thus, it would be interesting for future research to investigate the influence of analysed units at different levels on student outcomes. Further, in addition to the student and the school levels, future international comparisons could include the national level and apply a three-level hierarchical linear model (HLM) analysis to explore the phenomenon across nations on the same scale.

In sum, to broaden the scope of international comparative studies in science education, more participating countries, additional variables, an extra level in HLM modelling and a cross-survey analysis should also be taken into account in future studies.

6.6 Conclusion

The purpose of this study is to examine the ways in which attributes of student and school are related to student science achievement in Germany and Taiwan. Particular attention is given to psychological characteristics and contextual factors that may magnify or reduce the gap in science outcomes between nations. The issues regarding students' motivational beliefs, teachers' and parents' expectations and gender differences are discussed and explained using the ecological model and expectancy-value theoretical approach. Relationships are empirically tested applying HLM analyses.

Results show that students' attitudes toward science, family SES and parental expectations significantly and positively predict science achievement, but that no relationship exists between teacher quality and science outcomes in either Germany or Taiwan. Teachers' expectations and student gender are key predictors of science achievement only in Germany, and not in Taiwan. Although Germany is generally regarded as a modern country with high gender equity, boys continue to outperform girls in science. This finding could, however, be

explained by the internal diversity within Germany due to its large number of immigrant populations, its political system of federalism and its unique historical events. For example, those girls and boys from a region or a family with rigid cultural beliefs, conservative social norms, disadvantaged life circumstances or a struggling economy are more likely to have distinct attitudes toward science, and thus perform differently in science. On the other hand, the gap favouring boys in science outcomes has been closed in Taiwan, which might result from the successful gender equity education at all levels of schooling, increased gender equity awareness among the general public and parents' overemphasis on the science outcomes of their children regardless of their gender due to the low birth rate. It could also be that the impact of gender-stereotypical differences in science is too early to show among the fourth-grade population in Taiwan because of its late tracking system.

Furthermore, teachers' and parents' expectations generally do not predict the relationships between student gender and science outcomes within either nation, and only impact the relationship between students' attitudes toward science and science achievement in Taiwan. The relationship is strengthened by parental expectations, but weakened by teachers' expectations. The findings confirm the fact that parents have more influence than teachers on children's affective characteristics and achievement in science due to the universal phenomenon of irrational parenting in Taiwan. Although teachers' and parents' expectations positively and directly predict student science achievement in Germany, they do not significantly moderate the relationships between student gender and science achievement, or between students' attitudes toward science and science achievement. The increasingly powerful influence of peer groups could be the reason behind the findings that fourth-graders in Germany are less likely to be influenced by their parents or teachers, especially on subject-specific gender identity and motivational beliefs during their early adolescence years and within an early tracking schooling system.

Finally, based on the results and discussion in this study, the differences in teachers' and parents' educational expectations, children's motivational beliefs in learning science and sociocultural values between Germany and Taiwan might be the critical reasons behind the observed gap in science outcomes between these two nations. Findings in this study support the perspectives of the ecological model as well as expectancy-value theory, suggesting that teachers, parents and peers are under the influence of social norms and cultural values and play their roles in socializing individual students' affective characteristics or gender identity in various contexts of the home, classroom and school. It is therefore necessary for both Germany

and Taiwan to strengthen the connections among children, parents and teachers through positive educational expectations, effective cooperation, advancement of gender equality, and understanding of individuals' life circumstances and cultural background that would help build a trusty, respectful and encouraging science learning environment motivating children to learn science and benefiting their science outcomes. There is reason for optimism in these implications, because building a strong relationship among students, parents and teachers is adaptable to local contextual factors and is a sustainable way to improve science learning for every student regardless of their social origins or cultural background. Overall, the findings in this study are important, as affective characteristics and contextual factors are increasingly stressed by cross-national education comparative studies, with little empirical evidence in science domains and especially in a comparison between Germany and Taiwan.

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Appendix A

Table 4.3

Description of Variables

Variable name	Description
<i>Outcome</i>	
Science Achievement	Science plausible values for the TIMSS 2019 4th grade
<i>Student-level</i>	
GNDR	Student Gender (0 = girl, 1 = boy)
ATT	Students' Attitudes toward Science The index is created by TIMSS and based on students' responses to four statements about their science ability: <ul style="list-style-type: none"> a) I enjoy learning science b) I wish I did not have to study science c) Science is boring d) I learn many interesting things in science e) I like science f) I look forward to learning science in school g) Science teaches me how things in the world work h) I like to do science experiments i) Science is one of my favourite subjects j) I usually do well in science k) Science is harder for me than for many of my classmates l) I am just not good at science m) I learn things quickly in science n) My teacher tells me I am good at science o) Science is harder for me than any other subject p) Science makes me confused [1: disagree a lot; 2: disagree a little; 3: agree a little; 4: agree a lot]
SES	Family Socio-economic Status The index is created by TIMSS and based on students' responses to the statements about the number of books in the home, the number of home possessions, the highest level of education of either parent and the highest level of occupation of either parent. Number of books in the home [1: 0–10; 2: 11–25; 3: 26–100; 4: 101–200; 5: more than 200] Number of home possessions <ul style="list-style-type: none"> a) A computer or tablet b) Study desk/table for your use c) Your own room d) Internet connection e) Your own mobile phone f) <country-specific indicator of wealth> g) <country-specific indicator of wealth> h) <country-specific indicator of wealth> i) <country-specific indicator of wealth>

[1: yes; 0: no]

Highest level of education of either parent

[1: not applicable; 2: finished some primary or lower secondary; 3: finished lower secondary; 4: finished upper secondary; 5: finished post-secondary education; 6: finished university or higher]

Highest level of occupation of either parent

[1: not applicable; 2: never worked outside home; 3: general labourer; 4: skilled worker; 5: clerical; 6: small business owner; 7: professional]

School-level

TCHEXP

Teachers' expectations for student achievement (teachers' responses to a statement about the level they expect of student achievement [1: very low; 2: low; 3: medium; 4: high; 5: very high])

PAREXP

Parental expectations for student achievement (teachers' responses to a statement about the level parents expect of student achievement [1: very low; 2: low; 3: medium; 4: high; 5: very high])

TCHQLTY

Teacher quality is based on teachers' responses to the statements about years of teaching experience, major in education and science, the highest level of formal education, hours spent in formal professional development for science and self-perceived preparedness.

Years of teaching experience (the index is created by TIMSS and based on teachers' responses to the number of years of teaching experience. [1: less than 5 years; 2: at least 5 but less than 10 years; 3: at least 10 but less than 20 years; 4: 20 years or more])

Major in education and science (the index is created by TIMSS and based on teachers' responses to the statements about the highest level of formal education, major or main area(s) of study and a specialization in science. [1: no formal education beyond upper secondary; 2: all other majors; 3: major in primary education but no specialization in science; 4: major in primary education and specialization in science])

Highest level of formal education (teachers' responses to the statements about highest level of formal education [1: did not complete upper-secondary education; 2: upper-secondary education; 3: post-secondary, non-tertiary education; 4: short-cycle tertiary education; 5 bachelor's or equivalent level; 6: master's or equivalent level; 7: doctorate or equivalent level])

Professional development for science (teachers' responses to the statements about the hours in total they spent in formal in-service/professional development for science [1: none; 2: less than 6 hours; 3: 6–15 hours; 4: 16–35 hours; 5: more than 35 hours])
