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RESEARCH ARTICLE

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Relationship between Science Teaching Practices and Students' Achievement in Singapore, Chinese Taipei, and the US: An Analysis Using TIMSS 2011 Data

Abstract The assumption that inquiry-based instruction is more effective in influencing student science achievement than traditional didactic teaching has been the driving force of science education reform in recent decades and in many countries. However, the empirical relationship between these two kinds of science teaching and student science performance is not soundly established, which is worth a careful examination. Framed through the theoretical perspectives of inquiry-based instruction and culturally relevant pedagogy, using a two-level hierarchical linear modeling (HLM) approach and simultaneous multiple regression, this study examines the above relationship using the Trends in International Mathematics and Science Study (TIMSS) 2011 8th grade dataset from Singapore, Chinese Taipei, and the US. The study found that for the low-performing students, none of the inquiry-based teaching practice items measured had a significant relationship with the science achievements at any performance levels of students in any country/region except for the case of two inquiry-based teaching practice items that were positively related to Chinese Taipei students' achievements. No didactic teaching practice items were associated with the Singapore students' science achievement, three of these practice items were found negatively related to Chinese Taipei students' science achievement, and one traditional didactic teaching practice was negatively related to the science achievement of U.S. students. However, for medium- and high-performing students, none of these inquiry-based or traditional didactic science-teaching practices were found to be positive predictors of science performance in all three countries/regions. However, in the case of Chinese

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Taipei, one didactic teaching practice item was negatively related with the medium level performing students' achievement and two didactic teaching practices were found to hinder high-performing students' science achievements.

Keywords inquiry-based teaching practice, didactic teaching practice, science achievement, international comparison

Introduction

The global economy demands a country's workforce to be adequately educated in science (OECD, 2011) and helping all students learn science well becomes an important issue of social justice and equality for many countries (Jenkins, 2009; Labaree, 1997; National Research Council, 2012). Inquiry-based instruction has become a driving force in science teaching reform in many places including Singapore, Chinese Taipei, and the US as well as other European countries around the world (Abd-El-Khalick et al., 2004; Ministry of Education, Singapore, 2008) because it emphasizes teachers' engagement of their students in investigating natural phenomena in classrooms, outdoors, or laboratory settings that reflects how science knowledge is constructed within the various scientific communities (Chang & Mao, 1999; Odom, Stoddard, & LaNasa, 2007; Wilson, Taylor, Kowalski, & Carlson, 2010). In contrast, traditional didactic science teaching, currently assumed to be the most popular form of science teaching, sees students as passive receptors and stresses conveying facts and knowledge to them and is believed to contribute to lower science achievements and performance gaps (Smerdon, Burkam, & Lee, 1999).

Consequently, new curriculum standards and relevant professional development programs in the US have been developed to help teachers change their beliefs and instruction practices from traditional didactic methods to inquiry-based instruction (Capps, Crawford, & Constas, 2012; Keys & Bryan, 2001) after the National Science Education Standards started to be implemented (National Research Council, 1996). The new curriculum standards were expanded to include concepts of scientific inquiry that have been implemented in Taiwan (Abd-El-Khalick et al., 2004; Ministry of Education (Chinese Taiwan), 1999) and Singapore (Ministry of Education, Singapore, 2008) since the end of the 1990s.

However, a large number of international comparative studies continue to show that U.S. students had alarmingly poor performance in standardized science assessments when compared to some Asian countries and regions including Singapore and Chinese Taipei after the reformed national standards had been implemented for almost two decades (Gonzales et al., 2008; OECD, 2009; Lee, Buxton, Lewis, & LeRoy, 2006). As shown recently in the Trends in International Mathematics and Science Study (TIMSS) 2011, students in Singapore and Chinese Taipei had significantly higher average science scores than U.S. students at the 4th and 8th grade levels. According to 2012 data from the Programme for International Student Assessment (PISA) which focuses on assessing the application of science knowledge in unfamiliar settings, U.S. 15-year-olds also performed not as well as their peers from Singapore and Chinese Taipei (OECD, 2013). Given that inquiry-based science teaching is believed to be an effective tool in influencing student science achievement (Fogleman, McNeill, & Krajcik, 2011; Lynch, Kuipers, Pyke, & Szesze, 2005), these differences in international performances lead us to several challenging issues related to the role of inquiry-based science education reform in these places (Achieve, 2013; Ministry of Education (Chinese Taiwan), 1999; Ministry of Education, Singapore, 2008).

First, whether and to what extent inquiry-based instruction is more effective than traditional didactic teaching in improving students' science performance, is an unsettled question. At the theoretical level, there is still a serious debate over this question (Dean & Kuhn, 2007; Kirschner, Sweller, & Clark, 2006; Mayer, 2004; Rosenshine & Stevens, 1986). According to empirical studies conducted in Singapore and Chinese Taipei, traditional didactic science teaching is still a popular science teaching practice in secondary classrooms (Chin, 2006; Hogan et al., 2013; Chang, Chang, & Yang, 2009). Students in these areas actually showed higher performance in science (Provasnik et al., 2012). Thus, it is important to examine whether the assumption of the effectiveness of inquiry-based instruction is consistent across different countries as science teaching reform assumed in these countries.

Second, it is still not clear whether students with high and low performances can be benefited equally from inquiry-based science teaching in these countries. Some researchers argue that inquiry-based instruction is effective for high-achieving students to develop their knowledge of science (Kirschner et al., 2006). Other researchers doubt whether low-achieving students are able to deal with inquiry-based tasks that require higher order thinking skills (Zohar & Dori, 2003). Therefore, it is important to examine empirically whether inquiry-based science teaching promoted in the science teaching reforms can benefit students with different levels of performance in different countries.

Finally, student science learning in middle grades plays a central role in increasing students' science achievement later (Southern Regional Education Board, 2011). This period is regarded as a critical "turning point" for many young students in the education pipeline and it is one of the "last real opportunities to affect their educational and personal trajectory" (Jackson & Hornbeck, 1989, p. 831). Developmental and brain research also confirms that this period presents an opportunity to help students become successful thinkers, learners, and decision makers throughout their lives and helps them learn the science they need to thrive in the modern world (Mac Iver & Epstein, 2012; Thomas, 1993). Empirical studies have shown that in middle grades, differences begin to appear in students' attitudes toward science (Gibson & Chase, 2002). Students' science learning in high school, college and their careers can be accelerated only if they build a strong foundation at this critical point (Muller, Stage, & Kinzie, 2001; Southern Regional Education Board, 2011). Therefore it is necessary to examine whether students in the three regions at the middle grade level responded differently to inquiry-based and traditional didactic teaching practices.

These issues have helped raise two reasonable research questions. First, whether inquiry-based instruction and traditional didactic science teaching practices are significantly related to the performance of 8th grade students who have different levels of science achievements in Singapore, Chinese Taipei, and the US. Second, and whether such a relationship is consistently shown among 8th grade students in all these countries/regions. Drawing on the data from TIMSS 2011, this quantitative study examines these two questions central to the knowledge base of science teaching reform policy.

Theoretical Framework

This study is framed through the two conceptual lenses about science teaching approaches and their influences on student science learning. These assumptions become contentious as they are related to science teaching reforms in various countries, and neither has received sufficient empirical support.

Assumption of Inquiry-Based Instruction

The first line of assumption presumes that inquiry-based science teaching is effective in improving science learning of all students (National Research Council, 1996). This starts with the idea that children, no matter their backgrounds, are natural inquirers who ponder natural phenomena, find evidence for their questions, and seek explanations by interacting with their environment and others as well as using their prior knowledge actively. This resembles the process of scientific inquiry in principle (Dewey, 1910; Piaget, 1973; Vygotsky, 1978). According to this viewpoint, science teaching is presumed to help all students develop a meaningful understanding of the content and process of science, as well as how to solve problems in a meaningful context (Duschl, Schweingruber, & Shouse, 2007).

Therefore, science learning in a school context should be an inquiry-based process with the following four characteristics: (1) It engages students in developing meaningful questions that could lead them to new, broad, and deep understandings based on what they already know and believe (Bransford, Brown, & Cocking, 1999); (2) it offers students the opportunity to use their own observations and investigations to build important science concepts and relevant processes, get feedback, and then apply them in a variety of contexts (Donovan, Bransford, & Pellegrino, 1999); (3) it allows students not only to manipulate and regulate their own learning through the investigation, but also to evaluate their ideas and understanding using feedbacks from both teacher and their peers (Anderson, 1996, 2002); (4) it provides students the opportunities to interact with each other through articulating their ideas and challenging each other (Lee & Luykx, 2006; Bransford, Brown, & Cocking, 2000).

Proponents of inquiry-based instruction (Smerdon et al., 1999) see traditional didactic science teaching as problematic in helping students improve their science learning as it treats students as passive learners and only focuses on the delivery of decontextualized scientific facts to students, which might make them lose interest in learning science by disconnecting science knowledge from the students' own world (National Research Council, 1996). This line of assumption has been shaping the direction of science teaching reform towards inquiry-based instruction in the U.S. (Anderson, 1996, 2002; Keys & Bryan, 2001; National

Research Council, 1996, 2000, 2012) and in many other countries and regions (Abd-El-Khalick et al., 2004). One of the important goals of this study is to examine this line of assumption and see whether it is empirically valid for students with different performance levels in the context of science teaching in 8th grade classrooms in Singapore, Chinese Taipei, and the US.

Assumption of Culturally Responsive Teaching

The second line of assumption that frames this study is the perspective of culturally relative pedagogy. This theoretical assumption stresses that different racial groups have different learning needs, styles, and habits that can significantly shape their thoughts and what and how they learn in schools (Gay, 2000; Griner & Stewart, 2013; Ladson-Billings, 1994, 1997). In order to teach a particular racial or ethnic group of students, effective teaching approaches need to be developed with respect and consideration of their cultural structure, thoughts, and learning needs (Ladson-Billings, 1994, 1997). Thus, students with different racial and ethnic backgrounds require different teaching approaches to help them learn effectively, maintain their cultural integrity, and develop the ability to critique social inequities simultaneously (Ladson-Billings, 1995). A similar line of thinking in science education is found in “congruence theory” (Lee, Luykx, Buxton, & Shaver, 2007; Luykx & Lee, 2007). This theory emphasizes that science instruction should take into account students’ prior cultural and linguistic knowledge in relation to science (Geier et al., 2008) and needs to be developed with linguistic scaffolding that allows students with different cultural ways of learning to access science content (Meyer & Crawford, 2011).

This line of assumptions directly challenges the idea of inquiry-based instruction as the ultimate approach to improving all students’ science learning. As inquiry-based teaching represents the Western modern science education model (Carlone, Haun-Frank, & Webb, 2011; Mutegi, 2011), it may not align with the cultural habits of students in other countries or regions, such as Chinese Taipei and Singapore (Aun, Tiong, Kum, & Ang, 2004; Niehoff, Turnley, Yen, & Sheu, 2001). For example, students from Confucian cultures in the East are taught to respect knowledge transmitted directly by teachers based on textbooks rather than relying on their own inquiry and investigation (Lee, 1997; Trueba, Cheng, & Ima, 1993). Also, more science teachers in Singapore believe they should give students prescriptive and sequential directions when doing science experiments as compared to U.S. teachers, based on TIMSS 1994 data (Aun et al., 2004). The "teacher knows best" philosophy of the East provides the teacher's rationale for playing a teacher-centered didactic role in the classrooms (Aun et al., 2004). Meanwhile, students experience challenges and even loss of engagement in learning when they are taught with student-centered pedagogy (Lee, 2010). Another study conducted in Taiwan and drawing on a survey from 120 high school students also found that most students view learning science as "calculating and practicing tutorial problems," "increase of knowledge," and "understanding" while very few of them viewed science learning as "seeing in a new way" (Tsai, 2004).

Following this assumption and relevant studies, it is reasonable to question whether inquiry-based instruction in Singapore and Chinese Taipei is effective for student's science learning as is assumed in Western literature. A part of this study is designed to check whether and to what extent this line of thinking is valid indirectly by examining the influences of inquiry-based instruction and traditional didactic science teaching on the science achievements of 8th grade students within Singapore and Chinese Taipei as compared with students in the US.

Literature Review

To understand how well each research question can be empirically sustained, a careful empirical literature review was conducted based on the relevant empirical studies published in peer review journals using the following Education Resources Information Center (ERIC) searches. First, I searched articles using the keywords "science teaching," "Singapore," and "Taiwan." Second, I searched for articles using the keywords "achievement," "performance," "high-performing," and "low-performing" from 1990 to 2014, since inquiry-based instruction was officially proposed in the National Science Education Standards during the 1990s. Third, I searched through references in the articles brought up by the above searches. Finally, I narrowed down the studies obtained from the above searches to those related to K-12 science teaching in Singapore, Chinese Taipei, and the US where inquiry and/or traditional didactic science teaching approaches are used in relation to students' performances. This review of relevant empirical literature offers the following findings relevant to my research questions.

Relationship between Science Teaching and Student Science Performances

In relation to the first research question, whether inquiry-based instruction and didactic science teaching practices are significantly related to the overall science achievements of 8th grade students at different levels in the US, Chinese Taipei, and Singapore, our review suggests several findings.

First, most studies that examined the relationship between science teaching and student performance were conducted in the US and showed mixed results.

Several literature review articles (Shymansky, Kyle, & Alport, 1983; Minner, Levy, & Century, 2010; Furtak, Seidel, Iverson, & Briggs, 2012) indicated an overall positive effect of inquiry-based instruction on student science learning compared with traditional didactic science teaching. More studies not included in the above review studies further confirmed the above findings. For example, Erterpinar and Geban (1996), drawing on data from 43 students from two 8th grade classes, found that inquiry-based science teaching was more effective than traditional didactic science teaching in improving students' general science achievement. Similarly, the finding was also confirmed by a study comparing 322 students exposed to inquiry-based instruction with 270 students exposed to didactic teaching at 7th to 11th grade levels (Akkus, Gunel, & Hand, 2007), a study (Geier et al., 2008) that involved 5,000 students at 7th and 8th grade levels, a study (Odom et al., 2007) that collected data from 607 students from 7th and 8th grade levels in physics classrooms, and a study (Taraban et al., 2007) involving 408 high-school students from biology classes. Moreover, inquiry-based instruction was also found to be more effective in improving students' science process knowledge, for example constructing and reflecting (Geier et al., 2008), forming and testing hypotheses, communicating findings (Taraban et al., 2007), and their scientific explanation or argumentation (Wilson et al., 2010).

However, other studies showed no significant difference between traditional didactic and inquiry-based instruction. For example, Pine et al. (2006) found no significant difference in science achievement between 500 students in 5th grade taught using a curriculum that stresses inquiry-based teaching and 500 students taught following a textbook-based curriculum using the traditional didactic approach. This finding was also confirmed by an additional study (Wolf & Fraser, 2007) that drew on 165 students in 7th grade physical science classes and another study (Roehrig & Garrow, 2007) that compared students taught with inquiry-based teaching with students taught with more didactic-based chemistry classes. Finally, Blanchard et al. (2010) found that students exposed to didactic instruction had significantly higher scores in science processes than peers exposed to inquiry-based instruction, by drawing on data from 1,700 students from 12 high schools.

To further complicate the mixed findings is the fact that the studies reviewed involved small numbers of teachers, from two to thirteen, mostly from one school district, which makes it hard to generalize to other contexts. In addition, many studies did not involve data about teachers' actual instruction (Pine et al., 2006; Wolf & Fraser, 2007), others used qualitative data measuring teachers' science teaching practice, making it hard to compare the specific situation to other teaching settings (Akkus et al., 2007; Roehrig & Garrow, 2007). Only two studies (Blanchard et al., 2010; Pine et al., 2006) used control variables to examine the relationship between teaching approaches and student science learning, and their findings challenge the assumption that inquiry-based science teaching is better than traditional didactic in improving students' science learning. Thus, it is difficult to be certain whether the results of these studies were caused by teaching instead of other influences or biases. To address these limitations in the existing literature, this study examines the relationship between science teaching approaches and student science performance using large samples of teachers and students from the three places in the TIMSS 2011 database that surveyed teachers about traditional didactic or inquiry-based instruction defined consistently with relevant literature and allowed the controls for some important external influences.

Second, studies focusing on the effectiveness of science teaching on students with different levels of performance were few. In the US, most studies focused on analysis of racial performance gaps with the finding that inquiry-based instruction can be more effective for poor performing minority students. For example, some researchers (Lynch et al., 2005) found that inquiry-based instruction was effective in improving urban African-American students' science achievement based on 1,500 students in 8th grade in five middle schools. Other studies (Lee et al., 2006; Wilson et al., 2010) also showed that non-Caucasian students exposed to inquiry-based instruction had more pronounced improvement in science achievement than their peers exposed to didactic teaching at both elementary and middle school grade levels. Several qualitative studies (Gilbert & Yerrick, 2001; Yerrick & Gilbert, 2011) focusing on low-track African-American students also confirmed that inquiry-based instruction benefited low-track students learning science.

One study (Lorch et al., 2010) was designed to compare the effect of explicit instruction and inquiry-based experimentation on student science learning in five higher achieving and seven lower achieving schools in a school district in the US. The results showed that the achievement of students from both higher and lower achieving schools improved with both forms of instruction, even though students from higher achieving schools had greater gains than their peers from lower achieving schools. However, these results were not consistent with the results in another study conducted in Turkey (Kingir, Geban, & Gunel, 2012), which showed that low and middle achievers in the inquiry-based instruction group significantly outperformed those in the traditional group which had been taught by lecturing and teacher-directed discussion on the post-test. For the high achievers, there was no significant difference between the inquiry-based instruction group and the traditional didactic teaching group.

In short, studies on the relationship between inquiry-based and traditional didactic teaching on the science achievements of high and low performing students in the US only offered limited and inconclusive results. Few studies focused exclusively on high and low performing students using large datasets. This study addresses these gaps in the literature by examining the relationship between science teaching approaches and the performance of students with different achievement levels drawing on a large database of TIMSS 2011.

Third, the empirical research conducted in Singapore and Taiwan of China to examine the effectiveness of teaching practices on student science performance was limited (Chang et al., 2009; Chin, 2006; Hogan et al., 2013). The available studies offer mixed findings and those focusing on students with different levels of performance are virtually nonexistent. For example, Chang and Mao (1999) showed that students in the inquiry-based instruction group had significantly higher achievement scores than students in the traditional lecture group drawing on data from 319 students in 9th grade Taiwanese classes. By analyzing TIMSS 1999 data, another study (House, 2005) found that some inquiry-based teaching practices (e.g., students using things from everyday life in solving science problems, students working on science projects, and students doing experiments or practical investigations in class) were positively related to Chinese Taipei students' science achievement while two other traditional didactic teaching practices (students working from worksheets or textbooks on their own, teacher giving a demonstration of an experiment) showed no significant relationship. However, this study also found that one traditional didactic teaching practice, "the teacher showing how to do science problems," has a significantly positive association with science performance. One study (Chin, 2006) focusing on science teaching in Singapore found that students can be stretched mentally through more traditional didactic teaching featuring teacher-led questioning discourse followed by students uttering answers together drawing on the data of 14 lessons from six science teachers in four schools. However, science performance was not assessed in this study.

Nevertheless, two of the above studies (Chang & Mao, 1999; Chin, 2006) involved small numbers of science teachers while the other did not compare across the three countries and regions with a focus on high and low performing students (House, 2005). This study is designed to address these gaps by examining the relationship between science teaching approaches with the performance of students with different achievement levels drawing on data from teachers and their students in three different countries using the large database of TIMSS 2011.

Consistent Effectiveness of Science Teaching Approaches in Three Countries/Regions

In reference to the second research question of this study—whether the relationship between science teaching and student performance is consistently shown in two regions—only one study involving elementary teachers and students can be identified for review (Kaya & Rice, 2010). This study examines the relationship between inquiry-based science teaching and elementary student science achievement in terms of TIMSS 2003 4th grade data. The results show that students in Singaporean classrooms whose teachers placed more emphasis on science inquiry scored significantly higher than their counterparts who were exposed to less science inquiry while in the US where the opposite results were identified (Kaya & Rice, 2010). The current study is designed to examine the relationship between inquiry-based instruction and traditional didactic science teaching with the science performance of middle grade students in three countries/regions with different cultural backgrounds.

Methodology

Data Source and Participants

Data from Singapore, Chinese Taipei, and the US from TIMSS 2011 was selected for this study for the following four reasons.

First, it is a large-scale database based on the two-stage, nonrandom sampling design with schools first selected using probability-proportional-to-size sampling and then one or two whole classes were randomly selected in each school. Such sample sizes and the sampling approach of TIMSS 2011 ensured a more representational sample of 8th grade classroom contexts across the three different countries and regions (Martin & Mullis, 2012). The analysis of the large-scale data provides valuable and reliable information to policy makers and practitioners about the relationship between science instruction and the achievement of their students. The specific sample size information for teachers and students across the three countries/regions is presented in Table 1.

Table 1 Sample Size for Selected Teachers and Their Students across Three Countries/Regions in TIMSS 2011

Country/Region	Sample Size	
	Science teacher	Student
Singapore	330	5,927
Chinese Taipei	152	5,089
The US	357	6,071

Second, since the design of TIMSS 2011 is not simply random sampling, the weight for a given science teacher is designed to reflect the probability of a student's school being selected, as well as the probability that the student was selected within that school (Martin & Mullis, 2012). This weight was used to calculate most statistics in order to reduce biases associated with sampling in this study (Martin & Mullis, 2012).

Third, various science-teaching activities are collected through a teachers' questionnaire in TIMSS 2011 consistently in the three countries/regions as shown in Table 2. This allows the inquiry-based instruction or traditional didactic science teaching approach to be identified in a way that was consistent with the relevant conceptions in the literature reviewed. Questions designed for science teacher questionnaires ask teachers to report the frequency of these teaching activities in their science lessons.

Table 2 TIMSS 2011 Teaching Items Conceptualized and Recoded from the Teacher's Questionnaire

Inquiry-Based Instruction	Original Coding Recoding
1) Relate the lesson to students' daily lives	1 = every or almost every lesson
2) Use questioning to elicit reasons and explanations	2 = about half the lessons
3) Ask students to observe natural phenomena and describe what they see	3 = some lessons
4) Ask students to design or plan experiments or investigations	4 = never
5) Ask students to conduct experiments or investigations	
6) Ask students to give explanations about something they are studying	
7) Ask students to relate what they are learning in science to their daily lives	
8) Ask students to do fieldwork outside of class	
Traditional Didactic Teaching	
9) Summarize what students should have learned from the lesson	
10) Ask students to watch me demonstrate an experiment or investigation	
11) Ask students to read their textbooks or other resource materials	
12) Ask students to memorize facts and principles	
13) Ask students to use scientific formulas and laws to solve routine problems	
14) Ask students to take a written test or quiz	
Affective teaching practices	
15) Encourage all students to improve their performance	
16) Praise students for good effort	
17) Bring interesting materials to class	

For inquiry-based instruction, the following teaching activities were included in the survey: relating the lesson to students' daily lives, using questioning to elicit students' reasons and explanations, having students observe natural phenomena and describe what they see or investigate, having students design or plan experiments or investigations, having students conduct experiments or investigations, having students give explanations about something they are studying, relating what they learn in science to their daily lives, and having them do fieldwork outside of class. These activities are consistent with the conception of inquiry-based teaching in the literature (Anderson, 1996, 2002; Chang & Mao, 1999; Chin, 2006; National Research Council, 1996, 2000, 2012).

For didactic teaching, the components include the teacher summarizing what students should have learned from the lesson, students watching the teacher demonstrate an experiment, students reading their textbooks or other resource materials, students memorizing facts and principles, students using scientific formulas and laws to solve routine problems, and students taking a written test or quiz. These activities are again consistent with the conception of traditional didactic teaching (Chang & Mao, 1999; Pine et al., 2006; Smerdon et al., 1999).

In this study, the relationships between each of the science-teaching practice items relevant to the two kinds of teaching and the science performance of students at different performance levels in the three places were examined. In this way, I can compare and identify which specific areas of science teaching in each kind are effective for the science performance of which groups of students in the three places. It can also avoid the situation in which teachers who did not use certain kinds of science teaching practices of each kind were being forced into the group of either inquiry-based or traditional didactic science teaching.

Finally, TIMSS 2011 measures students' overall science achievement based on four content areas including biology, chemistry, physics, and earth science (Mullis et al., 2005). This offers researchers the chance to understand the quality of student science learning in association with the teaching approaches to which they were exposed. In addition, the overall science achievement also makes it possible to differentiate students between three different levels (low, medium, high) and answer the research questions of this study specifically.

Variable Construction

To answer the first research question, eight inquiry-based teaching practice items and five traditional didactic teaching items for which students were asked to respond were used as independent variables for each kind of teaching respectively to predict student science performance at class level. Each of these items asks students to choose one of four levels: 1) "in every lesson or almost every lesson," 2) "in about half the lessons," 3) "in some lessons," and 4) "never." To prepare for further analysis, the answers to each item were recoded to reverse the rank of using these instructional practices so that larger numbers indicate higher frequency while smaller numbers indicate lower frequency (see Table 2).

To examine the influences of the different instruction approaches on student science achievement, Social Economic Status (SES), student self-confidence in learning science, and three affective teaching practices were also controlled, as these variables are available in the data set. The purpose of controlling for these variables is that they are seen as likely to have a positive relationship with student science achievement, which could confound the effects of teaching approaches on student science performance. For example, students' SES was assumed to be the strongest influence on student academic performance in the studies of the later 1960s (White, 1982) and studies in science later in the US (Byrnes & Miller, 2007; Ma, 2010) while other factors, such as race, gender, and school effect, would not explain much variance in science achievement after SES had been controlled (Byrnes & Miller, 2007). Thus, a SES index in this study was created from the following three variables (Edward, 2001; Wang & O'Dwyer, 2011): 1) the number of books available in the home, for which students were asked to choose one of five answers (1 = 0–10; 2 = 11–25; 3 = 26–100; 4 = 101–200; 5 = over 200); 2) An index of parents' highest educational level based on two items asking student to choose one of five answers (1 = university degree; 2 = completed post-secondary education but not university; 3 = completed upper-secondary education; 4 = completed lower-secondary education; and 5 = less than lower-secondary education); 3) Students' home possessions, constructed from the items related to items supporting students' study, such as a calculator, computer, desk, dictionary, internet connection, encyclopedia, video game system, DVD player, three or more cars, etc., for which students are asked to respond to each item by choosing one of two answers (1 = Yes, 2 = No). Based on their answer, a composite of home possessions was computed by summing all the items listed. Then, a factor analysis was conducted using this composite variable with two other variables, the number of books in the home and the parents' highest education, to construct the SES variable as suggested by Wang & O'Dwyer (2011).

Student self-confidence in learning science is another strong predictor for student science achievement since students who believe they cannot be successful in science-related activities often put minimal effort into completing those tasks (Byrnes & Miller, 2007) and when they face a challenge, they usually give up or experience anxiety (Bandura, 1997). Some empirical studies also reported a strong positive relationship between middle school students' science self-efficacy and science achievement (Beghetto, 2007; Britner & Pajares, 2006). In this study, the science self-confidence variables were created based on the responses that students offered to the following four statements: 1) "I usually do well in science," 2) "science is harder for me than for many of my classmates," 3) "I am just not good at science," and 4) "I learn things quickly in science" by choosing one of the three answers 1 = Low; 2 = Medium; 3 = High (Foy & Olson, 2007). Then, the student science self-confidence variable was based on the means of students' responses to all the four items.

In addition, three science teaching practices, 1) encouraging all students to improve their performance, 2) praising students for good effort, and 3) bringing interesting materials to class, as shown in Table 2, were also used as control variables at the class level. These affective teaching practices were seen likely to be positively related with student science achievement based on the literature, in which affective teachers benefited low-track students learning science when inquiry-based instruction was conducted (Yerrick, Schiller, & Reisfeld, 2011) and secondary students in Taiwan scored higher when their teachers were more understanding and friendly drawing on the survey data (She & Fisher, 2002).

In order to understand the impact of science teaching practices on the science achievements of students with different levels of performance, student test scores at the 25th, 25th–75th, and 75th percentiles of each national distribution were used as dependent variables. In TIMSS 2011, students were tested with an incomplete or rotated-booklet design on all achievement variables. To estimate students' science score for the full test on all test items, item response theory (IRT) was used (Olson, Martin, & Mullis, 2008) to input five plausible values for each dependent achievement variable based on the student's observed responses to the limited assessment items in the booklets they accessed (Williams et al., 2009). These five plausible values were then used to represent the true ability of an individual (Foy & Olson, 2007). Scores at various percentiles of the performance distribution are estimated five times, each using a different plausible value in this study. The final statistic used for analysis is the average of five estimates (Huang, 2013).

According to the missing data pattern test (Little's MCAR test), the lacking data in this study was not missing completely at random (MCAR) ($p < .001$). EM is a maximum likelihood approach that can be used to create a new data set in which all missing values are inputted with maximum likelihood values based on observed relationships among all the variables (Acock, 2005). All the independent variables used in this study had rather low (< 2%) missing data except parents' highest education level (>15%), so EM was used to handle missing data in this study (Wang & O'Dwyer, 2011).

Data Analysis

Two-level Hierarchical Linear Modeling (HLM) is used for the analysis of data to examine the effects of various science-teaching practices on 8th graders' science achievements in Singapore and the US because some of the observed students are from the same classroom and school. This situation violated the assumption underlying traditional regression approaches that observations of any student are systematically related to the observations of any other individual student (Pedhazur, 1997). Thus, hierarchical modeling is more appropriate for answering research questions that involve data at multiple levels and reducing aggregation bias (Hox, 2010; Raudenbush & Bryk, 2002).

To assess the association between teaching approaches (level-2 independent variables) and student science achievements (level-1 dependent variables), controlling for individual differences on SES, self-confidence of learning science, and three affective teaching variables, the two level model is applied. The composite variables of SES and self-confidence of learning science in student level are centered at the grand mean as suggested (Enders & Tofighi, 2007) to control their impacts on the student science performance. The final models for each country or region in TIMSS 2011 datasets are shown below:

Level 1 (student level) model

$$Y_{ij} = \beta_{0j} + \beta_{1j}(SES) + \beta_{2j}(selfconfidence) + r_{ij}$$

Level 2 (class level) model

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(summarize) + \gamma_{02}(dailylife) + \ldots + \gamma_{017}(quiz) + \mu_{0j}$$

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

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

However, Chinese Taipei's data showed no significant variance among class level, which means HLM is not necessary to evaluate the different variance in the second level (Garson, 2013). Therefore, SPSS with simultaneous multiple regression is used to examine the effect of different teaching approaches on Chinese Taipei students' science achievement.

Results

Teaching Approaches and Lower Performed Students

My analysis showed that when SES, student science self-confidence, and affective instructional practice variables were controlled, low-achieving students across three countries/regions responded differently to inquiry-based instruction and traditional didactic science-teaching practice items (see Table 3).

Table 3 Science Achievements of Students in the 25th Percentile

Variables	The US		Chinese Taipei		Singapore	
	B	SE	B	SE	B	SE
V1	–2.14	2.82	4.15*	0.41	2.26	6.14
V2	–1.30	2.75	2.17	0.30	9.44	5.52
V3	–0.16	2.26	0.40	0.25	–9.87*	4.84
V4	–1.50	2.90	–3.32	0.36	18.38*	5.46
V5	3.99	3.18	2.79	0.48	–1.86	5.59
V6	0.89	2.83	2.30*	0.26	–3.72	5.39
V7	–4.44	3.00	–1.61	0.36	–4.45	5.36
V8	–2.92	2.41	–0.74	0.38	–7.14	5.42
V9	1.64	2.74	–2.12	0.26	0.04	4.63
V10	–0.49	2.64	–5.76*	0.38	–10.24	6.11
V11	–5.65*	2.22	–2.40*	0.27	–3.85	3.83
V12	1.29	2.20	3.05*	0.31	8.90	4.38
V13	0.06	2.47	–6.43*	0.30	–0.30	4.51
V14	3.86	2.55	1.02	0.38	0.65	5.31
V15	–1.58	3.95	–1.91	0.386	–13.52*	5.39
V16	2.71	3.73	–3.85*	0.36	5.79	5.41
V17	4.31	2.86	1.50	0.27	–7.21	5.46
SES	6.70*	1.19	9.36*	0.20	5.06*	1.28
SELF-CONFIDENCE	4.09	1.67	–9.09*	0.47	16.02*	1.90

Note. * $p < .05$. V1—V17refer to the 17 teaching practice variables showed in the same order as in Table 2. SES and SELF-CONFIDENCE are two control variables.

For the six traditional didactic teaching practice variables, in Singapore none of the didactic teaching items were associated with the science achievement of lower achieving students in a statistically significant manner. In Chinese Taipei, three traditional didactic teaching practices, "watch teacher demonstrate an experiment or investigation," "read their textbooks or other resource materials," and "use scientific formulas and laws to solve routine problems," were found to be negatively related to student science achievement ($ps < .05$) but another traditional didactic teaching practice ("have students memorize facts and principles") was positively related to student science achievement. In the US, only one traditional didactic teaching practice, "read their textbooks or other resource materials," was found to be negatively related to the science achievement of lower achieving students ($p < .05$).

As for the eight inquiry-based teaching practices, in Singapore the variable, "design or plan experiments or investigations," was found to be significantly and positively related to lower achieving students' science achievement ($p < .05$) and the other, "observe natural phenomena and describe what they see," was significantly related to student science achievement in a negative way ($p < .05$). In Chinese Taipei, two of the inquiry-based teaching practices, "give explanations about something they are studying" and "relate what they are learning in science to their daily lives" were found to be significantly and positively related to student science achievement ($ps < .05$). However, in the US, none of the inquiry-based teaching practices had significant relationships with the science performance of these students.

In terms of three control variables, in Singapore, students' SES and self-confidence in learning science were significantly positively related to low performing students' science achievement (ps $< .05$). In contrast, one of the affective teaching practices, "encourage all students to improve their performance" was significantly and negatively related to low performing students' science achievement ($p < .05$). In Chinese Taipei, students' SES was significantly and positively related to low performing students' science achievement ($p < .05$). Students' self-confidence in learning science and one of the affective teaching practices, "praise students for good effort," were found to be significantly but negatively related to low performing students' science achievement ($p < .05$). However, in the US, only SES was found to be significantly and positively related to low performing students' science performance ($p < .05$).

Teaching Approaches and Medium Achieving Students

Medium-achieving students in each country/region responded to both inquiry-based instruction and traditional didactic science teaching practices in almost the same way except for one practice in Chinese Taipei, where SES, student self-confidence with science, and affective instructional practice variables were controlled. These results are shown in Table 4.

Table 4 Science Achievements of Students in the 25–75th Percentile

Variables	The US		Chinese Taipei		Singapore	
	B	SE	B	SE	B	SE
V1	0.65	1.61	–0.27	0.18	1.63	3.49
V2	2.68	1.74	0.65	0.13	5.00	3.25
V3	0.32	1.25	–0.24	0.12	–0.27	2.95
V4	0.83	1.59	–1.41	0.17	6.50	3.41
V5	2.14	1.71	2.07	0.23	4.00	3.61
V6	–2.69	1.53	–0.06	0.12	–1.07	3.14
V7	0.40	1.70	–0.20	0.15	–2.18	2.98
V8	–0.86	1.40	0.60	0.17	0.88	3.17
V9	1.31	1.61	–0.89	0.12	0.66	2.65
V10	–1.41	1.39	1.25	0.18	–3.18	3.72
V11	–0.89	1.22	0.37	0.12	1.56	2.22
V12	1.03	1.31	0.28	0.13	–2.74	2.51
V13	1.42	1.45	0.44	0.14	3.77	2.54
V14	0.29	1.28	–2.15*	0.17	–6.32	3.32
V15	–3.62	2.22	–0.17	0.17	0.77	3.32
V16	–0.62	2.11	–0.23	0.15	–5.79	3.40
V17	0.23	1.34	–1.02	0.13	6.49	3.17
SES	4.58*	0.65	5.68*	0.09	2.73*	0.70
SELF-CONFIDENCE	6.39*	0.83	12.53*	0.15	12.78*	0.97

Note. * $p < .05$. V1—V17 refer to the 17 teaching practice variables showed in the same order as in Table 2. SES and SELF-CONFIDENCE are two control variables.

None of the inquiry-based and didactic teaching practice variables were found to be significantly related to science achievements of medium level performed students in each country/region except for one of the didactic teaching practice, "take a written test or quiz," which was found to be negatively related to science achievement of medium performing students in Chinese Taipei, $p < .05$. However, for the control variables, both students' SES and science self-confidence were found to be significantly and positively related to their science performance (ps < .05) while none of the three affective teaching practices were found to be significantly related to medium-achieving student science performance in each country.

Teaching Approaches and Higher Performing Students in Three Countries/Regions

All inquiry-based instruction and traditional didactic science teaching practices were found to be not significantly related to science achievement of the high performing students from Singapore and the US after controlling the student SES, self-confidence of learning science, and affective instructional practices (ps > .05) as shown in Table 5. However, two teaching practices were found to hinder high-performing students in Chinese Taipei. Specifically, one inquiry-based teaching practice, "use questioning to elicit reasons and explanations" and one traditional didactic teaching practice, "have students memorize facts and principles," were found to be negatively related to science achievement of the high achieving students in Chinese Taipei, ps < .05 (see Table 5).

Table 5 Science Achievements of Students in the 75th Percentile

Variables	The US		Chinese Taipei		Singapore	
	B	SE	B	SE	B	SE
V1	3.08	2.31	–1.63	0.26	4.51	2.74
V2	2.56	2.79	–1.40*	0.19	2.97	2.66
V3	–0.57	1.75	–1.05	0.19	0.14	2.28
V4	3.60	2.15	–1.64	0.26	1.08	2.72
V5	–1.97	2.32	1.03	0.34	2.46	2.86
V6	–0.84	2.13	0.63	0.18	–2.93	2.48
V7	–2.46	2.55	0.96	0.22	–3.03	2.38
V8	1.92	2.07	0.86	0.25	–4.61	2.45
V9	–0.52	2.36	–1.13	0.18	–0.35	2.08
V10	0.02	1.86	–0.23	0.26	2.28	2.79
V11	0.60	1.72	1.44	0.17	–1.60	1.70

(*To be continued*)

(*Continued*)

Variables	The US		Chinese Taipei		Singapore	
	B	SE	B	SE	B	SE
V12	−1.17	1.75	−2.08*	0.20	−3.02	2.03
V13	0.07	2.027	0.70	0.22	1.60	1.91
V14	−1.03	1.78	3.12	0.26	−4.14	2.80
V15	0.40	3.10	4.65*	0.27	2.51	2.78
V16	0.27	2.98	−2.83	0.23	−3.44	2.89
V17	0.01	1.89	1.88	0.20	0.84	2.62
SES	5.39*	1.19	3.94*	0.13	3.47*	1.02
SELF-CONFIDENCE	8.92*	1.37	11.60*	0.17	10.82*	1.35

Note. * $p < .05$. V1—V17 refer to the 17 teaching practice variables showed in the same order as in Table 2. SES and SELF-CONFIDENCE are two control variables.

In addition, students' SES and self-confidence in learning science were found to be significantly and positively related to their science performance ($p < .05$) in all three places. In the US and Singapore, none of the three affective instructional practices were significantly associated with high performance students' science achievement. However, in Chinese Taipei, one of the affective instructional practices, "encourage all students to improve their performance," was found to significantly contribute to high-achieving students' science performance, $p < .05$.

Discussion and Conclusions

This study did have three obvious limitations. First, using second-hand data without any observations of classroom teaching in each country/region prevented us from capturing the characteristics of science teaching approaches used in the classrooms through an alternative lens. Future studies need to examine science-teaching approaches using observations. Second, only limited items of inquiry-based and traditional didactic science teaching were used in the teaching survey data of TIMSS 2011. Therefore, research was unable to capture the richer picture of teaching approaches in classrooms that had characteristics not included in the survey items. Third, research was unable to control other variables which were not included in the survey but could be associated with student science performance, such as after-school tutoring (Huang, 2013). In spite of these limitations, this study and its' findings contribute to understanding about the two research questions in several ways.

First, this study suggests that students with low performance in all three countries/regions responded differently to two kinds of teaching practices. These different responses were not only found between the US and Asian locations but also among the Asian countries/regions. For example, science achievement of the students in Singapore was found to be positively related to one inquiry-based teaching practice, "design or plan experiments or investigations," but negatively related to the other practice, "observe natural phenomena and describe what they see." In Chinese Taipei, two different inquiry-based teaching practices, "give explanations about something they are studying" and "relate what they are learning in science to their daily lives," were found to be positively associated to low-achieving students' science learning. To some extent, these findings support a study (Kaya & Rice, 2010) that suggested that doing an experiment or practical investigation in class helps students learn science in Singapore, and two other studies conducted in Taiwan (Chang & Mao, 1999; House, 2005). In the US, none of the inquiry-based teaching practices were related to the low achieving students' science performance in either a positive or a negative way, which challenges a group of studies conducted in the US (Lee et al., 2006; Lynch et al., 2005; Wilson et al., 2010; Yerrick, Schiller, & Reisfeld, 2011), which suggest that inquiry-based teaching is useful for improving low achieving minority students' performance.

In addition, while one traditional didactic teaching practice, "read textbooks or other resource materials," was found to be significantly negative for students' science performance in the US, three practices, "read their textbooks or other resource materials," "watch teacher demonstrate an experiment or investigation," and "use scientific formulas and laws to solve routine problems," were found to be significantly negatively related to student science achievement in Chinese Taipei, which, to some extent, echoes the finding of another study with students in Taiwan based on the TIMSS 1999 data (House, 2005). However, none of the traditional teaching practices were related to low achieving students in Singapore, which challenges the assumption developed in the existing study based on the observations of teaching in Singapore (Chin, 2006).

Together, these findings indirectly suggest that the culturally responsive teaching assumption (Ladson-Billings, 1994, 1995, 1997) can be true for lower performing students.

This assumption suggests that students with different cultural backgrounds need different teaching approaches to meet their different learning needs and the characteristics of students' cultural backgrounds. Thus, if the goal of science teaching reform is to help improve all students' science learning, the kinds of effective teaching practices should be carefully explored in order to help lower performing students in different countries. Although this study brought up this issue, the findings of the study are not sufficient to help explain reasons for these different responses among low achieving students in different places (Lee, 1997; Trueba, Cheng, & Ima, 1993). In order to understand more about why certain science teaching practice work for some low achievement level students but not the others, further studies should focus more on teachers' perspective and students' view of learning science and examine science teaching in places with varied cultural backgrounds and contexts based on classroom observations.

Second, this study suggests that almost none of these inquiry-based and traditional didactic science teaching practices are found to be positive predictors for the science achievement of students with medium and high levels of performance in any of the three places. This finding further complicates the assumed general effectiveness of inquiry-based teaching for all kinds of students in different contexts in the existing literature (Chang & Mao, 1999; Furtak et al., 2012; Minner et al., 2010). At the same time, to some extent it supports other studies in the US (Blanchard et al., 2010; Pine et al., 2006; Roehrig & Garrow, 2007; Wolf & Fraser, 2007) that provide evidence to challenge the effectiveness of inquiry-based instruction.

Two interpretations can be used to explain this complicated situation. One is that the assumption that classroom teaching is a central factor in influencing student science achievement (Fogleman et al., 2011; Lynch et al., 2005) might not be true. Other social, cultural, family factors, and personal characteristics might contribute more significantly to student science achievement than the teaching factor (Muller et al., 2001; Peng & Wright, 1994). As shown in this study, SES and student science learning self-confidence were always positively related to the science performances of students at medium and high levels while teaching practices were not in all three contexts. Thus, efforts to improve student science performance should not focus simply on teaching without attention to the complex relationships of students' performances and teaching practice to the other social, economic, cultural, and historical contexts, in which such teaching practices are situated (Apple, 2001; Labaree, 2000; Ogbu & Simons, 1994; Sykes, Bird, & Kennedy, 2010). Additionally, the efforts to change teaching alone in order to solve social problems often prove to be futile as shown repeatedly in the U.S. history of educational reform (Labaree, 2008).

Another possible reason can be that the frequency of teaching practices used by the TIMSS 2011 teacher questionnaire may not be able to capture the characteristics of teaching that were actually implemented in the classroom (Pine et al., 2006). Although science teaching reform did contribute, to some extent, to the transformation of science teaching practice in the classroom (Gao, 2014), the components of teaching mentioned in the survey may not reflect the essential components of either inquiry-based instruction or didactic science teaching. Thus, this limitation of the instrument may compromise the finding of this study about inquiry-based instruction as a more effective teaching strategy for student science learning (Blanchard et al., 2010; Flick, 1995). To verify this assumption, the observation-based data of teaching practice needs to be used in the studies while this study did not collect and analyze such data on teaching practices used in the classroom.

Third, the finding that medium and high performance students in the US and Singapore did not respond positively and significantly to hardly any of the inquiry-based and didactic teaching practices to some extent indirectly challenges the assumption of culturally responsive teaching for higher performing students (Ladson-Billings, 1994, 1995, 1997). This finding seems to suggest that medium or higher performing students may have higher learning motivation and self-regulated learning skills (Pintrich & de Groot, 1990), which allow them to be able to adapt to different learning contexts and teaching practices flexibly. Therefore, to vary teaching practices culturally might not be so important in helping change science learning outcomes as the literature assumed (Ladson-Billings, 1994, 1995, 1997).

However, the above assumption was clearly challenged by the following findings. Higher performing students responded negatively to inquiry-based teaching practice, “using questioning to elicit reasons and explanations” and the didactic teaching practice, “having students memorize facts and principles” and medium achieving students responded negatively to the didactic teaching practice, “take a written test or quiz” in Chinese Taipei. Thus, this complex situation about the relationship between teaching practices and medium and higher achieving students in different countries seems to suggest that if culturally responsive teaching theory is right, then such teaching approaches for students in different countries and regions may not have been identified using existing instruments. Therefore researchers need to work hard to develop them for students in different countries and regions.

The implication of this finding is that the teaching practices that help students from different countries with varied cultural backgrounds learn effectively or ineffectively can be different in different places (Lee et al., 2006). The teaching practices assumed theoretically effective should be carefully examined and tested with students in different contexts before being used as the model of teaching to shape teaching practices in the classroom (Sykes et al., 2010).

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