An Exploratory Study of the Research on Instructional Practices
in Taiwanese, Finnish and American Secondary Science Classrooms

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Abstract

In the past decade, students from the United States have continued to underperform on science assessments relative to their consistently high performing counterparts, including Taiwan and Finland. Theoretically, countries should be able to improve their own education systems by analyzing those of high performing countries. The present study specifically explores the research surrounding instructional practices in Taiwanese, Finnish, and American secondary science education; it aimed to discover what pedagogical strategies each country most regularly implemented and their effectiveness. The research studies included in this review of literature were peer-reviewed research articles published in reputable scholarly journals in the past two years. Although it was difficult to define what instructional practices each country most regularly implements, this study did determine that five specific instructional practices were found to be most effective internationally, in terms of increased student conceptual knowledge or performance. These practices were: engineering design, modeling, argumentation, technology integration, and efficacy-enhancing teaching. In addition, various trends throughout the literature emerged, including a necessity for teachers to make science content relevant and applicable and to mimic the way science is enacted in the field. The results from this study provide obvious meaningful implications for pre-service and current secondary science educators.

Keywords: science, instructional practices, secondary, Taiwan, Finland, United States
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Before delving into the instructional practices enacted in secondary science classrooms in the Taiwan, Finland, and the United States and their effectiveness as determined by recently published research studies, this chapter will give an introduction to the recent international emphasis on science success. In addition, this chapter will address relevant terminology used to describe science instructional strategies used in the Taiwanese, Finnish, and American education systems to provide foundation for the present study.

International Benchmarking

In an era marked by globalization and worldwide scientific competitiveness, international benchmarking has begun to receive considerable attention in the field of education (Hong, 2012; Marshall & Alston, 2014; Ruthven, 2011). By assessing student achievement in science on a global level, international benchmarking provides means for the comparison of education systems. High levels of student achievement in science have been consistently correlated with later success in the college, the labor market, and the economy (Hong, 2012). Thus, a country with a record for high performance in science assessments is predicted to be a more competitive global force. Theoretically, by analyzing the science instructional practices used in high-performing education systems around the world, other countries should be able to pinpoint ways to improve their own systems (Ruthven, 2011). This type of research-informed and evidence-based education reform is becoming increasingly common around the world (Ruthven, 2011). International benchmarking is helpful in the United States in making decisions regarding educational policy. Nevertheless, in the past decade our students have continued to underperform in science assessments relative to the consistently top-performing countries as well as to our set
national standards (Marshall & Alston, 2014). On a more personal and tangible level, the findings from such analyses can inform my practice as a future secondary education science teacher as well.

Among the most recognized international benchmarking studies are the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA). TIMSS is a product of the International Association for the Evaluation of Educational Achievement (IEA) and managed in the United States by the National Center for Education Statistics (NCES) (TIMSS, 2016). TIMSS data is collected from students in over 70 international education systems in grades 4 and 8. It has been conducted every four years since 1995.

PISA is coordinated by the Organization for Economic Cooperation and Development (OECD), an intergovernmental organization of industrialized countries, and like TIMSS, is conducted in the United States by NCES (PISA, 2016). PISA has measured 15-year-old students’ reading, mathematics, and science literacy every three years since 2000. The last studies conducted by TIMSS and PISA were in 2011 and 2012 respectively. Consistently high performing countries in these secondary science international assessments include Singapore, China, South Korea, Japan, Russia and Finland.

On the 2011 TIMSS assessment, Chinese Taipei had 24% of students meet or exceed the “Advanced” proficiency level while Finland had 13% and the U.S. had 10% (TIMSS Findings, 2011). On this same assessment, 4% of Chinese Taipei students, 1% of Finnish students, and 7% of American students were below the “Low” proficiency level (TIMSS Findings, 2011). Table 1.1 depicts this data published by the National Center for Education Statistics. The excluded
percentages in each education system represent students that reached the “average” benchmark in science.

Table 1.1

*Percentage of 8th-grade students reaching the 2011 TIMSS international benchmarks in science, by education system*

<table>
<thead>
<tr>
<th>Education System</th>
<th>Advanced</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Chinese Taipei</td>
<td>24</td>
<td>4</td>
</tr>
<tr>
<td>Finland</td>
<td>13</td>
<td>1</td>
</tr>
</tbody>
</table>

On the 2012 PISA assessment, Chinese Taipei had 8.3% of students perform at science literacy proficiency level 5 and above while Finland had 17.1% and the U.S. had 7.5% (PISA Findings, 2012). On this same assessment, 9.8% of Chinese Taipei students, 7.7% of Finnish students, and an astounding 18.1% of American students performed at level 2 and below (PISA Findings, 2012). Table 1.2 depicts this data published by the National Center for Education Statistics. Missing data in this table includes those students who reached levels 3 or 4 science literacy proficiency level on the 2012 PISA.

Previously conducted studies suggest that these trends are not confined to the past five years. In fact, in the past decade, American students’ science performance has generally stagnated or increased just slightly in comparison to the consistently top performing countries (Marshall & Alston, 2014).
Table 1.2

Percentage of 15-year-old students performing at 2012 PISA science literacy proficiency levels 5 and above and below level 2, by education system

<table>
<thead>
<tr>
<th>Education System</th>
<th>Level 5 and above</th>
<th>Below level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>7.5</td>
<td>18.1</td>
</tr>
<tr>
<td>Chinese Taipei</td>
<td>8.3</td>
<td>9.8</td>
</tr>
<tr>
<td>Finland</td>
<td>17.1</td>
<td>7.7</td>
</tr>
</tbody>
</table>

There are many factors that impact student achievement on international assessments. These may include differences in instruction strategies, social supports for education, economic supports for education, or educator requirements. For this purpose of this paper, I selected published studies that documented meaningful discrepancies in the science instructional strategies implemented by these countries. For the sake of this literature review, instructional strategy/practice, teaching strategy/practice, and pedagogical strategy/practice will be used synonymously. These terms represent the modes of instruction that teachers employ to help their students achieve learning goals. These methods accentuate social interaction among students and between students and their teacher (Juuti, Lavonen, Uitto, Byman & Meisalo, 2010). The purpose of this study is to identify these instructional practices and compare their effectiveness in an international context, specifically in the Chinese Taipei (Taiwan), Finland, and the United States.

These three countries were specifically selected as education system representatives of their three respective continents, Asia, Europe, and North America. A professional in the science
Relevant Terminology

Instructional strategies articulated in this literature review will fall under two categories, teacher centered and student centered. These two categories were selected because this is where most of the published research fell. Teacher centered will represent traditional, commonplace, didactic instruction. This generally includes but is not limited to traditional lectures, note taking, and workbook or textbook assignments. On the other hand, student centered instruction embodies constructivist, inquiry-based, active, or cooperative learning.

Student centered strategies are typically selected to promote higher-order thinking skills, while teacher centered strategies generally elicit lower-order thinking. Higher-order includes the ability to evaluate and create while lower-order includes the ability to remember and understand.

Constructivism “is a learning theory found in psychology which explains how people might acquire knowledge and learn. It therefore has direct application to education. The theory suggests that humans construct knowledge and meaning from their experiences” (University of Sidney, 2016, p. 1). Constructivism is a comprehensive framework that integrates various cognitive, affective and social factors that influence learning (Beerenwinkel and von Arx, 2016). Common applications of constructivism in the science classroom are student-centered, inquiry-based strategies. Beerenwinkel and von Arx (2016) depict that learning in this framework is understood as “an active, highly individual construction process building on pre-knowledge and personal experience, and taking place in a specific social and historical context in distinctive classroom settings,” (p. 2). This definition is broad because a true, explicit constructivist theory has not been established. In fact, features of constructivist-oriented instruction are still being
researched and identified. Nevertheless, constructivist-oriented, student-centered learning has become prominent in recent innovations and reforms in science education internationally. These reforms typically exemplify the need for instructional methods such as inquiry-based learning, problem-based learning, and discovery learning (Beerenwinkel and von Arx, 2016). The effectiveness of these specific constructivist methods have substantial theoretical foundations and research-based support.

Both the TIMSS and PISA assessments are geared to assess students’ higher-order thinking skills through questions involving critical problem solving. An example of a released question from the 2011 TIMSS assessment for 8th grade is depicted in Figure 1.1 below.

Figure 1.1

*Released science question from the 2011 8th grade TIMSS assessment (IEA, 2016)*

The graph indicates the number of antelopes in a certain area over a period of time. Which of the following factors is most likely to have caused the sudden change in population between 1999 and 2000?

A. global warming
B. absence of predators
C. depletion of the ozone layer
D. brush fires that destroyed the food supply
Likewise, an example of a released question from the 2002 or 2006 PISA assessment of science literacy is revealed in Figure 1.2 below. This is an open-ended question that requires students to apply their content knowledge in a real world context to make predictions.

Figure 1.2

*Released science question from the 2002 or 2006 PISA assessment (National Center for Education Statistics, 2016)*

**Question 4: SUNSCREENS**

The light-sensitive paper is a dark gray and fades to a lighter gray when it is exposed to some sunlight, and to white when exposed to a lot of sunlight.

Which one of these diagrams shows a pattern that might occur? Explain why you chose it.

**Answer:**

**Explanation:**

As demonstrated in the example questions above, most questions on both the TIMSS and PISA assessments generally present tasks that require students to invent new solution strategies, generate hypotheses or interpret data; thus, a significant number of items require student-
produced, open-ended responses as opposed to multiple choice (Dossey, McCrone, O’Sullivan, & Gonzales, 2006). PISA’s approach in particular is focused on how well students can apply their knowledge to real-life scenarios (Dossey et al., 2006).

This shift in the question style of international assessments alone is indicative of the growing global trend toward inquiry-based science instruction. Such instruction within secondary science education allows students to investigate natural phenomena within and outside of the classroom, mimicking the way science knowledge is actually constructed (Gao, 2014) as opposed to didactic instruction in which students are simply passive receptors memorizing and regurgitating scientific facts and processes.

**Education Systems at a Glance**

When comparing the science instructional practices implemented in the United States, Taiwan and Finland, it’s useful to have an understanding of the education systems in which they operate.

The National Center on Education and the Economy depicts that since the 1960s, Taiwan has aimed to transform its labor-intensive, industry-centered economy into a knowledge economy (2016). To develop and maintain this new economy Taiwan upgraded its workforce training and enacted numerous education reforms related to both curricula and professional requirements and continued professional development. Despite this investment in education and the resulting high international test scores, Taiwan’s education system has been heavily criticized for putting too much pressure on students and placing too much emphasis on exams. In response to these critiques, Taiwan has decentralized its curriculum, allowing schools to develop their own curricula based on the national educational framework. Most schools have established Curriculum Development Education Committees, comprised of teachers, parents, principals,
administrators, pedagogical experts, and community stakeholders, that aim to design curricula to be more innovative, community-centered, and constructivist-based as opposed to textbook and rote memorization centered as it was in the past. Until 2014, compulsory education in Taiwan lasted only nine years, until the end of junior high school (MOE, 2012). Students are now required to complete a full twelve years, through the end of senior high school, comparable to the United States. Taiwanese teachers are generally paid well and are provided with expansive benefits packages (2016).

The National Center on Education and the Economy also gives an overview of Finland’s education system (2016). In the early 1990s Finland’s declining economy forced it to rethink its economic strategy. The government decided to invest in the development of the telecommunications sector. By 2003 Finland was successfully recognized as a global telecommunications capital. The education was able to respond to the workforce needs because of a series of extensive reforms. These reforms began in 1972 with the establishment of a unified comprehensive education structure and national curriculum guidelines, along with the restructuring of teacher education and professional development programs. To complement its reformed economy, mathematics, science, and technology inevitably took precedence in Finnish curricula, as did constructivist-oriented skills such as problem solving, teamwork, creativity and interdisciplinary studies. To adapt to the changing economic and countrywide needs the Finnish government prepares a new development plan for education and research every four year.

Over seventy percent of Finnish students have achieved secondary school completion. Finland, like Taiwan, is also a consistent high performer on international benchmarking assessments. Due to this success, their Ministry of Education and Culture has devised a unit devoted entirely to helping foreigners learn about their education system. Although there are
many interlocking factors that contribute to Finland’s success in the international benchmarking realm, the NCEE (2016) suggests that most onlookers have come to believe that “if there is a key to the success of the Finnish system, it is in the quality of their teachers and the trust that the Finnish people have vested in them,” (p. 1). Furthermore, teaching in Finland is a highly sought out, desirable and selective profession that elicits a competitive salary and benefits package (Abrams, 2011). Only one in ten applicants to the country’s eight Master’s in education programs are accepted (NCEE, 2016). Especially significant with regard to the present study is that Finnish classes in grades seven through nine are capped at sixteen (Abrams, 2011).

The U.S. Department of Education identifies the United States’ system of education as highly decentralized (2005). Although the federal government does play a significant role in funding and foundation of education, it does not have the authority under the Tenth Amendment to establish or license schools or to govern education institutions at any level. This has been the case since the early history of the United States in the seventeenth and early eighteenth centuries. States are responsible for setting broad curriculum guidelines that outline what students should be able to do. All states require students to attend school but the ages of compulsory attendance vary between ages 16 and 18. The No Child Left Behind Act of 2001 is “a landmark in education reform designed to improve student achievement and change the culture of U.S. schools,” (USDE, 2005, p. 1). Margaret Spellings, Former Secretary of the U.S.D.E. (2005) outlines that this act was designed to identify and provide help to schools and districts in need of improvement, ensure teacher quality as a high priority, give more resources to schools, expand parental options, and to implement “educational programs and practices that have been clearly demonstrated to be effective through rigorous scientific research,” (p. 2). In 2007, the No Child
More recently, in response to concerns for America’s student performance in science and mathematics, the science education community, with the support of the Carnegie Foundation, developed a new conceptual framework for science education, the Next Generation Science Standards (NGSS), led by the National Research Council (NRC) (NGSS, 2010). The NRC framework and NGSS aimed to take into account the science expectations of high performing countries. To do this, the NRC assembled a forty-member writing committee of nationally and internationally recognized individuals in their respective fields. The group consisted of practicing scientists, Nobel laureates, cognitive scientists, science education researchers, and science education standards and policy experts (NGSS, 2016). The final draft of the framework, published in 2012, “draws on current scientific research—including research on the ways students learn science effectively—and identifies the science all K–12 students should know,” (NGSS, 2016, p. 2). This current scientific research mostly originates from the analysis of ten high performing countries’ PISA and TIMSS results as well as their set science standards and expectations. These countries include: Ontario Canada, Chinese Taipei, England, Finland, Hong Kong, Hungary, Ireland, Japan, Singapore and South Korea. The NGSS are not federally mandated standards; nevertheless, they are predicted to play a critical role in future state educational policies (Moore, Tank, Glancy, and Kersten, 2015).

**Research Questions**

I will be conducting an exploratory study on the research surrounding secondary science education (grades 6-12) instructional strategies in Taiwan, Finland, and the United States. The research questions that this review of the literature will specifically target are as follows:
1. Which pedagogical practices have these three countries regularly implemented in the past two years?

2. What does the literature say about the effectiveness of these pedagogical practices?
Methodology

This chapter will provide insight into the design of the present study, particularly, how the studies included in the literature review were selected and in what manner the studies were analyzed.

Research Design

This is a literature review of peer-reviewed research studies published in academic journals that discuss instructional strategies in secondary science classrooms, specifically in the United States, Taiwan, and Finland. These research studies expose the effectiveness of such strategies in the classroom setting. On a larger scale, these three countries’ chosen and most often implemented pedagogical practices could be seen as a precursor of international benchmarking assessment scores. However, this study primarily aims to inform pre-service and practicing teachers’ pedagogical approaches and guide them in making instructional time as effective as possible. Effective refers to the efficiency of the instructional practices and the students’ levels of retention and comprehension following the instructional practices, as well as the students’ development of higher-order thinking and scientific inquiry skills. The present study also places emphasis on the encouragement of a genuine interest and relevance of science in the students’ lives.

Article Selection Criteria

To be included in this literature review the research study must have met the following criteria. It must be a peer-reviewed study or scholarly article that was published in a scholarly journal. It must relate to or discuss at least one pedagogical approach in a secondary science classroom, grades six through twelve. The article or study must not specifically or solely focus on Professional Development. The article must have been published in the past two years (2015-
2016). The assumption here being that results from the most recent TIMSS and PISA assessments were given time to inform science instruction by this point. The content area must be general science, physics, biology, engineering, or chemistry. The location or the focus of the conducted study must include the United States, Taiwan or Chinese Taipei, or Finland. Internationally focused studies that did not specify a certain geographic location were also accepted. The article could not be a position paper or a critical review. Articles surrounding teaching quality or student social/emotional factors were excluded. If a study found in the database or specific academic journal search failed to meet any one of these criteria, it was excluded from this literature review.

**Scope of Literature**

Two databases were searched for peer-reviewed academic studies: Articles+ and EBSCOhost: Education Full Text. EBSCOhost is specific to the discipline of Education while Articles+ is more general. In the Articles+ database the following search phrases were used, search 1a: “science pedagogical approach,” search 1b: “science instructional strategies in secondary education,” search 1c: “instructional strategies in secondary science education in Taiwan,” and search 1d: “instructional strategies in secondary science education in Finland.” Table 1 displays the number of studies that surfaced in the Articles+ database from respective search phrases. The number of studies found includes studies that did not meet the selection criteria and that were excluded from this literature review. The number of studies used for analysis includes all studies from this database that met selection criteria and that were included in this literature review.
Table 2.1

Number of Studies Found and Included from Articles+ Database

<table>
<thead>
<tr>
<th>Search</th>
<th>Studies found</th>
<th>Studies included in analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Search 1a</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Search 1b</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Search 1c</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Search 1d</td>
<td>15</td>
<td>1</td>
</tr>
</tbody>
</table>

In the EBSCOhost database the following search phrases were used, search 2a: “science pedagogical approach,” search 2b: “science classroom practice,” search 2c: “science instructional strategy,” search 2d: “Taiwan science,” search 2e: “TIMSS science,” search 2f: “Finland science,” search 2g: “Europe science,” search 2h: “science pedagogy,” search 2i: “China science pedagogy,” and search 2j: “Finland science pedagogy.” Table 2 displays the number of studies that surfaced in the EBSCOhost database from respective search phrases. The number of studies found includes studies that did not meet the selection criteria and that were excluded from this literature review. The number of studies used for analysis includes all studies from this database that met selection criteria and that were included in this literature review.
<table>
<thead>
<tr>
<th>Search 2a</th>
<th>Studies found</th>
<th>Studies included in analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Search 2b</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Search 2c</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Search 2d</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Search 2e</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Search 2f</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Search 2g</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Search 2h</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Search 2i</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Search 2j</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

In addition to these two database searches, I conducted a more specific search for studies discussing instructional practices in secondary science classrooms that were published in one of the following five reputable scholarly journals: The Journal of Research in Science Teaching, Science Education International, Science Education, Research in Science Education, and the International Journal of Science Education. Articles included in this study from these five journals met all aspects of the article selection criteria and were published in the past two years (2014-2016).

The Journal of Research in Science Teaching is the official journal of the National Association for Research in Science Teaching. Scholarly manuscripts within the domain of the
Journal of Research in Science Teaching include, but are not limited to, investigations employing qualitative, ethnographic, historical, survey, philosophical, or case study research approaches; position papers; policy perspectives; critical reviews of the literature; and comments and criticism,” (Abd-El-Khalick and Zeidler, 2016, p. 1). Included and excluded articles from this journal are displayed in Table 3.

Table 2.3

<table>
<thead>
<tr>
<th>Volume</th>
<th>Number of issues</th>
<th>Number of articles</th>
<th>Articles included</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>10</td>
<td>65</td>
<td>4</td>
</tr>
<tr>
<td>53</td>
<td>3</td>
<td>23</td>
<td>1</td>
</tr>
</tbody>
</table>

Science Education International is the quarterly journal of the International Council of Associations for Science Education (ICASE). “ICASE is a large network of science education associations, institutions, foundations and companies, facilitating communication and cooperation at the regional and international level,” (Zhang, 2016, p. 1). Included and excluded articles from this journal are displayed in Table 4.

Table 2.4

<table>
<thead>
<tr>
<th>Volume</th>
<th>Number of issues</th>
<th>Number of articles</th>
<th>Articles included</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>4</td>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td>26</td>
<td>4</td>
<td>31</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>4</td>
<td>29</td>
<td>1</td>
</tr>
</tbody>
</table>
Science Education “publishes original articles on the latest issues and trends occurring internationally in science curriculum, instruction, learning, policy and preparation of science teachers with the aim to advance our knowledge of science education theory and practice,” (Rudolph, 2016, p. 1). Included and excluded articles from this journal are displayed in Table 5.

Table 2.5

<table>
<thead>
<tr>
<th>Volume</th>
<th>Number of issues</th>
<th>Number of articles</th>
<th>Articles included</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td>6</td>
<td>56</td>
<td>3</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

Research in Science Education is an international journal “publishing and promoting scholarly science education research of interest to a wide group of people,” (RISE, 2016, p.1). Included and excluded articles from this journal are displayed in Table 6.

Table 2.6

<table>
<thead>
<tr>
<th>Volume</th>
<th>Number of issues</th>
<th>Number of articles</th>
<th>Articles included</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>6</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>46</td>
<td>1</td>
<td>9</td>
<td>0</td>
</tr>
</tbody>
</table>

The International Journal of Science Education is an education and educational research journal that “bridges the gap between research and practice, providing information, ideas and opinion,” (IJSE overview). It is comprised of empirical research papers, papers on innovations and developments, position papers, theoretical papers and letters to the editors. “All research
articles in this journal have undergone rigorous peer review, based on initial editor screening and anonymized refereeing by at least two anonymous referees,” (Gilbert and van Driel, 2016, p. 4). Included and excluded articles from this journal are displayed in Table 7.

Table 2.7

<table>
<thead>
<tr>
<th>Volume</th>
<th>Number of issues</th>
<th>Number of articles</th>
<th>Articles included</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>18</td>
<td>134</td>
<td>10</td>
</tr>
<tr>
<td>38</td>
<td>3</td>
<td>26</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2.8 lists the distribution of journals in which all the studies used in this literature review were found, as well as the number of studies found in each journal. Two studies from the International Journal of Science Education were also found in the EBSCO search.
Table 2.8

*Number of Studies Included in Analysis Published in Each Scholarly Journal*

<table>
<thead>
<tr>
<th>Title of Journal</th>
<th>Number of studies included in analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journal of Research in Science Teaching</td>
<td>5</td>
</tr>
<tr>
<td>Science Education International</td>
<td>3</td>
</tr>
<tr>
<td>Science Education</td>
<td>4</td>
</tr>
<tr>
<td>Research in Science Education</td>
<td>4</td>
</tr>
<tr>
<td>International Journal of Science Education</td>
<td>13</td>
</tr>
<tr>
<td>Education</td>
<td>1</td>
</tr>
<tr>
<td>Journal of Science Teacher Education</td>
<td>1</td>
</tr>
<tr>
<td>Science Teacher</td>
<td>1</td>
</tr>
<tr>
<td>Journal of STEM Education</td>
<td>1</td>
</tr>
<tr>
<td>Science Scope</td>
<td>2</td>
</tr>
</tbody>
</table>

**Analysis**

The studies in the articles selected were analyzed in a manner that aims to highlight trends and commonalities within the literature. This analysis will most likely find that the articles emphasize a select number of pedagogical strategies. Once the strategies were identified in the research-based article, the effectiveness of each were recorded and assessed for inclusion in this literature review. Obvious implications for science instruction are likely to ensue following the analysis of these thirty-five research-based articles.
Review of the Literature

The purpose of this literature review was to explore instructional strategies executed in Taiwanese, Finnish, and American secondary science education classes. Recently published research studies from scholarly journals discussing these instructional practices were compiled and analyzed. This chapter highlights trends and commonalities that surfaced throughout the literature. The reoccurring instructional practices found in the articles can be divided into the following categories: Engineering Design, Modeling, Argumentation, Technology and Efficacy-Enhancing Teaching. Table 3.1 reveals how many of the sample of thirty-five research articles discuss each of these strategies. There is apparent overlap as to what strategies each article addresses because some articles measured the effectiveness of more than one instructional strategy.

Table 3.1

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Number of research studies discussing each strategy</th>
<th>Percentage of research studies discussing each strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Design</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>Modeling</td>
<td>18</td>
<td>51</td>
</tr>
<tr>
<td>Argumentation</td>
<td>19</td>
<td>54</td>
</tr>
<tr>
<td>Technology</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>Efficacy-Enhancing</td>
<td>6</td>
<td>17</td>
</tr>
</tbody>
</table>
**Engineering Design**

Although both scientists and engineers contribute to scientific knowledge in some sense, they do so in different ways. Scientists ask questions about the world, predict explanations to those questions, and then test their ideas with experiments. Engineers on the other hand identify problems, create potential solutions to those problems, and then test those solutions to evaluate their effectiveness (Science Buddies, 2016). Engineering Design is a creativity-based process. Similar to the scientific method, it is not a linear or sequential process but rather an ongoing process in which ideas are tested, then redesigned, and re-tested over and over again until optimal results are achieved (Senler, 2015).

The United States’ recently instated Next Generation Science Standards (NGSS) focused on eight science practices, four of which pertain to engineering design; planning and carrying out investigations, using mathematics and computational thinking, constructing explanations, and asking questions (McNeill et al., 2015). Moore et al. (2015) discuss the significance of endorsing increasing visibility and understanding of these standards for students, teachers and administration. Before the NGSS were instated, engineering design was only present in thirty-six of the fifty states’ science state standards documents (Moore et al., 2015). Furthermore, only twelve of those states explicitly included the terms “engineering” or “technological design.” The remaining fourteen states had no elements of engineering design included in their state adopted science standards at all (Moore et al., 2015).

Exposure to engineering design activities in precollege education would enhance students’ technological literacy, problem solving skills, and divergent thinking abilities (Antink-Meyer & Lederman, 2015; Moore et al., 2015). A study found American science classrooms more likely to promote declines in divergent thinking ability than they were to promote rises in
divergent thinking ability (Antink-Meyer & Lederman, 2015). This is typical of students who view science as a linear process in which there is one correct answer to every problem as opposed to a circular process in which a multitude of creative ideas should be explored as possible solutions (Hathcock et al., 2015). Huang et al. (2015) also found the integration of engineering design activities to expand students’ exploratory learning in physics. This approach in which students are encouraged to explore all possible solutions to a scientific problem promotes interest in science and reduces content knowledge misunderstandings (Hathcock et al., 2015; Huang et al., 2015; Schneider et al., 2016).

Furthermore, students that are probed to solve actual scientific problems through creative means will begin to view science as relevant and applicable (Beerenwinkel & von Arx, 2016; Berland & Crucet, 2016). The challenge, skill and interest that ensue from engineering design teaching practices were found to be enhancers of optimal learning moments in American and Finnish science classes (Schneider et al., 2016). These teaching practices encourage engagement and contribute to science learning as well as social and emotional development (Schneider et al., 2016). Beerenwinkel and von Arx (2016) similarly found that Finnish students were most intrinsically motivated when their physics classes were structured in a way that fostered a high amount of autonomy and allowed them to take ownership over their learning.

In Finland, another qualitative study found the majority of high performing high school students to claim to believe it is their responsibility to take an active, articulate and personal stance in changing the world for the better (Vesterinen et al., 2016). Engineering design encourages this ideology by prompting students to identify problems in the world, brainstorm creative solutions to those problems, and then carry out investigations surrounding those potential solutions.
Modeling

Modeling and Engineering Design are similar pedagogical strategies in that they both emphasize students’ application of science content knowledge as opposed to passive regurgitation of science content knowledge. Modeling is unique in that it enables students to replicate large-scale or abstract scientific phenomena in the classroom. Models provide meaningful tangible or written support structures (Jong et al., 2015). They can be used to illustrate current understandings of science knowledge, be a tool for generating new questions or predicting phenomena, or test solutions to engineering design problems (Cheng & Brown, 2015; Namdar & Shen, 2015). Nevertheless, modeling is found to be most effective when students are encouraged to make intuitive connections between their creations and the paralleling science concepts or standards (Berland & Crucet, 2016).

Multiple studies in both Taiwan and the U.S. found modeling to be vital in science education because it paved way for scientific reasoning and inquiry by allowing the student to represent the nature of the phenomena or structure and then to manipulate these models to test hypotheses (Cheng & Brown, 2015; Jong et al., 2015). In addition to modeling-based instruction, there is need for modeling-based text (Jong et al., 2015). Students in Taiwan who were using the modeling-based text as opposed to the standard school system Chemistry textbook experienced significant improvement in conceptual learning (Jong et al., 2015). Harris et al. (2015) yielded similar results in the U.S. when comparing post-test results of students taught a project-based, modeling curriculum versus students taught the traditional district-adopted textbook curriculum.

**Virtual modeling programs.** Various studies have examined the effectiveness of virtual modeling programs on students’ conceptual understandings. High school teachers in particular emphasized the necessity for three-dimensional simulations in illustrating difficult physics
principles and life and molecular science phenomena (Huang et al., 2015). With three-dimensional computer simulations, students are able to explore all possibilities of a certain principle under various conditions (Huang et al., 2015). Many American schools have provided teachers with interactive white boards and computer-to-screen projectors that can be used to project these three-dimensional simulations to the entire class (Sparapani & Calahan, 2015).

Other studies discussed virtual programs that simulate real-life experiments that wouldn’t be feasible to model in the traditional classroom setting (Leite et al., 2015; Sadler et al., 2015; Scogin & Stuessy, 2015). Scogin and Stuessy (2015) found PlantingScience, a “computer-mediated collaborative learning environment intertwining scientific inquiry and classroom instruction,” to be an ideal curriculum use for the Next Generation Science Standards model. The program allows student teams to design and execute their own experiment while collaborating with volunteer research scientists from around the world (Scogin & Stuessy, 2015). Results from this multiple case study demonstrate a general positive correlation between PlantingScience and student inquiry engagement. Another study examined ninety-two WebQuests that each prompt students with real-life scenarios concerning the sustainability of Earth (Leite et al., 2015). In a scaffolded manner students are then probed to solve problems relating to the scenario. Leite et al. (2015) found that WebQuests “bring the outside world into the classroom, shorten distance not only between people but also between people and real world phenomena, (and) permit real time observation and discussion,” (p. 150). Similarly, educational computer games have consistently been shown to support learning by simulating actual scientific work (Sadler et al., 2015). In American Biology classes, a biotechnology curricula featuring a game-based approach was found to promote students’ abilities to grasp basic biological principles and to promote the students’ interest in learning science (Sadler et al., 2015). Like the WebQuests, these games were
able bridge the gap between the real world and allow students to work through conflict as they would if the situation were actually in front of them (Leite et al., 2015; Sadler et al., 2015).

**Hands-on modeling approach.** The previously discussed virtual modeling programs are valuable in that they allow students to concretize and further conceptualize abstract concepts that wouldn’t otherwise be able to be visualized. However, modeling practices also extend to laboratory and activity-based methods that provide students with hands-on approaches to envisioning science concepts.

In many cases Taiwan was found to provide separate and up-to-date science laboratories in the junior high schools and high schools for each discipline including biology, chemistry, earth science and physics; meanwhile, each American science classrooms typically included science laboratory elements within the classroom where everyday instruction took place (Sparapani & Calahan, 2015). Furthermore, the Taiwanese science teachers rarely used the provided laboratories except for the last few days of a marking period once final grades were submitted while American teachers were more willing to spend class time on experiments, especially if encouraged by their administration (Sparapani & Calahan, 2015). On the occasion that the Taiwanese laboratories were used, the teachers typically modeled the experiment while students observed (Sparapani & Calahan, 2015). Although it appears American students more often perform laboratory exercises than their Taiwanese counterparts, American middle-school students were found to have misguided views of what “experiments” actually are (Senler, 2015; Sparapani & Calahan, 2015). The American students in this study often referred to all hands-on modeling activities as “experiments” even if they didn’t involve critical aspects of experimentations, such as controlling and testing variables (Senler, 2015). This study highlighted the necessity for teachers to differentiate between true experimentation, task problem solving and
scientific exploration, all of which are valid but dissimilar modeling practices (Olaniyan & Omosewo, 2015; Senler, 2015). Students generally considered “experimentation” to include a series of procedures that they are instructed to follow step-by-step (Senler, 2015). This undermines the intuition, curiosity and creativity that true experimentation and exploration demands (Hathcock et al., 2015; Senler, 2015). On the other hand, the Target-Task Model is a systematic approach comprised of six stages that students are instructed to follow methodically (Olaniyan & Omosewo, 2015). Table 3.2, adapted from Olaniyan and Omosewo (2015), depicts the six stages from the model and highlights the promotion of activity-based learning and critical thinking in each.

Table 3.2

<table>
<thead>
<tr>
<th>Stage</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-task</td>
<td>Teacher introduces topic and explains task stage.</td>
</tr>
<tr>
<td>Task</td>
<td>Students complete task collaboratively, in pairs or groups.</td>
</tr>
<tr>
<td>Planning</td>
<td>Students prepare a written, detailed report about the task stage.</td>
</tr>
<tr>
<td>Report</td>
<td>Students deliver reports to the teacher, either orally or written.</td>
</tr>
<tr>
<td>Analysis</td>
<td>Teacher highlights relevant learning ideas to the entire class.</td>
</tr>
<tr>
<td>Practice</td>
<td>Students independently practice teacher-selected problems.</td>
</tr>
</tbody>
</table>

In a study in the U.S. students, regardless of initial competency level, taught with the Target-Task Model performed substantially better on the post-test assessment than those taught using ordinary lecture methods; however, the model was found to particularly enhance performances among low scorers (Olaniyan & Omosewo, 2015).
**Field trips.** Sciences processes taking place outdoors and out in the community provide opportunities for modeling experiences outside of the traditional classroom. Outdoor or community-centered field trips allow students to have direct experience with natural phenomena and scientific experimental design in action (Alon & Tal, 2015). However, a study determined that these field trips to natural environments were not always enrichments to classroom teaching and were not always effectively connected to school curriculum (Alon & Tal, 2015). Field trips were often not acknowledged by American middle school students as contributing to their learning, their attitudes toward the environment, or their environmental behavior (Alon & Tal, 2015). On the other hand, a comparison study between American and Chinese students’ scientific learning progressions found that the American students generally demonstrated a better ability to assess the environmental impact of human behaviors than did the Chinese students (Chen & Anderson, 2015). Vesterinen et al. (2016) deem citizenship as crucial element of science education that is associated with higher performance. This increased focus on sustainability and socioscientific issues would be exemplified in field trips that were well planned and well executed (Alon & Tal, 2015; Vesterinen et al., 2016).

**Critiques of implementing modeling strategies.** Regardless of their general positive impact on students’ conceptual understanding, a range of studies did note that modeling practices must be integrated thoughtfully (Alon & Tal, 2015; Cheng & Brown, 2015; Harris et al., 2015; Leite et al., 2015; Sadler et al., 2015; Senler, 2015; Vesterinen et al. 2016). Additionally, more studies recognize that modeling strategies may not always be feasible options (Harris et al., 2015; Sparapani & Calahan, 2015).

American teachers found project-based curriculum to be more time consuming than the district-adopted textbook curriculum (Harris et al., 2015). For this reason, a problem-based,
modeling-focused curriculum may require a strict pacing guide and lengthy teacher preparation to ensure that the curriculum standards are met (Harris et al., 2015). Harris et al. (2015) expect these challenges to ease naturally with time as teachers become more accustomed to the nature of the curriculum. Student success rates with this curriculum were also shown to increase with the amount of time teachers have taught with a problem-based curriculum and mindset (Harris et al., 2015). In some cases, teachers’ ability to integrate modeling and problem solving into curriculum depends on the government’s imposed curriculum, examination schedules, class sizes, school resources, and teacher preparation programs (Sparapani & Calahan, 2015).

Instructional practices operating in Taiwanese classrooms in particular, appeared to be mandated by administration and were directly related to high school and university entrance exams (Sparapani & Calahan, 2015). However, if the school’s administration encouraged and provided resources for modeling practices, teachers were more likely to implement them (Sparapani & Calahan, 2015).

Other challenges that the literature addressed with regard to modeling included students’ misuse and misinterpretation of models (Cheng & Brown, 2015; Senler, 2015). Both American and Taiwanese students were found to often have trouble developing their own models, especially if they had little prior experience with modeling in the classroom (Cheng & Brown, 2015). Scaffolding was found to be an effective way of supporting such students and guiding their thought processes (Cheng & Brown, 2015). Without scaffolding, the students may not have moved beyond basic descriptive and piecemeal explanations (Beerenwinkel & von Arx, 2016; Cheng & Brown, 2015). Thus, the teachers’ support of students as well as the administrations’ support of teachers were found to be imperative in the ability of modeling practices to be
integrated in the classroom (Beerenwinkel & von Arx, 2016; Cheng & Brown, 2015; Senler, 2015; Sparapani & Calahan, 2015).

**Argumentation**

Argumentation naturally complements most modeling strategies. In scientific argumentation, students are able to communicate their evidence-based claims, often derived from modeling practices, to one another in respectful and effective manners (Huff & Bybee, 2015; Jin et al., 2015). The intent is that through scientific argumentation students will be able to construct knowledge by generating, verifying, communicating, debating, and modifying explanations just as scientists do in the field (Huff & Bybee, 2015; Jin et al., 2015; *The Science Teacher*, 2013). Unlike typical arguments, these scientific arguments are based on tangible, empirical evidence as opposed to opinions, beliefs and emotions (*The Science Teacher*, 2013).

For the purposes of the present study, scientific argumentation will encompass inquiry-based instruction and critical discourse; all of which fall under the Constructivist learning theory framework (Beerenwinkel & von Arx, 2016).

Argumentation is a new wave of science instruction that pushes school science to shift away from the overemphasis of facts, concepts, and principles and towards the true construction of science knowledge through collaboration (Jin et al., 2015). There has been great focus on scientific argumentation in the U.S.’s Framework for K-12 Science Education and Next Generation Science Standards reforms (McNeill et al., 2015; *The Science Teacher*, 2013; Wilcox et al., 2015). The United States’ Next Generation Science Standards focus on eight science practices, three of which include argumentation elements. These elements are: constructing explanations, engaging in argument from evidence, and obtaining, evaluating and communicating information (McNeill et al., 2015). The Programme for International Student
Assessment has even incorporated argumentation skill into their competencies, suggesting that science literacy indicates the application of science knowledge to scientifically explain phenomena and make predictions using data as evidence (Tsai, 2015). In the midst of an examination driven environment, Taiwan has even recently started to emphasize inquiry-based instruction in recent science education reforms (Jin et al., 2016; Sparapani & Calahan, 2015).

Numerous studies demonstrated that argumentation strategies allow students to acquire deeper understandings of science content knowledge (Bathgate et al., 2015; Ho & Liang, 2015; Huff & Bybee, 2015; Hsu et al., 2015; Jin et al., 2015; Scogin & Stuessy, 2015; Tsai, 2015; Wang & Buck, 2015; Yang et al., 2015). These deeper understandings were generally exemplified in the students’ verbal and written arguments (Wang & Buck, 2015).

**Student-student critical discourse.** Some studies concluded that social context has a strong impact on students’ argumentation skills and thus on their science conceptual understanding (Huff & Bybee, 2015; Yang et al., 2015). Students in social online argumentation groups were found to greatly outperform their peers participating in individual online argumentation groups (Yang et al., 2015). Furthermore when students were prompted to critique and build off of their classmates’ arguments, they were able to best construct high-quality arguments (Cheung, 2015; Huff & Bybee, 2015; Tsai, 2015; Yang et al., 2015). Jin et al. (2015) found this critical discourse to be an essential dimension of argumentation in which students exchange views and resolve their differences of opinion. Furthermore, when students approved or refuted others’ arguments, they were simultaneously able to strengthen their own understandings of the material (Cheung, 2015; Jin et al., 2015; Yang et al., 2015).

**Teacher-student critical discourse.** Many studies emphasized that strong teacher guidance is crucial when implementing argumentation practices (Hathcock et al., 2015; Hsu et
Wang and Buck (2015) determine that argumentation is “an intellectual ability that requires explicit instruction,” (p. 346). This explicit instruction refers to teachers’ thorough explanation of what an argument is and how it is constructed (Wang & Buck, 2015). Once students could formulate solid arguments independently, teachers needed to model effective dialogue and support student to student communication (Hsu et al., 2015). This was most effectively accomplished when teachers encouraged students to articulate their rationales before sharing (Hsu et al., 2015). Sometimes teachers needed to indicate specific cases for criticism and/or comparison between groups (Hsu et al., 2015).

In addition, teachers could guide and engage students’ argumentative thought process by using inquiry-based questioning and cognitive prompts (Hathcock et al., 2015; Hsu et al. 2015). Such questioning throughout the lesson fosters reflection and permits students to connect the new material with their prior knowledge (Hsu et al., 2015). Hathcock et al. (2015) adapts Llewellyn’s four types of inquiry-based questions for guidance as indicated in Table 3.2. The incorporation of these cognitive prompts yielded American students that were better able to solve ill-structured problems and generate creative products than their peers that were not taught using these prompts (Hathcock et al., 2015).


Table 3.3

*Llewellyn’s four types of inquiry-based questions from Hathcock et al. (2015)*

<table>
<thead>
<tr>
<th>Types of questions</th>
<th>Uses</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarifying questions</td>
<td>Encourage students to make thoughts and understandings more explicit when they have not provided a reasonable explanation.</td>
<td>What do you mean by that? Can you be more specific?</td>
</tr>
<tr>
<td>Focusing questions</td>
<td>Encourage students to narrow answers and be more specific when they have given vague or generalized explanations.</td>
<td>Can you give me an example of that? What pattern do you see?</td>
</tr>
<tr>
<td>Probing questions</td>
<td>Encourage students to provide more evidence to their explanations by justifying, supporting, analyzing, or giving cause and effect descriptions. They are used when students have provided a partially explained answer.</td>
<td>What are you thinking about when you say that? What do you think you should do next?</td>
</tr>
<tr>
<td>Prompting questions</td>
<td>Encourage students to come to a particular conclusion through clues or hints. They are used to guide students into thinking about a question or topic in a more focused way.</td>
<td>What can you do to make it fall faster? Have you thought about…?</td>
</tr>
</tbody>
</table>
Likewise, a study conducted in Taiwan found that the integration of cognitive prompts resulted in greater learning gains of content knowledge as well as higher quality evidence and reasoning (Wang, 2015).

Alongside cognitive prompts, students’ ability to acquire meaningful conceptual understandings also rests on teachers’ ability to effectively structure inquiry lessons (Hathcock et al., 2015; Hsu et al., 2015; Wang, 2015). This requires that teachers explicitly state and clarify learning goals as well as the tasks of the inquiry or argumentation process at hand (Hsu et al., 2015). This clarity was also found to decrease chaos during discussion or even hands-on activities (Wilcox et al., 2015).

Scaffolding was determined to be an effective way of structuring inquiry-based tasks (Cheng & Brown, 2015; Hsu et al., 2015; Leite et al., 2015; Wang, 2015; Williams & Clement, 2015). In both Taiwan and the U.S. students taught in fully scaffolded groups compared to partially scaffolded groups were able to come up with more sophisticated and coherent explanatory models to explain complex abstract concepts (Cheng & Brown, 2015). Williams and Clement (2015) found that successful teachers’ scaffolding statements in the whole class discussions fell into five groups: participation in the discussion, supporting their discussion of previous ideas, their codes of representation, empirical evidence, and their current ideas and models. Without scaffolding this instruction, mostly through written or verbal cognitive prompts, students were not able to move beyond descriptive and piecemeal explanations (Cheng & Brown, 2015).

**Critiques of implementing argumentation strategies.** As with most instructional strategies, various challenges were associated with the implementation of argumentation practices. Jin et al. (2016) concluded that while teachers recognize the importance of teaching the
cognitive processes and disciplinary reasoning behind scientific knowledge and skills, they find it difficult to execute. Especially, in high-stakes testing environments where class time is limited and curriculum requirements are lengthy (Jin et al., 2016). On the other hand, Wilcox et al. (2015) concluded that while inquiry instruction takes more time, it is more effective in that students retain more of the content. “The additional time required to teach science inquiry is worth the investment,” (Wilcox et al., 2015, p. 65). This investment was found to extend to all students, regardless of initial science proficiency levels or language barriers (Wang & Buck, 2015; Wilcox et al., 2015). Nevertheless, teachers that reported being pressed for time generally dominated classroom discussions and seldom initiated inquiry activities (Jin et al., 2016). This was especially true for senior teachers with limited professional development experiences in inquiry-based instruction (Jin et al., 2016).

There were however also critiques surrounding teachers that did appear to be incorporating inquiry based strategies. Teachers in the United States were often found to mistake all hands-on scientific activities for scientific inquiry, even though they didn’t include elements of critical discourse or argumentation (Senler, 2015). As a result, the students began to identify all hands-on activities as “experiments” even though they lacked the meaningful intuition and questioning of true experimental design (Senler, 2015).

Yet another study addressed the social context of middle and early high schoolers with regard to argumentation strategies. Bathgate et al. (2015) suggested that the “presumed confrontational nature of argumentation may run against cultural norms, particularly during the sensitive time of early adolescence,” (p. 1590). Students sometimes had difficulty executing respectful and evidence-backed argumentation strategies, as opposed to personally driven argumentation strategies (Bathgate et al., 2015). Teachers that modeled argument-building
practices with this social context in mind, meaning that they emphasized evidence-backed argumentation on multiple accounts, generally found that their students were able to separate their personal conflicts with peers during science class (Bathgate et al., 2015).

**Technology Integration**

Technology has recently established a large and valuable presence in science classrooms internationally. Countless software programs have been developed as alternative means of teaching science content (Huang et al., 2015; Leite et al., 2015; Sadler et al., 2015; Scogin, Tsai, Yang). These programs have been found to provide unique opportunities for modeling, inquiry, argumentation and collaboration in the classroom.

Huang et al. (2015) found three-dimensional computer simulations effective at concretizing abstract physics concepts in American high school classes. These interactive simulations allow students to manipulate physics principles to explore all its possibilities under various situations (Huang et al., 2015). When used to supplement the teacher’s physics lesson, they were found to provide clarity and eliminate misunderstandings in the material (Huang et al., 2015).

Other programs present students with simulations of real-world phenomena and guide them through problem-solving activities related to that phenomena (Leite et al., 2015; Sadler et al., 2015). These include science-based computer games and WebQuests. In the computer games, students are presented with a specific goal or a problem to solve (Sadler et al., 2015). They must then apply their scientific content knowledge to the problem at hand. These computer games often include actual data as evidence and comprise objectives of future civic life contexts, allowing students to see their class content put into a real world context (Tsai, 2015).

Technology used in this way allows students the unique opportunity to manipulate a game world
that’s defined by specific rules and internal relationships that mimic those of the real world (Sadler et al., 2015). Researchers found that this biotechnology, computer game-based approach attributed to significant gains on proximal and distal assessments of biological content knowledge in American high school classes (Sadler et al., 2015). In addition, they were thought to contribute meaningful variation to an otherwise traditional teaching style (Sadler et al., 2015; Tsai, 2015). WebQuests take on a similar problem-based, active learning approach. These programs vary in length and sometimes allow collaboration within small groups, but almost all of the analyzed WebQuests were found to scaffold information to students piece-by-piece mimicking a true experimental or exploratory study (Letie et al., 2015; Tsai, 2015).

More research found computer programs to be effective at facilitating students’ scientific argumentation skills while improving their science content competencies (Tsai, 2015; Yang et al., 2015). Students participating in online argumentation consistently outperformed their counterparts on PISA scientific competency assessments (Tsai, 2015). Similarly, another study revealed that students in social online argumentation groups greatly outperformed their peers participating in individual online argumentation groups (Yang et al., 2015).

These online argumentation programs were primarily internet-based and allowed students to collaborate with one another while using different information sources to solve problems (Tsai, 2015; Scogin & Stuessy, 2015; Yang et al., 2015). Without this collaboration aspect, students are only able to self-reflect on their ideas using their prior knowledge. Social argumentation with other students allows students to construct high-quality arguments and thus high-quality knowledge through online critical discourse (Yang et al., 2015). This online collaboration is not restricted to student-student contact, however. Scogin and Stuessy (2015) analyzed PlantingScience, a collaborative learning computer program that allows students to
directly communicate with scientists from around the world. Through the program’s interface, students were able to ask the scientists questions about their current research and daily work (Scogin & Stuessy, 2015). The scientist-mentors were found to be most effective at integrating scientific terminology, relating issues of the nature of science, and making real world and modern connections to scientists (Scogin & Stuessy, 2015). In addition, the program revealed a general positive association between the scientist’s online motivational support and student inquiry engagement (Scogin & Stuessy, 2015). Such innovative collaboration would not be possible without the Internet.

**Critiques of implementing technology in the classroom.** Technology in the classroom, as discussed in the present study, permits students to concretize abstract concepts, to provide valuable variation in science pedagogy, and to shorten the distance between themselves, experts in the field, and real world phenomena. Nevertheless, the implementation of such practices pose potential obstacles; particularly in that programs like the ones discussed may not be accessible to some teachers. A comparison study between technology use in the classroom in Taiwan and the U.S. revealed that the actual use of available technology varies greatly from school to school and from teacher to teacher (Sparapani & Calahan, 2015). Compared to Taiwan, the U.S. typically demonstrated more administrative support for technology integration in the form of purchasing technology and arranging training for teachers (Sparapani & Calahan, 2015). Nevertheless, U.S. teachers also reported that they wished their schools had more access to technology (Sparapani & Calahan, 2015). They often believed the lack of funds was preventing the school from having more access (Sparapani & Calahan, 2015). The same study indicated that class sizes might have significant impact on the availability of technology resources as the cost of technology typically increases with the number of students using the technology (Sparapani & Calahan, 2015).
Considering science class sizes in Taiwan are generally 50-65 students may be a possible reason for the more limited access to technology in the classroom (Sparapani & Calahan, 2015).

**Efficacy-Enhancing Teaching**

Numerous recently published studies included in this literature review emphasized a student’s strong epistemic beliefs about science as a prerequisite for his or her success in science. These studies are grounded in the self-determination theory that assumes human beings are inclined to engage in intrinsically or extrinsically motivating activities (Bandura, 1997; Beerenwinkel & von Arx, 2016). This theory is also the foundation of the constructivist framework of learning (Beerenwinkel & von Arx, 2016).

Efficacy-enhancing teaching as a pedagogical strategy “refers to the use of instructional strategies during regular (science) teaching, which can provide students with positive performance accomplishments, vicarious experiences, verbal persuasions, and physiological states,” (Cheung, 2015, p. 104). The ultimate goal of this strategy is to provide students with positive experiences in the science classroom so that they develop confidence regarding their abilities to perform well in science.

Efficacy-enhancing teaching can be used in conjunction with other pedagogical strategies, such as argumentation or modeling. In fact, it was found to be most effective when implemented during laboratory or hands on experiments (Cheung, 2015). Using Albert Bandura’s (1997) four sources of positive experiences, Cheung (2015) outlines methods of regularly implementing efficacy-enhancing teaching. Other research studies propose similar manners of promoting strong self-efficacy in students. Students were found to be most successful if their assignments were set to an appropriate level of difficulty (Beerenwinkel & von Arx, 2016; Cheung, 2015; Schneider et al., 2016). Likewise, students were found to be most
intrinsically motivated to learn when they felt competent and had a relatively high amount of autonomy (Beerenwinkel & von Arx, 2016).

Vicarious experiences and peer collaboration were also found to increase students’ science interest and success (Cheung, 2015; Ho & Liang, 2015; Huff & Bybee, 2015; Yang et al., 2015). These vicarious experiences promoted surface and deep motivation in students in Taiwan, the United States and Finland as they began to believe that learning science is about applying their skills to increase the knowledge and understanding we have about the world (Ho & Liang, 2015; Schneider et al., 2016). On the other hand, Taiwanese students who considered science learning to be ‘memorizing’, ‘testing’, and ‘calculating and practicing’ were motivated to learn science solely to pass tests or pursue further education without gaining a true appreciation or conceptual understanding of the content (Ho & Liang, 2015). This lack of intrinsic interest and motivation in science learning has been an international concern for some time; particularly, as a result of the most recent PISA results. New science standards in both the United States and Finland (the Next Generation Science Standards and the Finnish National Core Curriculum) have been designed to combat this disinterest by encouraging and even requiring teachers to implement instructional practices that present the material as interesting, challenging and relevant to students’ lives (Schneider et al., 2016).

Cheung (2015) also found efficacy-enhancing teaching to be beneficial to students when teachers verbally praised students who demonstrated improvement. Likewise, low-achieving or shy students benefitted from teacher encouragement for them to participate in learning activities (Cheung, 2015). Overall, establishment of an inviting and respectful classroom environment was found to be vital regardless of what science-content centered instructional strategy was currently being implemented (Cheung, 2015).
Discussion

This study explored experimental research surrounding the effectiveness of pedagogical strategies in Taiwanese, Finnish and American secondary science classrooms using recently published research studies from scholarly journals. Within the articles included in this literature review, five prominent instructional practices emerged that were found to be effective in contributing to an increase in student conceptual understanding and/or performance on assessments. These practices are: engineering-design, modeling, argumentation, technology integration, and efficacy enhancing teaching.

There appears to be a limited amount of literature defining the most regularly implemented pedagogical practices in each country. However, out of the thirty-five research based studies analyzed in the present study, many researched or discussed the importance of implementing specific strategies in the classroom.

Table 4.1

*Number of studies from the review of literature that analyze or discuss one of the five major instructional practices that emerged from the present study*

<table>
<thead>
<tr>
<th>Instructional practice</th>
<th>Taiwan</th>
<th>Finland</th>
<th>United States</th>
<th>International</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Design</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Modeling</td>
<td>4</td>
<td>2</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Argumentation</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Technology</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Efficacy-Enhancing</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 4.1 depicts the number of studies conducted in each geographic area that investigate or discuss one of the five major instructional practices: engineering design, modeling, argumentation, technology integration, or efficacy-enhancing. The majority of the studies discuss more than one strategy. Table 4.1 suggests that the majority of science education research conducted in the past two years has taken place in the United States. However, this assumption is based solely on the thirty-five research based studies included in the present study. Table 4.1 also identifies a strong emphasis on research surrounding modeling and argumentation practices in the secondary science classroom.

**Implications for Practice**

The evidence-based practices discussed in this study provide clear implications for practicing as well as pre-service secondary science teachers like myself internationally. I will discuss these implications first more generally and later more specifically with regard to each of the five instructional practices.

Various overarching themes emerged from the analysis of all five pedagogical strategies. There appeared to be an overarching emphasis on teachers’ effort to make science content relevant and applicable to their students’ lives and futures. This was often related to the notion that students were more intrinsically motivated to learn the material, they retained more information and developed deeper conceptual understandings (Alon & Tal, 2015; Beerenwinkel & von Arx, 2016; Berland & Crucet, 2016; Ho & Liang, 2015; Schneider et al., 2016). My findings suggest that teachers will also be more successful if they encourage students to make connections between science content knowledge and real-world science phenomena; most efficiently accomplished through engineering design activities, software programs such as WebQuests, modeling practices, and inquiry-based activities. From the students’ perspectives,
science content should not be viewed as necessary fragments of memorization for the upcoming examination, but rather as intriguing explanations about themselves and the world around them. Simply put, secondary science instructional practices should allow students to visualize and even manipulate the science content in meaningful ways.

Furthermore, in the research articles analyzed, science was exhibited as a system for improving the world. Either tangibly or virtually, students should be shown that science allows us to generate, test and communicate potential solutions to the natural and man-made problems in our world. This brings up another theme that frequently surfaced throughout the literature. The research studies consistently suggested that science as taught in the classroom should mimic the way that science knowledge is actually constructed in the science community (Beerenwinkel & von Arx, 2016; Berland & Crucet, 2016; Gao, 2014; Leite et al., 2015; Sadler et al., 2015; Tsai, 2015). Science is a curiosity-driven, communication-intensive process that is not treated as such when teachers passively relay science content to students with the expectation that they are able to regurgitate it on the next examination. Moreover, chosen science pedagogical strategies should allow and encourage students to mold their prior knowledge and experiences to fit with the new material (Beerenwinkel & von Arx, 2016).

Aside from making the science content relevant and applicable, teachers should support students in taking responsibility for their own learning in the science classroom. This requires that teachers instill a natural challenge, interest in, and appreciation for the science material they’re relaying to students. These efficacy-enhancing qualities will shine through any instructional practice, even the most traditional and didactic.

Overall, there appeared to be a general consensus that teachers should strive to incorporate a variety of pedagogical strategies in their practice. Traditional lecturing alone is no
longer viewed as an effective or an acceptable means of teaching science. That is, unless the teacher intends on teaching solely to a fact-driven examination. Test-driven environments restrict the feasibility of variety in instructional practices. This is most clearly demonstrated by Taiwan, a historically examination-driven country in which teachers rarely or sometimes ineffectively implement modeling strategies (Sparapani & Calahan, 2015). Perhaps a reason why the United States has consistently performed lower on international benchmarks is that the country as a whole places greater emphasis on conceptual understandings as opposed to the routememorization associated with examinations, as Taiwan has in the past. Nevertheless, assessment is still a significant part of instruction. That being said, teachers should consider forms of assessment beyond the confines of fact-driven summative assessments. These may include projects that allow students creative expression as they demonstrate their mastery of the science material.

Furthermore, the research as a whole indicates that Taiwan, Finland, and the United States would benefit from often employing any combination of engineering design, modeling and argumentation strategies as well as technology and efficacy-enhancing strategies in the classroom. In a way, all of these strategies build off of one another. Engineering design requires that teachers present students with a problem and then allow them to think critically and creatively in generating a solution to that problem. Modeling practices, whether virtual or hands-on, allow students to test the solution derived from engineering design activities and to gather evidence that they would later communicate through argumentation strategies. On the other hand, due to time or curriculum constraints, these strategies can also be employed individually in efforts of successfully strengthening students’ conceptual understandings.
In addition to these implications for secondary science teachers, the present study suggests implication for policy makers and education system administration as well. This study urges all countries to question whether or not international benchmarking should continue to serve as an indicator of an education system’s success. Findings portrayed in Table 4.1 indicate that the U.S. appears to be most progressive in researching and implementing the five strategies found to be most effective. Yet, results from international benchmarking suggest otherwise, that American students to be falling behind in science education compared to their counterparts. Obviously, something does not line up here. Avenues for future research surrounding this predicament are addressed in the following subsection.

Policy makers may also consider that placing extreme emphasis on any assessments, even international benchmarking, may not provide the best, most lasting or most meaningful learning experiences for students. This also brings about yet another potential avenue for future research that will be discussed.

Limitations and Areas for Future Research

Every evident limitation in the present study suggests a probable avenue for future research. The most prominent of these limitations is the scope of research studies included in this literature review. This study only focused on studies published in the past two years (2015-2016). Thus, I was restricted from analyzing how the focus of secondary science instructional practices has changed over the past few decades. A broader scope of articles may give valuable insight into the effectiveness and evolution of science pedagogical strategies over a longer period of time. Furthermore, this small selection of studies made it difficult to make large assumptions surrounding international comparisons of instructional strategies. Teaching styles and practices inevitably vary within a country by state/providence, school system, and even classroom. It was
difficult to fairly define which pedagogical practices each country “most regularly” implemented using only the research studies included in this literature review. Moreover, there appeared to be a limited amount of literature pertaining to certain practices in certain geographic locations, particularly in Taiwan and Finland. Many of the studies included in this exploratory study were published in international scholarly journals and were conducted on an international scale. Future research could potentially explore the instructional practices actually integrated into Taiwanese, Finnish and U.S. secondary science classrooms through more quantitative means. This would allow for more fair and comprehensive postulations as to what pedagogical strategies each country most regularly implements. This data would allow insight into the degree of emphasis that each country places on examinations, particularly the TIMSS and PISA. From here, more encompassing conclusions could be drawn surrounding the effectiveness of instructional practices.

Lastly, perhaps future research could analyze critical aspects of international benchmarking assessments, particularly the TIMSS and PISA, on a more intensive, international scale. Knowing how students become eligible to take this exam, how they’re selected, how many are selected, etc. could help in determining whether international benchmarking should continue to serve as an indicator of an education system’s success. Furthermore, this future research could investigate the content on these international benchmarking assessments, specifically, whether it lines up with every country’s secondary science curriculum and whether it is truly conceptually based.

Conclusion

This exploratory study of the literature surrounding instructional practices in Taiwanese, Finnish and American secondary science classrooms demonstrated the effectiveness of various
instructional practices including engineering design, modeling, argumentation, technology and efficacy enhancing teaching. These strategies were deemed effective and successful when employed individually but also in conjunction with one another. As a whole, variation in secondary science pedagogy was found to be a valuable aspect of science teaching that was associated with students’ deeper conceptual understandings and intrinsic motivation toward the science material.
References


Gilbert, J. K., & van Driel, J. (Ed.). (2016). *International Journal of Science Education Aims and


Retrieved April 25, 2016, from

http://www2.ed.gov/about/offices/list/ous/international/edus/index.html


https://nces.ed.gov/surveys/pisa/


https://nces.ed.gov/timss/


http://dx.doi.org/10.1080/09500693.2014.979378


http://dx.doi.org/10.1080/09500693.2015.1045957