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SELF-EFFICACY, SCIENTIFIC REASONING, AND LEARNING ACHIEVEMENT IN THE STEM PROJECT-BASED LEARNING LITERATURE

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ABSTRACT

The main goal of education is to prepare students for future job opportunities and civic responsibilities, and this is one of the biggest challenges in the 21st century. Science, Technology, Engineering, and Mathematics (STEM) Project-Based Learning (PjBL) prepare students to master their new role as a global citizen with greater responsibilities. This systematic review analyzed 265 papers that are related to the STEM PjBL. The papers were collected from well-known databases such as Web of Science® and SCOPUS by using the quality assessment and relevant criteria. This study inspected the top 48 distinguished papers by covering three dimensions, Search result, Subject, and Research methodology. STEM and PjBL come together, due to the natural overlap between the fields of Science, Technology, Engineering, Mathematics and PjBL. The fully integrated STEM with PjBL can increase the effectiveness of teaching. Nonetheless, this inspection uncovered that previous research has not fully integrated STEM with PjBL. Thus, despite the wealth of existing research, there are still significant opportunities for future research on STEM PjBL in high schools to prepare students for 21st century challenges.

Keywords: Enhanced teaching and learning, 21st century skills, project-based learning STEM, systematic literature reviews

1.0 INTRODUCTION

Science, technology, engineering, and mathematics (STEM) is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real world lessons (Bruce-Davis et al., 2014; Gerlach, 2012). STEM incorporates teamwork and solves problems by using a questioning and answering technique that is incorporated with research, and students are engaged in processes of inquiry, design, and/or investigation. STEM is particularly suited for PjBL because of the natural overlap between the fields of science, technology, engineering and mathematics (Capraro & Jones, 2013). So, STEM and project-based learning match each other. Project-Based Learning (PjBL) has been described as an innovative approach to learning that teaches a multitude of strategies critical for success in the 21st century comparing to the conventional model (Cervantes, Hemmer, & Kouzekanani, 2015). STEM project-based learning can further develop the affective domain of creativity, including adventurousness, curiosity, imagination and challenge (Lou et al., 2017). The PjBL is different from the conventional model in that students drives their own learning through inquiry, as well as work collaboratively to research and create projects that reflect their knowledge (Bell, 2010; Cervantes, 2013; McGrath, 2004). If we are serious about reaching 21st century educational goals, Project-Based Learning must be at the center of 21st century instruction (Clark, 2014; Larmer & Mergendoller, 2010).

Schwalm and Tylek (2012) defined that Project-Based Learning (PjBL) is an approach to instruction that presents students with real-world, multidisciplinary problems that demand critical thinking, engagement, and collaboration (Grant, 2009). In PjBL, students go through an extended process of inquiry in response to a complex question, problem, or challenge. Rigorous projects help students learn key academic content and practice 21st century skills such as collaboration, communication and critical thinking (Department of Education, 2015). STEM PjBL is defined as a learner-centered instructional model (Hou, Chang, & Sung, 2007) and tend to model "real-world" situations, with a focus on group work and hands-on experiences (Pleiss, Perry, & Zastavker, 2012). Hands-on experiences are essential for the 21st century employees. In STEM PjBL students are engaged in activities that are designed to either answer a question or solve a problem with appropriate solutions (Gardiner, 2014; Vega, Jiménez, & Villalobos, 2013).

Bandura (1997) has argued that self-efficacy leads to higher goals being set. Achieving higher goals are increasing the positive effects of self-efficacy by providing an evaluative context to aid self-regulation. As Pintrich and de Groot (1990) reported students with high self-efficacy tend to persist more toward achieving their goals. Besides the self-efficacy students should have scientific reasoning skills as well, if they want to prepare themselves for 21st century challenges. Scientific reasoning, referred to as 'formal reasoning' (Piaget, 1970) and 'critical thinking' (Hawkins & Pea, 1987; Pea, 2004). Bao et al. (2009) mentioned that the development of general scientific abilities is critical to enable students of science, technology, engineering, and mathematics (STEM) to successfully handle open-ended real-world tasks in future careers. Scientific-reasoning skills can be developed through training and can be transferred (Adey, Shayer, & Shayer, 2006). These two self-efficacy, and scientific reasoning skills, leads students to gain better achievements in the high school and the life. Generally, project-based learning improves students' achievement, and authentic problem-solving opportunities (Cakici & Turkmen, 2013; Gulbahar & Tinmaz, 2006).

Few systematic literature reviews have been done on the STEM PjBL and its effect on self-efficacy, scientific reasoning, and learning achievement. Strobel and Van Barneveld (2009) done a meta-synthesis of meta-analyses comparing problem-based learning to conventional classrooms. In another study, Ritz and Fan (2014) conducted an international review to determine the state-of-the-art of the application of technology education within the STEM approach to educational reform. Kramer, Walker, and Brill (2007) explored the barriers associated with teachers implementing PjBL methods in the information and communication technology assisted learning method. Two more literature reviews on the STEM PjBL topics had been done recently and investigated the popularity of project-based learning (Duke, Halvorsen, & Strachan, 2016) and educating STEM students among young first-generation female Mexican-Americans (Jessica et al., 2011). None of the above mentioned review papers analyzed the effects of STEM PjBL on the three variables (self-efficacy, scientific reasoning, and learning achievement). Therefore, this systematic literature review attempts to cover the research gap and analysis literatures on the topics of STEM PjBL, self-efficacy, scientific reasoning, and learning achievement.

2.0 LITERATURE REVIEW

Science, technology, engineering and mathematics (STEM) education is well placed to teach skills that are relevant in the information-rich modern economy. STEM skills include problem-solving and rigorous analysis of evidence. The investigative nature of STEM fields also makes them ideal training grounds for developing objective and critical ways of thinking (West, 2012). According to Turner (2013) STEM education is not just an area of study, but it is also a way of teaching and learning that is project-based, collaborative, and focused on solving real-world problems. STEM programs educate the whole student, emphasizing innovation, problem solving, critical thinking, and creativity. STEM professionals impact our daily lives with the resources and technological advances they have come to depend upon. STEM is our future (Turner, 2013). Research tells us that students learn best when encouraged to construct their own knowledge of the world around them (Laboy-Rush, 2011; Satchwell & Loepp, 2002). In the STEM PjBL lessons, students gained higher scores in the statewide assessment only if teachers showed higher fidelity in implementing STEM PjBL. Students, who were provided lower quality STEM PjBL lessons, showed a negative growth rate (Capraro et al., 2016; Han, Yalvac, Capraro, & Capraro, 2015). Variables used in this study are defined and explained in the following sections.

2.1 Science, Technology, Engineering, and Mathematics (STEM)

In the 1990s, the National Science Foundation (NSF) began using “SMET” as shorthand for “science, mathematics, engineering, and technology”. When an NSF program officer complained that “SMET” sounded too much like “smut”, the “STEM” acronym was born (Sanders, 2009). Schools with a strong emphasis on STEM education often integrate science, technology, engineering, and mathematics into the entire curriculum (Barakos, Lujan, & Strang, 2012). One view of STEM focuses on exposing students to authentic experiences and applying rigorous content to solving real world problems. Hundreds of reports and programs have been commissioned in the United States regarding STEM Education–all having three parallel concerns: the future need for more scientists, technicians, engineers, and mathematicians, the necessity for more innovative workers trained in science, technology, engineering and mathematics; and recommendations for what schools should do to solve the shortage (Zollman, 2012). United States is not alone in pursuing this direction in STEM education. Different countries are exploring STEM because of political and economic pressures and because some believe it is a means to improve the delivery of this knowledge.

Deslauriers, Schelew, and Wieman (2011) recommended that teachers adopt a variety of methods of instruction, including one in which the students are actively engaged in the learning process like STEM. While literature has reported several characteristics of STEM, the following are the most common ones. First, it is integrated. Using a curriculum centered on principles from science, technology and engineering, and mathematics, students learn to apply previously obtained information to creatively address a problem they have never before encountered. Second, STEM education is inquiry-based. Distinct from the conventional classroom, which is typically lecture-based, a STEM classroom asks students to work together to solve problems by using, questioning and answering techniques incorporated with research. Third, STEM incorporates teamwork and instruction in the “soft skills” needed for business and industry. Asking students to practice these skills promotes confidence and gives them insight into their own character as they become aware of personal traits they may not have realized they had, such as leadership skills. Fourth, STEM is appealing. Students enjoy classroom discussion and participation to solve a meaningful problem. Fifth, STEM education is fulfilling. Teachers are able to perceive themselves as facilitators of the learning process and not merely instructors (Roberts, 2012).

2.2 Project-Based Learning (PjBL)

Project-Based Learning (PjBL), was developed based on the theory of constructivism. It is a type of active learning that engages students in “relatively long-term, problem-focused, and meaningful units of instruction that integrate concepts from a number of disciplines or fields of study (Blumenfeld et al., 1991). According to Holbrook, Rannikmae, and Valdmann (2014), project-based learning has been defined as a model for classroom activity where the focus on the teacher is diminished, and the focus on student activity is increased with a greater emphasis on long-term interdisciplinary and integrated addressing of real-world issues in a practice-based format. Project-Based Learning (PjBL) has been described as an innovative approach to learning that teaches a multitude of strategies critical for success in the 21st century compared to the conventional model (Barron & Darling-Hammond, 2008; Bell, 2010; Blumenfeld et al., 1991; Cervantes et al., 2015).

STEM PjBL is an interdisciplinary teaching and learning approach leading students to explore ill-defined problems across subjects within a constrained environment. An interdisciplinary approach, hands-on activities, collaboration, team communication, knowledge construction, and formative assessment have been indicated as primary components of STEM PjBL (Barron et al., 1998; Han, 2013b; Slough & Milam, 2013; Thomas, 2000). As STEM literally stands for four subjects, STEM PjBL combines disciplines from science, technology, engineering, and mathematics (Capraro & Jones, 2013; Lou et al., 2011). STEM Project-Based Learning (STEM PjBL) also places students in realistic, contextualized problem solving environments. Project can serve a bridge between phenomena in the classroom and real life experience (Blumenfeld et al., 1991; Holubova, 2008; Slough & Milam, 2013). Tseng et al. (2013) concluded that combining PjBL with STEM can increase effectiveness, generate meaningful learning and influence student attitudes in future career pursuit.

2.3 Self-Efficacy

Bandura (1977) in an attempt to offer a theoretical explanation for human behavior change fixed the framework of self-efficacy. He defined self-efficacy as one’s own ability to perform a particular task, emphasizing the specificity of the task. The self-efficacy literature also links student’s science self-efficacy to persistence in science majors and career choices in science (Britner & Pajares, 2006; Dalgety & Coll, 2006), and achievement in science for high school students (Bøe et al., 2011; Lau & Roeser, 2002). These studies indicate that development of self-efficacy that occur in STEM PjBL, can lead to perform better problem solver.

2.4 Scientific Reasoning

Scientific reasoning is also referred to as “formal reasoning” (Piaget, 1970) and “critical thinking” (Hawkins & Pea, 1987; Pea, 2004). Scientific reasoning delineates the skills needed to conduct scientific inquiry, such as argumentation, drawing inferences from data, and engaging in experimentation (Soyyilmaz et al., 2017; Zimmerman, 2007). Scientific reasoning, in early studies, represents the ability to systematically explore a problem, formulate and test hypotheses, control and manipulate variables, and evaluate experimental outcomes (Bao et al., 2009; Zimmerman, 2007). It represents a set of general skills involved in science inquiry supporting the experimentation, evidence evaluation, and argumentation that lead to formation and modification of concepts and theories about the natural and social world (Han, 2013a). Scientific reasoning has been widely accepted as the core component of STEM education. Since scientific reasoning represents a set of skills and abilities that are necessary for successfully conducting science inquiry tasks, it has also been widely emphasized in science education standards and curriculum. Much research has been conducted to understand how scientific reasoning interacts with other areas of learning. For instance, research has shown that scientific reasoning skills have a long-term impact on student academic achievement (Georghiades, 2000). Researchers have found positive correlations between student scientific reasoning abilities and measures of learning gains in science content (Coletta & Phillips, 2005; Lawson, 2000).

2.5 Learning Achievement

Learning achievement indicates learning quality and competences of teacher and teaching methods, which could be measured by examination scores (Somnuek, 2014). The learning achievement evaluated by students' oral and artifact reports, the feedback they give to others, and their academic examination scores (Shih, Chuang, & Hwang, 2010). There are many studies investigating the effect of PjBL on learning achievement (Ayan, 2012; Filippatou & Kaldi, 2010; Kizkapan & Bektas, 2017). The relationship between self-efficacy and scientific reasoning with students' achievement is declared in the previous studies. For instance, research has shown that scientific reasoning skills have a long-term impact on student academic achievement (Georghiades, 2000). Self-efficacy literature also links student's science self-efficacy to their achievement in science for high school students (Bøe et al., 2011; Lau & Roeser, 2002). Cheng (2013) showed that self-efficacy has a positive effect on learning achievement.

3.0 RESEARCH DESIGN

This systematic literature review study analyzed 265 papers relevant to the STEM PjBL. A systematic review allows discovering the consistency and variation within studies in one filed and provides an exhaustive summary (Carbonell et al., 2014; Davies, 2000). The papers were collected from well-known databases such as Web of Science® (WoS) and SCOPUS by using the quality assessment and relevancy criteria (Jamali et al., 2015). The search of "STEM" in the title AND "Project-based learning" in the topic of documents in the WoS database retrieved 120 papers, consist of one review article (search date was 23 June 2017). The reverse search of "Project-based learning" in the title AND "STEM" in the topic of documents in the WoS database retrieved 28 papers. However, the same research results from the SCOPUS database retrieved 212 documents, including two review papers. The reverse search on the SCOPUS database retrieved 65 documents. Additional papers were collected from Web of Science® (WoS) and SCOPUS by looking for the three variables self-efficacy, scientific reasoning, and learning achievement in the title or topic of papers AND STEM or PjBL in the other way around. By compiling all documents and delete the duplicated items and remove irrelevant papers 265 papers remained.

The total number of paper which used for literature review were 265 papers categories in three differs passes for reading. These three steps were chosen according to a paper entitled “How to read a paper," written by Keshav (2007). The first pass is a quick scan to get birds-eye view of the paper. The researcher makes a decision whether to do any more passes, in the first pass. In the second pass, the researcher reads the paper with grater care, but ignores details such as proofs. It helps to jot down the key points, or make comments and decide to keep the paper for next pass. The third pass is to attempt to virtually re-implement and re-create the paper. The researcher can identify the paper’s innovations and its hidden assumptions by comparing this re-creation with the actual paper (Keshav, 2007). The study inspect the top 48 distinguished papers by covering three dimensions, Search result, Subject, and Research methodology. These 48 papers passed all three passes. The key to the third pass is to fully understand the paper, pinpoint implicit assumptions, missing citations to relevant work and potential issues with experimental or analytical techniques (Keshav, 2007).

4.0 ANALYSIS AND DISCUSSION

Table 1 maps over 48 papers of the current research on STEM, Project-Based Learning, Self-Efficacy, Scientific Reasoning, Achievement, and Problem Solving.

Table 1: Summary Findings of Previous Studies

	Reference	**Search result**					**Subject**			**Research methodology**			
No.	**References and document title**	**STEM**	**Project-Based Learning**	**Self-Efficacy**	**Scientific Reasoning**	**Learning Achievement**	**High school**	**University**	**Other**	**Case study**	**Qualitative**	**Quantitative**	**Mixed method**
1	This research: Self-Efficacy, Scientific Reasoning, and Learning Achievement in the STEM PjBL Literature	✓	✓	✓	✓	✓	x	x	x	x	x	✓	x
2	(Thomas, 2000)	x	✓	x	x	x	x	x	✓	x	x	x	x
3	(Cheng, 2013)	x	✓	✓	x	✓	x	✓	x	x	x	✓	x
4	(Sawtelle, 2011)	x	x	✓	x	✓	x	x	x	x	x	x	✓
5	(Schaffer et al., 2012)	x	✓	✓	x	x	x	✓	x	x	x	✓	x
6	(Han, Capraro, & Capraro, 2015)	✓	✓	x	x	✓	✓	x	x	x	x	✓	x
7	(Lou et al., 2011)	✓	✓	x	x	x	✓	x	✓	x	x	✓	x
8	(Hsu et al., 2015)	x	✓	x	✓	x	✓	x	x	x	x	✓	x
9	(Bandura, 1977)	x	x	✓	x	x	x	x	✓	x	x	✓	x
10	(Coletta & Phillips, 2005)	x	x	x	✓	x	x	✓	x	x	x	✓	x
11	(Pleiss et al., 2012)	x	✓	✓	x	x	x	✓	x	x	✓	x	x
12	(Pintrich & de Groot, 1990)	x	x	✓	x	✓	✓	x	x	x	x	✓	x
13	(Lawson et al., 2000)	x	x	x	✓	x	x	✓	x	x	x	✓	x
14	(Gulbahar & Tinmaz, 2006)	x	✓	x	x	✓	x	✓	x	✓	x	x	x
15	(Mettas & Constantinou, 2008)	x	✓	x	x	x	x	x	✓	x	x	x	✓
16	(Aziz, Shamsuri, & Damayanti, 2013)	x	✓	x	✓	x	x	x	✓	x	x	x	✓
17	(Wurdinger et al., 2007)	x	✓	x	x	x	x	x	✓	x	✓	x	x
18	(Baran & Maskan, 2010)	x	✓	x	x	✓	✓	x	x	x	✓	x	x
19	(Speckels, 2012)	x	✓	x	x	✓	x	x	✓	x	✓	x	x
20	(Jeon, Huffman, & Noh, 2005)	x	x	x	x	x	✓	x	x	x	x	✓	x
21	(Olivarez, 2012)	✓	✓	x	x	x	✓	x	x	x	x	✓	x
22	(Xu & Liu, 2010)	x	✓	x	x	x	x	✓	x	x	x	✓	x
23	(Tiwari et al., 2006)	x	x	x	✓	x	x	✓	x	x	x	✓	x
24	(Han et al., 2015)	✓	✓	x	x	x	x	x	✓	✓	x	✓	x
25	(Chua, Yang, & Leo, 2014)	x	✓	x	x	x	x	✓	x	x	x	✓	x
26	(Clark, 2014)	x	✓	✓	x	x	x	x	✓	✓	x	x	x
27	(Cervantes, 2013)	x	✓	x	x	✓	✓	x	x	x	x	✓	x

28	(Jungert, Hesser, & Träff, 2014)	x	x	✓	x	✓	x	x	✓	x	x	✓	x
29	(Machado, Borromeo, & Malpica, 2009)	x	✓	x	x	x	x	✓	x	x	x	x	✓
30	(Land & Greene, 2000)	x	✓	x	x	x	x	✓	x	x	✓	x	x
31	(Popescu, 2014)	x	✓	x	x	x	x	✓	x	✓	x	✓	x
32	(Tseng et al., 2013)	✓	✓	x	x	x	x	✓	x	x	x	x	✓
33	(Meng, Idris, Leong, & Daud, 2013)	✓	✓	x	x	x	✓	x	x	x	x	✓	x
34	(Byun, Ha, & Lee, 2010)	x	x	x	x	x	x	✓	x	x	✓	x	x
35	(Kubiatko & Vaculová, 2011)	x	✓	x	x	✓	x	✓	x	x	x	x	✓
36	(Doppelt, 2003)	x	✓	x	x	✓	x	x	✓	x	x	x	✓
37	(Barak & Zadok, 2009)	x	✓	x	x	✓	✓	x	x	x	✓	x	x
38	(Komarraju & Nadler, 2013)	x	x	✓	x	✓	x	✓	x	x	x	✓	x
39	(Capraro & Jones, 2013)	✓	✓	x	x	x	x	x	✓	x	x	x	x
40	(Zeineddin & Abd El-Khalick, 2010)	x	x	x	✓	x	x	✓	x	x	x	✓	x
41	(Sanders, 2012)	✓	✓	x	x	x	x	x	✓	✓	x	x	x
42	(Hong, Chen, & Hwang, 2013)	x	✓	x	x	✓	✓	x	x	✓	✓	x	x
43	(Mills, 2009)	x	✓	✓	x	x	x	✓	x	x	x	✓	x
44	(Hampton & Mason, 2003)	x	x	✓	x	✓	✓	x	x	x	x	✓	x
45	(Liu, Lou, & Shih, 2014)	✓	✓	✓	x	x	✓	x	x	x	x	✓	x
46	(Moore & Rubbo, 2012)	✓	✓	x	✓	x	x	✓	x	x	x	✓	x
47	(Han, 2013a)	✓	✓	x	✓	x	x	x	✓	x	x	✓	x
48	(Capraro et al., 2016)	✓	✓	x	x	x	✓	x	x	x	x	x	✓

Over 265 papers are reviewed, and top 48 of them listed on the Table 1. Table 1 visually indicates the research gap within previous studies and identifies opportunities for future research. The growing literature body on self-efficacy, scientific reasoning, and learning achievement in the STEM has produced significant discoveries of the Project-Based Learning. The overview was structured along the search result, subject, and research methodology by illustrate the insights and findings. To identify the research gap in the previous literature, just locate the "x" on the Table 1. It is helpful to look at the preferences and distributions of the population of references across the topic. STEM is particularly suited for PjBL because of the natural overlap between the fields of science, technology, engineering and mathematics (Capraro & Jones, 2013). However, out of 48 references, 36 of them worked on PjBL while only 13 of them researched on both STEM and PjBL fields. In other words, the majority of the references identified for this analysis concentrates on a single subject of PjBL. References in all categories are focused strongly on study at the university level (19 references) and learning achievement with19 references. References that focused on high school level and scientific reasoning (nine references) are small in number and occur rarely in the both STEM and PjBL fields (only six references). The majority of the references (27 references) identified for this analysis concentrates on quantitative research method followed by eight references which used qualitative research method. The case study research method was not so popular and used very rarely with only six references.

Almost none of the papers listed in the Table 1 cover all research areas, which are STEM, Project-Based Learning, self-efficacy, scientific reasoning, and learning achievement. The literature indicated that using a STEM PjBL teaching strategy can help students' problem solving performances more than conventional teaching instructions (Jeon et al., 2005; Psycharis, 2013). Despite the wealth of existing research, there are still significant opportunities for future research on STEM PjBL in high school. Therefore, more studies should be done on this subject. Ralph (2016) suggested that the skills that students learned from STEM PjBL enhances the educational process and prepares them for the future career setting.

5.0 CONCLUSION

This study analyzed 265 references on STEM Project-Based Learning with respect to the research area, subjects they have studied, and research methodology applied in doing the research. Most of the references (36 out of 48 references) have selected Project-Based Learning as their focus followed by 13 references on STEM. References that focused on high school level and self-efficacy, scientific reasoning, and learning achievement are very small in number (only one in the self-efficacy and learning achievement) and occur really in the both STEM and PjBL fields. The literature inspected in this review study revealed that more research need to be performed on STEM project based learning in high school. Therefore, future studies should cover the effect of STEM PjBL teaching method in the high school on preparing students for 21st century challenges. STEM PjBL was perceived to be important for future education and careers. Although there were many researches about the relationship between self-efficacy, scientific reasoning, and achievement, few of them compared the effect of STEM PjBL teaching method with conventional teaching method among high school. So it is necessary to do deep research on the comparisons of STEM PjBL with conventional teaching methods on self-efficacy, scientific reasoning, and achievement in high school.

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