Research Article

Good Practices For Stem Based Learning Management And Assessment For Secondary Education Classrooms In Thailand

Suttipong Boonphadung[a] , Pintipa Seubsang[b]

[a]Assistant Professor, Faculty of Education, Suan Sunandha Rajabhat University, Thailand.
[b]Ph.D. in Education, Faculty of Education, Suan Sunandha Rajabhat University, Thailand.
[a] suttipong.bo@ssru.ac.th , [b] pintipa.se@ssru.ac.th

Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 23 May 2021

Abstract: The idea of STEM education is not new, but it is considered to be innovative and still limited in Thai education. Thai teachers have tried adopt this concept in managing their classrooms and assessing their learners. This study aimed to investigate good practices for STEM based learning management and assessment that is currently applied by STEM Education Centers in Thailand. Participants of this qualitative research included coordinators of the center (n=8), and teachers (n=16) who were trained by the centers. Content analysis was used to analyze the data from interviews, focus group, and observations. The analysis indicated the instructional model on good practices including an implementation of problem-based instruction and project-based in curricular developed by teachers of the centers. Moreover, the good practices regarding classroom management and assessment were shown through 5E's cycle. The cycle aims at encouraging students' thinking process and problem-solving. The findings also showed authentic assessment as a good practice for assessing learners 'performances. The results suggest that transdisciplinary integration combined with 5E's cycle, which is a good practice for STEM based learning management, can promote learners' interest in science, technology, engineering, mathematics, and other related careers.

Keywords: Good practices, STEM based learning management, STEM based assessment, Secondary education, Thailand

1. Introduction

In comparing to other ASEAN countries, Thailand is still facing an issue on quality of education. According to the data from 2015–2016, Thai students' comparative advantage in science and mathematics was ranked far lower than the international and ASEAN average. This issue was also supported by the latest Programme for International Student Assessment (PISA) score results published by the Organisation for Economic Cooperation and Development in 2015. (Office of the Education Council, 2014; Schwab, 2015; Kilenthong, 2017; The Institute for the Promotion of Science and Technology, 2017). The test is designed to measure the thinking process in mathematics, science and reading of 15-year-old students in both vocational and secondary schools. According to the PISA score results, Thailand was ranked 55th out of the 72 countries in the overall result. Due to the concern with the low results of Thai students, the Ministry of Education launched a new policy for developing Thai students' essential skills of the 21st century that are 3R's and 8C's skills. 3R's refers to the skills of reading, arithmetic, and writing. 8C's includes the skills of critical thinking and problem solving, creativity and innovation, cross–cultural understanding, collaboration, teamwork and leadership, communications, information and media literacy, computing and ICT literacy, career and learning skills, and compassion. This policy was established to focus on developing students' knowledge and skills in science and technology. It is believed that this knowledge and skills can promote the nation's competitiveness particular in production, innovation and services. Furthermore, the Ministry of Education also aims to improve educational strategies in the areas of science, mathematics and technology. This improvement is believed to be able to enhance the quality of Thai human resources. As the result, the Thai Government adopted STEM Education (Science Technology Engineering and Mathematics Education) as an approach to learning and development. The concept of STEM education is based on the constructivist education approach. It integrates the areas of science, technology, engineering and mathematics. Moreover, this approach also aims at developing students to master keys skills for success in today's world, such as critical thinking, problem solving, communication and collaboration (The National Science Teachers Association, 2016; Jolly, 2017). Through STEM, students can develop their creative and critical thinking mindset. This development can promote the student to be a powerful thinker and effective inventor who is ready to engineer and solve real-world problems (Morrison, 2006; Dejarnette, 2016).

Due to this government's requirement, The Institute for the Promotion of Teaching Science and Technology (IPST) has established 13 national STEM Education centers as learning hubs in 12 provinces across Thailand (The Institute for the Promotion of Teaching Science and Technology, 2014). However, many critics have raised concerns about STEM Education whether it should be implemented as an independent course or as part of a course, and how learning achievement can be measured and evaluated (Pitt, 2009). This concern is in line with an idea of Pearson (2017) who suggested that educators or teachers should design a clear scope of expected learning outcomes, and integration and implementation of STEM education because it can help identify the learning approach, objectives and assessment strategies. In addition, Moore, Johnson, Erin, and Guzey (2016) pointed out that the lack of an engineering foundation can cause difficulties in using STEM Education as a way to develop students. In particular, there is the vagueness in difficulties in using STEM Education as a way to develop students. In particular, there is the vagueness in implementing STEM Education in terms of a course administration.

The idea of STEM education is not new, but it is considered to be innovative and still limited in Thai education. Although the implementation of STEM in particular has been reported to be useful and effective in educational contexts, there has been a lack of uptake of the approach. The gap between studies reporting successful outcomes in integrating STEM education in Thai classroom and the continued lack of attention to approaches in terms of practices that support effective STEM education led to this study's focus. Since STEM is still questionable, this study aimed to investigate good practices of implementing the concept of STEM in Thai classrooms for promoting learning performance of students. Establishing good practice of STEM for learning management and assessment appears to be a useful framework or guidelines for designing classroom teaching practices in the Thai educational context that can encourage students to connect knowledge gained in classrooms with their daily and professional lives. Students with experience in STEM based learning activities are regarded to be better prepared to work in demanding positions in various career sectors. Producing high performance STEM-related human resources can thus increase Thailand's economic potential and the growth of the country.

2. Literature Review

2.1 The Notion of STEM Education

The notion of STEM education initiatively created by the National Science Foundation (NSF) of The United States of America, is an educational approach that integrates the disciplines of science, technology, engineering, and mathematics into one unit, or lesson (Sanders, 2009, p. 20; Vasquez, Sneider, & Comer, 2013) with the emphasis of making connections between the subjects and real-world contexts (Israel, Maynard, & Williamson, 2013; Moore & Smith, 2014). Moreover, this educational approach that aims at providing learners with opportunities to investigate a problem, search for possible solutions, ask questions, examine ideas, think creatively, collaboratively negotiate and work as a group, and use their intuition (Hernandez et al., 2014 as cited in McDonald, 2016, p. 532; Srinath, 2014; Psycharis, 2016, p. 317). This approach can lead learners to become creative problem solvers and ultimately more markable in the workforce. By implementing this approach in classrooms, Han, Capraro, and Capraro (2015) pointed out that teachers can assign students a project-based assignment that allows them to perform the investigative approach known as 'inquiry-based science'. In so doing, this type of classroom activity can invoke skills of creative problem-solving, questioning, and teamwork among students (Han, Capraro, & Capraro, 2015). This idea is in line with Wilhelm's suggestion that encourages teachers to use project-based tasks following STEM education (Wilhelm, 2014). She also suggested that the task should allow students to establish goals, design directions or approaches, and appropriating knowledge and available technologies for performing the task (Wilhelm, 2014). Lawrenz and Huffman (2006) also added some examples of activities in the task that are experiment, case study, observation and research, and etc.

In addition, Daml (2017) addressed that when teachers adopt the idea of STEM in classroom activities, they should encourage their students to make a connection between problems and current situations or careers available in the local community. This classroom activity promotes students' appropriation of knowledges in STEM subjects –Science, Technology, Engineering, and Mathematics, in an integrated way. Students are also encouraged to creatively think and design an appropriate problem-solving strategy (Trueman, 2014).

Asunda and Mativa (2016) pointed out that STEM educational approach can promote deep understanding and learning retention. They added that this can be done through integrating Wiggins and Mctighe's backward process for designing courses and content units. This process primarily has teachers consider the learning goals as the first step. These learning goals embody the knowledge and skills they want their students to have constructed when leaving the course. Once the learning goals have been established, the next stage is consideration of assessment and instruction around the grounded learning outcomes (Wiggins & McTighe, 2005). However, it is important to note that to successfully reach the main goal of STEM education, teachers should have a complete understanding on the concept of STEM education, and accurate and appropriate ways of integrating STEM in classrooms (English, 2016; Sahin, 2015; Pitt, 2009).

According to the related literature, this approach engages learners in applying knowledge to solving problems in daily life and finding new processes or solutions to benefit their lives and occupations through project-based and problem-based learning activities. Students can develop their knowledge and skills through activities. These STEM based activities provide them with the opportunity to apply knowledge via the process to solve real life problems, and finally achieve solutions or the ability to bring innovation and competence into professions as a result.

2.2 Assessments in STEM Education

As stated earlier, the notion of STEM education relies on the real-world context-based inquiry (Brown, Ernst, Clark, Deluca, & Kelly, 2017). Therefore, learning assessment in the idea of STEM education relates to the authentic assessment through formative approach. The idea of formative assessment mainly refers to monitoring students during the learning process in order to provide them with ongoing feedbacks. Due to this ongoing process, students can identify their strengths and weaknesses that are needed to be improved.

To achieve the main goal of the formative authentic assessment in STEM education, teachers needed to have effective and reliable tools for performing an assessment (Saxton, Burns, Holveck, Kelley, Prince, Rigelman, & Skinner, 2014, p. 19). Moreover, the tools need to be relevant to and support the expected learning outcomes. Importantly, the assessment should focus on learners' ability in applying knowledge and skills such as establishing a hypothesis, solving problems in a new situation, and so forth. Nadelson and Seifert (2017, p. 223) additionally asserted that the assessment should also emphasize learners' abilities in integrating various disciplines for solving a problem or overcoming an obstacle. In this way, the assessment should rely on the aspect of accuracy and appropriateness of students' process of knowledge application (Nadelson & Seifert, 2017, p. 223).

Based on the idea of assessment in the STEM education, this study adopted the idea of authentic formative assessment for grounding good practices for STEM based learning management and assessment. The idea of this assessment approach was regarded as useful for monitoring learners' developmental process. Moreover, it can be used to modify teaching and learning activities to improve learners' attainment as well as to enhance quality of classroom management following the notion of STEM in the Thai context.

2.3 The Notion of Good Practices

The notion of good practices for learning management and learning assessment in STEM education refers to an establishment of a good practical strategy or model for learning management that can produce good results in terms of developing learners' knowledges, performances, skills, and desirable characteristics. To establish the good practices, this study adopted the concept of Third space. Third space is the in-between, or hybrid space where the first and second spaces work together to generate a new third space (Bhabha, 1990, 1994). In other words, it is a conclusion of studying two particular groups that are different or similar in order to create a new idea. The process of creating the third space can be done through a creative and rational discussion with the purpose of finding facts and/or making a conclusion (Engeström, n.d. as cited in Naudé, 2013, p. 66; Soja, 1996; Flessner, 2014, p. 232).

Based on the concept of Third space, in this study the researchers collected data on how teachers, who came from eight different STEM education centers in Thailand, performed their STEM based teaching. The data was collected though interview, focus group, and observations during the teaching-learning process. After gaining the data, the researchers conduct an analysis ana synthesis through looking at connections and conflicts between the process and outcomes. To achieve this, the researchers analyzed content validity of the data in order to identify model of the good practices that can enhance the quality of Thai education as a result.

2.4 Research Objectives

This study focused on establishing good practices for STEM based learning management and assessment for teachers in the secondary schools. Hence, the researchers generated two research objectives: to investigate the implementation of STEM education in learning management of teachers in the eight STEM education centers in Thailand, and to investigate their implementations of learning assessments in the classrooms.

3. Methodology

This research analyzed data collected from 8 of 13 STEM education centers in Thailand. These centers were purposively selected on the grounds that they had necessary knowledge and experience of the topic on STEM education, had the capability to reflect and articulate their views and were keen and consented to participate in this study.

In order to capture the best possible picture of STEM education practices of teachers in the centers, the research instruments were principally based on the interaction between the researchers and the participants. Thus, the research instruments used to collect data were interviews, focus group, and observations. The instruments were tested content validity index (CVI) by five experts in the field of STEM education, measurement and evaluation, curriculum and instruction, and research and development. The I–CVI was between 0.91 to 1.00 and S–CVI was between .90 to .95. According to Lynn (1986) and Aljojo, Adams, Alkhouli, Fitch, & Saifuddin (2009), this CVI value indicated that the instruments can be used to collect data in this study. After data collection, the researchers conducted an analysis in order to finalize the research findings.

Figure 1. Performing interviews, focus-group, and observation with the participants

4. Result

4.1 Good Practices for Learning Management in Thailand

As pointed out earlier, the researchers conducted interviews, focus group with the participants from eight STEM centers in Thailand, and performed observations during the teaching-learning process. The findings of this study have been divided into two parts: Good practices for learning management, and good practices for learning assessment.

The findings showed that the good practices for STEM based learning management can be in the form of 5E's of inquiry-based learning and engineering design process. The results suggested that these forms of teaching practice should be designed with the role of a teacher as a coach who provides learners with advice during the learning process. Moreover, the teaching and learning in the classroom should allow learners to realize the learning objectives and encourage them to see the connection between knowledges and their real lives. To achieve this, teachers can adopt active classroom activities or challenging project-based activities in order to motivate and engage learners in the process of thinking. The findings also indicated that the activities under the idea of STEM education should focus on developing learners' soft skills of the 21st Century through classroom activates. These activities should be designed to stimulate learners' creative thinking, collaboration skills, communicative skills in speaking and writing, and construction of knowledge in terms of making connection between the four disciplines in STEM education and real-world situations or relevant careers. These activities can promote learners' problem-solving in a complex situation, analytical and systematic thinking, critical thinking and questioning, and engineering system thinking. The research findings pointed out that to promote these skills, teachers can adopt active learning methods that engage learners in active interaction, and authentic problems.

In addition, to encourage learners' knowledge construction in terms of making connection between the four disciplines in STEM education and real-world situations, teachers can design their learning lessons that are in line with the context of schools and local communities. Moreover, teachers should consider the complexity of problem-solving activities, and how they relate to learners' real lives. Teachers also need to establish conditions for the activities or tasks that can stimulate learners' high order thinking skills such as critical and analytical thinking, logical thinking. These kinds of activity can challenge learners to articulate their problem-solving process as well as develop the skills of 4Cs and 8Cs.

The results also showed that curricula that are designed to be relevant to the school contexts, or local communities with an integration of the four disciplines of STEM education is a good start for shifting from the traditional education to the STEM. The integration in a curriculum can be done through multidisciplinary because it allows learners to study a topic or a theme from the viewpoint of more than one discipline (science, technology, engineering, and mathematics) and solving a problem using a different disciplinary approach. In so doing, learners are stimulated to see the connection between different subjects of the respective curriculum. This way can help develop learners' knowledge about a certain discipline that can engender in their capacity to analyze knowledge/information and apply it to real life cases. The results also pointed out that this way of learning management can influence learners to construct practical experiences that promote their responsibility in self-directed learning, adjustments, confidence in expressing opinions and thoughts in logical ways, and communication. Importantly, learners eventually recognize the advantages and values of knowledge and development as well as have a positive attitude.

The results added that a good practice for learning management according to STAM education particularly in Thai context should relate to the concept of STAR STEM. Therefore, teachers and or educators need to have a clear understanding of the role of STAR STEMS in order to designing an effective STEM based curriculum that is appropriate to the Thai context. The idea of STAR refers to four elements. First is the role of "Student" who is good, discipline, and proud of being a Thai citizen. Second is the role of "Teacher" who encourages learners to think, to be creative as well as the role of teacher as an advisor, and a supervisor. Third is the "Academic" role that concerns integrating the development of learners' knowledge on different subject matters and the desired characteristics. The last element is "Revolution" which refers to the importance of adjustment, immediate adaptation to changing environment or circumstances. Particularly, the concept of STAR STEMS also indicates four important aspects for teachers and/or educators to include when designing their learning managements. The first aspect concerns "Situation-Based Learning" (SBL) that is designed to include the aspect of morality in Thai ways. The second aspect is "Thai-Technology" that concerns the King's philosophy and Thai local wisdom. The third aspect relates to "English-Engineering" that refers to efficiency, system, and communication in English. The fourth aspect includes "Moral-Mathematics" that relates to the notion of logical proof and morality. The fourth aspect concerns "Socio Geology" that refers to the connection between knowledge and social geography. These aspects are considered to be important for developing the quality of Thai education and building an effective human resource for the 21st era.

4.2 Good Practices for Learning Assessments in Thailand

As the main aim of STEM education is to engage learners in applying knowledge to solve problems in daily life, the findings suggested that teachers should adopt authentic assessment that focuses on assessing knowledge procedure and attribute. In light of assessing knowledge, the criteria should include the aspects of comprehension of a particular knowledge, and ability of conveying knowledge through explanation. In order to design an effective assessment of learners' knowledge for STEM education, teachers should have clear assessment objectives, valid assessment tools, and reflective practice of learners or teacher' feedback on what students have learned, what they should improve, and so on. Additionally, the findings also added that learners should also take part in reflecting their learning process through giving feedback on what they have learned, what should be included in the lessons, what should be improved.

In terms of attribute, the criteria should relate to learners' behaviors. This area of assessment should be designed based on the desired characteristics, that was established by the Ministry of Education in Thailand, namely diligence, frugality, honesty, discipline, politeness, cleanliness, unity, and generosity. To gather information and to make judgements about what students do in relation to the outcomes, teachers can conduct the assessment through observations with scoring rubric and or rating scale. For example, teachers can use 3, 4 or 5 measurement scales and detailed description of the characteristics for each level.

Lastly, the results showed that the learning assessments can include learners' reflections. To gain this information, teachers can use survey forms on students' opinion or satisfaction towards the teaching-learning activities. The data gained from the survey can be used to improve the learning management.

5. Discussion

Discussion of the study has been divided into two sections: Guidelines for STEM based learning management, and Guidelines for STEM based learning assessment.

5.1 Guidelines for STEM Based Learning Management

As the findings of the study suggested, the implementation of 5E's of inquiry-based learning in managing teaching and learning based on the notion of STEM education is good practices in STEM instruction. These findings are in line with the ideas of McCullar (2015) and Stump, Bryan, and McConnell (2016). They supported that the concept of 5E's can be used to manage teaching and learning in STEM education because it leads learners through the active process of knowledge inquiry including engage, explore, explain, elaborate, and evaluate. The 5E's model brings coherence and connections between educational activities, and helps teachers make decisions on supportive interactions with students. The study of Ceylan and Ozdilek (2015) supported this point. They adopted 5E's instruction model to design teaching-learning management in STEM education and found that after students participated in the 5E's learning activities, their academic achievements were improved (Ceylan & Ozdilek, 2015).

The effective implementation of STEM education also relies on the use of relevant technology and engineering design process for planning problem-solving activities. Moreover, teachers can adopt the concept of interdisciplinary or transdisciplinary in designing teaching-learning activities. These concepts can help create a holistic and practical learning environment. It is also worth noting that when designing teaching-learning activities, teachers should establish clear steps within the process. Moreover, the steps should be dynamic. Billiar, Hubelbank, Oliva, and Camesano (2014) supported this point. They argued that the dynamic steps within a teaching-learning process can encourage learners to investigate problems of a case, establish objectives or goals to be achieved, examine the best process or strategy for solving the problem, and presenting the results or outcomes, and reviewing and improving their performances (Billiar, Hubelbank, Oliva, & Camesano, 2014; Boonphadung, 2018).

5.2 Guidelines for STEM Based Learning Assessment

Good practices for STEM based learning assessments should concerns the aspects of KPA which refers to Knowledge (K), Procedure (P), and Attribute/Attitude (A). The assessment should also include feedbacks after each teaching-learning activity. In this way, teachers should allow their learners to perform learning reflection. Importantly, teachers should have a clear objective of the assessment, and assessment tools. These results are in agreement with Intalapaporn et al. (2015)'s argument which pointed out that teachers should allow their learners to perform a task in group in order to encourage them to exchange ideas and provide feedbacks for their peers. Moreover, teachers should also provide students with feedback on their performances as a way to recheck learners' understanding on a particular topic or learning lesson (Intalapaporn, Patphol, Wongyai, & Pumsa–ard, 2015).

Authentic assessment was found to be one of the good practices for STEM based learning assessment. This assessment can identify learners' abilities in knowledge application within an interdisciplinary context or any conditions of integration (Bicer, Capraro, & Capraro, 2017). This idea has also been supported by Nadelson and Seifert (2017) as they proposed that learning assessments in STEM education should not only emphasize learners' knowledges but also learners' abilities in knowledge application in real cases.

Furthermore, good practices for learning assessment according to STEM should include the assessment of the levels of a learner's knowledge. The result of this assessment can be used by the teacher to plan appropriate teaching-learning activities for enhancing the levels of learners' knowledge. To do this, teachers can apply Bloom's perspective on assessment methods as a framework. This perspective offers clear measurement levels that can be adapted to be used in learning assessment of STEM education.

6. Conclusion

Good practices for STEM based learning management and assessment for secondary education classroom can be pointedly summarized in a diagram as follow.

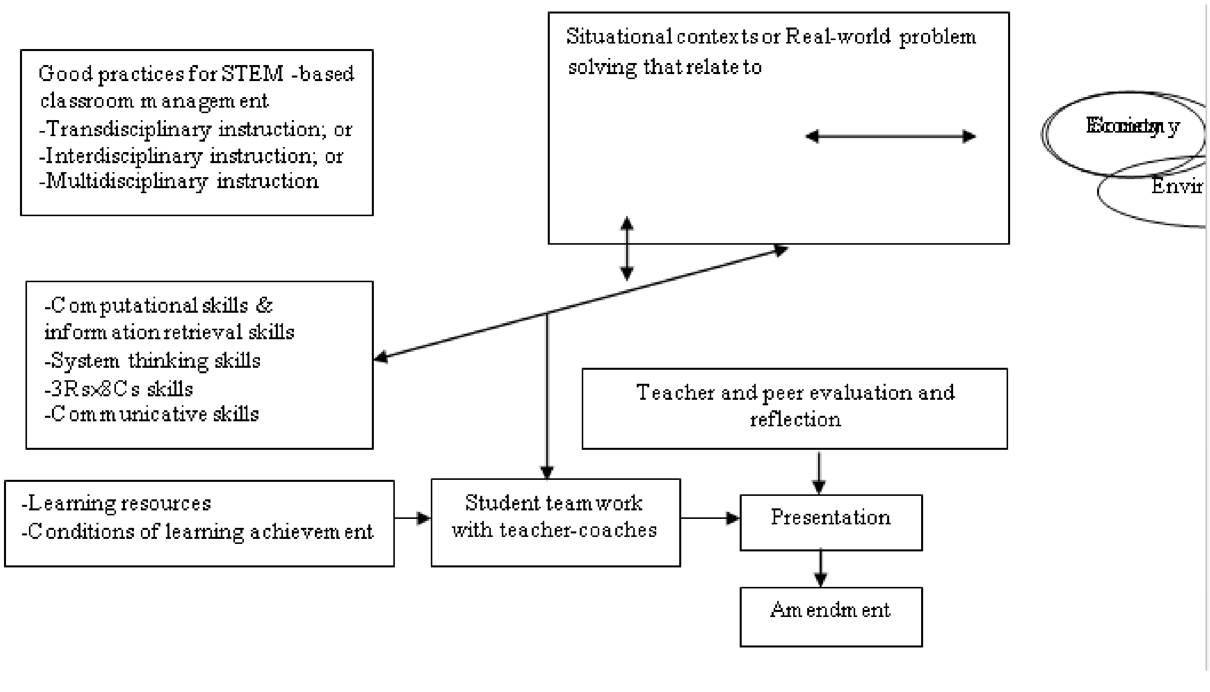

Figure 2. A summary of good practices for STEM based learning management and assessment

Figure 2 shows a summary of good practices for STEM based learning management and assessment for secondary education classrooms in the context of Thailand. Teachers of the secondary level education can adopt the concept of transdisciplinary, interdisciplinary, or multidisciplinary instruction for designing STEM based learning management of a particular subject. In this way, the teacher can design an activity that encourages his/her learners to apply mathematic or technological knowledge for solving a problem. Particularly, the case of problem should relate to the real-world or local situations of economy, society, and environment. The activity should stimulate learners to implement the skills of computation, information retrieval, system thinking, 3R×8C, and communication during the problem-solving or the learning process. In the activity, learners work as a group and are provided with necessary learning resources and conditions of learning achievement such as time frame, tools, budget, or breakeven point. After conducting the problem solving, the teacher allows learners to perform a presentation, answer questions, and receive teacher and peer feedbacks. The feedback should focus on useful advice for learners to improve their problem-solving practices.

The contribution that this study has made is to make transparent the process of bringing in the idea of STEM based learning management and assessment in the Thai context. Although the study was conducted with a small group of participants, the researchers attempted to show the reality of the process by collecting data from teachers in the STEM centers through in-depth interviews, focus group, and observations of the actual teaching-learning process. The findings of this study have shown how the teaching-learning activity was managed and how the assessment was conducted. The researchers believe that the focus of making visible the process of learning management and assessment with the notion of STEM education can inform the organization and planning of successful ways to develop the education system in the Thai context.

7. Recommendation

Since the notion of STEM education appears to be new in the Thai context, the researchers realized that in reality it tends to be difficult to bring in the system or approach, or at least it is difficult to implement it in the same way as it is suggested in the books. Therefore, it is necessary to educate and train teachers the new idea of teaching and learning through workshops or seminars that allow teachers and experts to exchange knowledge and experiences regarding STEM education.

Acknowledgment

This research was supported and granted by National Research Council of Thailand (NRCT) and Suan Sunandha Rajabhat University, Bangkok, Thailand.

References

1. Aljojo, N., Adams, C., Alkhouli, A., Fitch, T., & Saifuddin, H. (2009). A study of the reliability and validity of the Felder-Soloman index of learning styles in Arabic. In 8 th European Conference on e-Learning (ECEL), University of Bari, Italy.
2. Asunda, P. A., & Mativo, J. (2016). Integrated STEM: A new primer for teaching technology education. Technology and Engineering Teacher, 75(4), 8–13.
3. Bhabha, H. K. (1990). The third space: Interview with Homi Bhabha. In J. Rutherford (Ed.), Identity, community, culture, difference. London: Lawrence & Wishart, 207–221.
4. Bhabha, H. K. (1994). The location of culture. London: Routledge.
5. Bicer, A., Capraro, R. M., & Capraro, M. M. (2017). Integrated STEM assessment model. EURASIA Journal of Mathematics, Science and Technology Education, 13(7), 3959–3968.
6. Billiar, K., Hubelbank, J., Oliva, T., & Camesano, T. (2014). Teaching STEM by design. Advances in Engineering Education, 4(1), 1–21.
7. Boonphadung, S. (2018). The development of learning model for enhancing critical thinking ability in mathematics of junior high school students. Humanities and Social Sciences Journal of Graduate School, Pibulsongkram Rajabhat University, 12(1), 218–236.
8. Brown, R., Ernst, J., Clark, A., DeLuca, B., & Kelly, D. (2017). STEM curricula. Technology and Engineering Teacher, 77(1), 26–29.
9. Capraro, R. M., & Corlu, M. S. (2013). Changing views on assessment for STEM project-based learning. In Capraro, R. M., Capraro, M. M., & Morgan, J. R. (Ed.), STEM Project-Based Learning, (pp. 109–118). The Netherlands: Sense Publishers, pp. 109–118.
10. Ceylan, S., & Ozdilex, A. (2015). Improving a sample plan for secondary science course. Procedia–Social and Behavioral Science, 177, 223–228. Retrieved from http://doi:org10.1016/ j.sbspro.2015.02.395.
11. Daml, M. (2017). Using community events to enliven STEM education. Teaching Children Mathematics, 23(6), 376–379.

12. Dejarnette, N. K. (2016). America's children: Providing early exposure to STEM (Science, Technology, Engineering and Math) initiatives. Reading Improvement, 53(4), 181–187.
13. English, L. D. (2016). STEM education K–12: Perspectives on integration. English International Journal of STEM Education, 3(3), 1–8.
14. Flessner, R. (2014). Revisiting reflection: Utilizing third spaces in teacher education. The Educational Forum, 78(3), 231–247.
15. Han, S., Capraro, R., & Capraro, M. M. (2015). How science, technology, engineering, and mathematics (STEM) project-based learning (PBL) affecting high, middle, and low achievers differently: The impact of student factors on achievement. International Journal of Science and Mathematics Education, 13(5), 1089–1113.
16. Intalapaporn, C., Patphol, M., Wongyai, W., & Pumsa-ard, S. (2015). The study guidelines for learning management of the STEM education for elementary students. Veridian E-Journal, Silpakorn University, 8(1), 62–74.
17. Israel, M., Maynard, K., & Williamson, P. (2013). Promoting literacy-embedded, authentic STEM instruction for students with disabilities and other struggling learners. Teaching Exceptional Children, 45(4), 18–25.
18. Jolly, A. (2017). STEM by design: Strategies and Activities for Grades 4–8. New York: Routledge.
19. Kilenthong, W. (2017). Situation of Thai's education in year 2013/2014: The need of competition and the decentralization of the Thai education system, Office of the education council. Bangkok: Century Co.
20. Lawrenz, F. P., & Huffman, D. (2006). Methodological pluralism: The gold standard of STEM evaluation. In D. Huffman, & F. P. Lawrenz (Eds.), Critical issues in STEM education evaluation (pp. 19–34). (New Directions for Evaluation, No.109), San Francisco, CA: Jossey-Bass.
21. Linn, R. L., & Miller, M. D. (2005). Measurement and assessment in teaching (9th Edition). Upper Saddle River, N.J.: Prentice Hall.
22. Lynn, M. R. (1986). Determination and quantification of content validity. Nursing Research, 36(6), 382–385.
23. McCullar, H. (2015). Am I really teaching engineering to elementary students? Lessons from an environmental engineering summer camp for first and second graders. Science and Children, 52(7), 80–84.
24. McDonald, C. V. (2016). STEM education: A review of the contribution of the disciplines of science, technology, engineering and mathematics. Science Education International, 27(4), 530–569.
25. Moore, T. J., & Smith, K. A. (2014). Advancing the state of the art of STEM integration. Journal of STEM Education: Innovations and Research, 15(1), 5–10.
26. Moore, T. J., Johnson, C. C., Erin E. P-B., & Guzey, S. S. (2016). The need for a STEM road map. In STEM road map: A framework for integrated STEM education, edited by, Carla C. Johnson, Erin E. Peter-Burson, and Tamara J. Moore, 3–12. New York: Routledge.
27. Morrison, J. S. (2006). TIES STEM education monograph series: Attributes of STEM education. Retrieved from http://daytonos.com/pdf/stem.pdf.
28. Nadelson, L. S., & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. The Journal of Educational Research, 110 (3), 221–223.
29. Naudé, L. (2013). Boundaries between knowledges: does recognition of prior learning assessment represent a third space? International journal of continuing education and lifelong learning, 5(2), 57–70.
30. Office of the Education Council. (2014). Situation of Thai's Education on the World Stage in Year 2014. Bangkok: Prigwan Graphics Co., Ltd.
31. Pearson, G. (2017). National academies piece on integrated STEM. The Journal of Educational Research, 110(3), 224–226.
32. Pitt, J. (2009). Blurring the boundaries- STEM education and education for sustainable development. Design and Technology Education: An International journal, 14(1), 37–48.
33. Potter, B. S., Ernst, J. V., & Glennie, E. J. (2017). Performance-based assessment in the secondary STEM classroom. Technology and Engineering Teacher, 76(6), 18–22.
34. Psycharis, S. (2016). The impact of computational experiment and formative assessment in inquiry-based teaching and learning approach in STEM education. Journal of Science Education & Technology, 25(2), 316–326.
35. Sahin, A. (2015). A practice-based model of STEM teaching. Sense Publishers: The Netherlands.
36. Sanders, M. (2009). STEM, STEM education, STEMmania. The Technology Teacher, 68(4), 20–26.
37. Saxton, E., Burns, R., Holveck, S., Kelley, S., Prince, D., Rigelman, N., & Skinner, E. A. (2014). A common measurement system for K-12 STEM education: Adopting an educational evaluation methodology that elevates theoretical foundations and systems thinking. Studies in Educational Evaluation, 40, 18–35.

38. Schwab, K. (2015). The global competitiveness report, 2015-2016. Retrieved from http://www3.weforum.org/docs/gcr/2015–2016/GlobalCompetitiveness Report 2015–2016.pdf.
39. Soja, E. W. (1996). Third space: Journeys to Los Angeles and other real and imagined. Places Oxford: Blackwell.
40. Srinath, A. (2014). Active learning strategies: An illustrative approach to bring out better learning outcomes from science, technology, engineering and mathematics (STEM) students. International Journal of Emerging Technologies in Learning, 9(9), 21–25.
41. Stump, S. L., Bryan, J. A., & McConnell, T. J. (2016). Making STEM connections. Mathematics Teacher, 109(8), 576–583.
42. The Institute for the Promotion of Science and Technology. (2017). The summary of research about PISA in year 2015. Retrieved from https://drive.google.com/file/d/0BwqFSkq5b7zScUJOOV9ldUNfTlk/view.
43. The Institute for the Promotion of Teaching Science and Technology. (2014). Handbook for STEM education network. Bangkok: National STEM Education Center.
44. The National Science Teachers Association. (2016). A societal perspective for STEM. NSTA Press: The BSCS 5E Instructional Model: Creating Teachable Moments.
45. Trueman, R. J. (2014). Productive failure in STEM education. Journal of Educational Technology Systems, 42(3), 199–214.
46. Vasquez, J. A., Sneider, C., & Comer, M. (2013). STEM lesson essentials, grades 3–8: Integrating science, technology, engineering, and mathematics. Portsmouth NH: Heinemann.
47. Wiggins, G. & McTighe, J. (2005). Understanding by design. Alexandria, VA: ASCD.
48. Wilhelm, J. (2014). Project-based instruction with future STEM educators: An interdisciplinary approach. Journal of College Science Teaching, 43(4), 80–90