# A Systematic Review: Issues in Implementation of Integrated STEM Education

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**Abstract**: The current trends require STEM education to integrate the four disciplines (science, technology, engineering and mathematics) into a mega discipline. However, implementing integrated STEM education is not an easy task as many issues arise following its implementation. Therefore, a systematic review was conducted to gather evidence from the latest empirical studies to discover the core issues related to integrated STEM education. PRISMA guideline was used to trace the relevant article from the year 2010 until the year 2019 using databases of Wiley, Scopus and Google Scholar. Hence, a total of 17 articles were identified. Findings showed that teacher is the core issue. It implies that the teacher is the most important element in the pursuit of integrated STEM education.

**Keywords**: Integrated STEM, Issue, Science, Teacher

## 1. Introduction

The current situation all over the world emphasizes the aspect of sustainability. This can be seen from the aspect of the existence of the sustainable development goals (SDG). Therefore, STEM education is important. The concept of integrated STEM has emerged as one of the core topics in education. Seminal scholars are focused on integrating the concept of engineering and technology design into the teaching and learning of Science / Mathematics (Bybee 2010). While other scholars mentioned it as an effort to combine the whole or part of the STEM disciplines into a single class, unit or lesson that relates to a subject with the real life (Moore et al. 2014). In addition, Kelly and Knowles (2016) stated that STEM is a teaching approach involving two or more STEM components in an authentic context, which leads to increased student learning. Although there is no consensus agreement on the meaning of integrated STEM education, majority of scholar stated that integrated STEM education is the combination of STEM components related to real life. Since then, a lot of initiatives for integrated STEM education have been launched not only in western countries but all over the world (Kang 2019; MOE 2013; NGSS Lead States 2013). To improve integrated STEM education, Next Generation Science Standards (NGSS) is introduced in the United State. Engineering and technology are incorporated into K-12 science education. Meanwhile, in other developing countries such as South Korea and Malaysia, different initiative is introduced. The element of arts is added as a new feature in South Korea as a school program. This program is utilised whether in or out of school. Besides, STEM education has been crafted in Malaysia Education Blueprint 2013-2025. This initiative is used as a roadmap for strengthening the STEM delivery education system in Malaysia through three waves (Rasid et al. 2020). Wave 1 (2013-2015) is specially made for building momentum and foundations. Wave 2 (2016-2020) is focusing on accelerating the system, whereas the third wave (2021-2025) is more on operational flexibility.

So far, researchers discovered that integrated STEM education can benefit the students, future teachers, economy and quality of life. For students, integrated STEM education increases their interest as well as enhance their motivation, skill, critical thinking and knowledge in science subjects (Akyildiz 2014; Baker & Galanti 2017; Kelley & Knowles 2016). Meanwhile, meta-analysis study by Wohono et al. (2020) also revealed a moderate level for STEM enactments and students learning outcome in Asia countries. Shahril (2018) mentioned that integrated STEM also gives a positive impact on future teachers' preparation process. Moreover, according to Kasza and Slater (2017), STEM can enhance imagination, hands-on skills, observation skills, design skills, engineering skills and high-level thinking skills for future teachers. Apart from that, integrated STEM education also drives economic development and improves the quality of life through STEM field job of STEM creation and innovation (Langdon et al. 2011).

As for Systematic Literature Review (SLR) on integrated STEM, only three studies were available namely that conducted by Thibaut et al. (2018), Kang et al. (2019) and Margot and Kettler (2019). The study by Thibaut et al. (2018) reviewed and constructed the instructional practices in integrated STEM. Their finding showed five categories of instructional practices. The first category is the integration of STEM content and the second category is problem-cantered learning. Meanwhile, inquiry-based learning is in the third category and the other two categories were design-based learning and cooperative learning. All five categories are rooted in a social constructivist theory. Furthermore, a study from Kang et al. (2019) focused on the effects of integrated STEM (STEAM education) on teaching and learning in South Korea. Their study revealed that STEAM initiative increased teacher's confidence level in their teaching and learning. Margot and Kettler (2019) studied teachers' perceptions and STEM talent. Two interesting findings were revealed by Margot and Kettler (2019). Firstly, teachers valued the implementation of integrated STEM education. Secondly, the teachers also reported six barriers faced namely pedagogy, curriculum, structural, students, assessments and support.

Although ample studies have been found to support the implementation of integrated STEM education, it is yet unclear why the implementation of integrated STEM is still unsuccessful. Therefore, this study examines the existing literature on the issues in integrated STEM education. This study attempts to understand the core issues in implementing integrated STEM education. Thus, the following questions were used to examine the issues that exist in the literature: 1) Is there any issue in implementing integrated STEM education? and 2) What is the core issue in implementing integrated STEM education?

## 2. Method

This systematic literature review utilised the PRISMA guidelines as indicated in Fig. 1. This systematic review processes involved three steps that started with identification, screening, eligibility and inclusion.

### 2.1 Identification

In the identification process, databases of *Scopus, Wiley and Google Scholar* were used to search relevant articles. To do so, three steps were practiced, as follow: (i) Boolean search "+, -, AND NOT" was used (ii) specific keyword terms and their variants were used including *integrated STEM, STEM education, STEM, issue* and (iii) references were used to track other suitable articles for this study. After the initial process, the result yielded a total of 316 articles from *Scopus,* 701 from *Wiley and 1*671 from *Google Scholar.* In the meantime, an additional 500 studies were identified following manual searches using the reference lists of the recovered articles to locate other related articles that might have been omitted during the database search. However, 1208 duplicate studies were removed, leaving a total of 1480 articles retrieved.

### 2.2 Screening

The second stage continued with the screening process based on a set of criteria shown in Table 1. This study included the publication timeline between the year 2010 until the year 2019. Only article journal and dissertation thesis that used the English language were included, which focus on issues in integrated STEM education. For the first screening process, from 1480 articles, 825 articles were excluded.

**Table 1**. Screening process

| Criteria | Inclusion | Exclusion |
|---|---|---|
| Publication timeline | 2010-2019 | 2009 and before |
| Document type | Article and dissertation thesis | Conference proceeding, chapters in book, book series, books etc. |
| Language | English | Non-English |
| Nature of the study | Focus on issue in integrated STEM education | Not focus issue in integrated STEM education |

### 2.3 Eligibility and Inclusion

After the first screening, only 655 of them were eligible. However, before the articles were reviewed, the second screening was carried out by checking the quality of articles. Criteria quality assessment of articles adapted from Mc Dermott et al. (2004) were used as shown in Table 2. The articles were graded into four types namely A, B, C and D (see Table 3). After a careful selection practice, 637 articles were excluded and only grade A (18 articles) articles were included in this systematic review as indicated in Fig.1.

**Table 2**. The criteria quality assessment of articles

| No | Criteria | Descriptions |
|---|---|---|
| 1 | Goals and objectives | Does the article clearly state the goals and objectives? |
| 2 | Study context | Does the article clearly explain how the study involved planning, implementation and conducted development? |
| 3 | Sample | Does the article provide a sufficient sample of research? |
| 4 | Methodology | Does the article provide a research methodology description that includes frameworks, data collection and data analysis for the study? |
| 5 | Data | Is support such as schedule, interview/focus and feedback from observations included? Is the information clearly translated and analysed? |
| 6 | The results of the study are validated | Does the researcher verify the study analysis using expert review, feedback or other mechanisms? |

Adapted from Mc Dermott et al. (2004)

**Table 3**. Grading of the article

| Grade | Description |
|---|---|
| A | The six criteria were qualified |
| B | Approximately five designated criteria qualified |
| C | Four criteria qualified |
| D | Qualified with just three criteria |

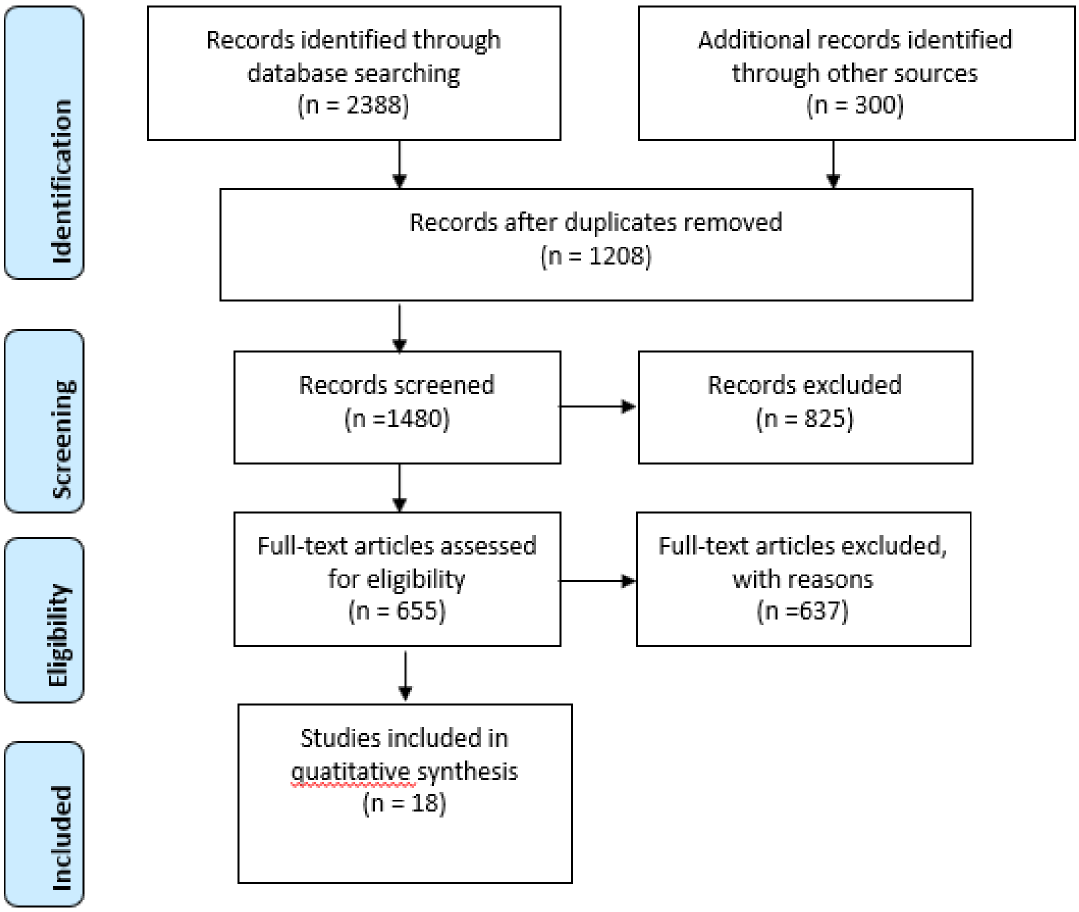


**Fig. 1.** A flow diagram illustrating study selection process (adapted from PRISMA diagram—Moher et al., 2009)

## 3. Results and Discussion

To answer the two objectives, all the findings were analysed and synthesised into tables (Table 4, Table 5 and Table 6) and figures (Figure 2 and Figure 3). Table 4 shows the summary of the included articles based on name of researcher, year of publication and findings.

**Table 4.** Summary of included articles

| Researcher | Year | Findings |
|---|---|---|
| Capobianco | 2010 | -Teachers' confidence level in implementing integrated STEM teacher was low due to lack of knowledge and skill. |
| Wang | 2011 | - Teachers reported difficulty in integrating technology in integrated STEM lesson due to lack of technology resources.<br>- Teachers faced a pedagogical problem as well<br>- The lack of a good STEM curriculum was also a major challenge, as they do not see the connection between curriculum and co-curriculum |
| Stohlmann et al. | 2012 | -Often required a large number of materials and resources for students such as building tools, electronic materials and other design materials<br>- Teachers' self-efficacy and pedagogy |
| Ashgar et al. | 2012 | -The internal barriers related to teachers' beliefs, capacity, knowledge and skills.<br>- External systemic barriers to an integrative PBL approach between curriculum content and time, issues related to expensive, resource-intensive and insufficient educational materials. |
| Mc Mullin & Reeve | 2014 | - The barrier in implementing integrated STEM teaching included teacher preparation time, pedagogy, skills and resources. |
| Gresnight et al. | 2014 | - lack of time/space, obstacles in curricular<br>- lack of teacher pedagogy on integration<br>- self-efficacy of teachers was low<br>- assessment of integrated curricular became a problem |
| Coppola & Schnedeker | 2015 | -The barriers facing teachers were time, support and lack of training, materials/resources and administrative support. |
| El-Deghaidy & Mansour | 2015<br>2016 | -Self-efficacy of teachers and knowledge of STEM content were the issues in Saudi Arabia's implementation of STEM integration |
| Eckman et al. | 2016 | - Teachers must have profound knowledge of the content of science, technology, engineering and mathematics they teach |
| Ayres | 2016 | -Content knowledge and pedagogical shifted challenges for teachers, making the integrated STEM reform to become slow.<br>-teachers also lack confidence and willingness to teach integrated STEM due to lack of knowledge, skill, materials and resources |
| Guzey et al. | 2016 | - To implement integrated approaches and new curricular materials, teachers need opportunities to learn new knowledge and skills to implement an integrated program. |
| Nadelson & Seifert | 2017 | -Required a profound curriculum and lesson restructuring.<br>-Costly and time-consuming to create a school culture and environment that support an integrated STEM approach to teaching and learning<br>- Teacher STEM knowledge and professional mindset |
| Estapa & Tank | 2017 | - Teachers need support for the content of STEM disciplines as well as enactment pedagogy |
| Bahrum et al. | 2017 | -Changes in the curriculum (STEM) naturally affect teaching and learning and evaluation in national exams. |
| Shernoff et al. | 2017 | -Teacher STEM knowledge and professional mindset, skills, motivation, time, evaluation as well as insufficient resources and teaching material |
| Thibaut et al. | 2018 | -Lack of skills on how to integrate STEM teaching and learning |

| | | |
|---|---|---|
| Margot & Kettler | 2019 | - Barriers reported such as teaching challenges, curriculum challenges, structural challenges, teacher knowledge, assessment and time |

A total of 17 articles and one dissertation thesis were chosen for review. Based on Table 4, 60 findings were reported by 17 researchers. The findings differ between researchers such as curriculum, material and resources, teacher, assessment and time. Asghar, Ellington and Rice (2012), Gresnigt, Taconis, Van Keulen, Gravemeijer and Baartman (2014), Guzey, Moore and Harwell (2016), Nadelson and Seifert (2017) as well as Wang, Moore, Roehrig and Park (2011) cited the curriculum as one of the barriers to STEM integration. This barrier increases with curriculum changes (Guzey et al. 2016; Margot & Kettler 2019; Wang et al. 2011). This is because a link between curriculum and teaching is the main guide for teachers (Wang et al. 2011). One example of the barrier facing the teachers is how to integrate PBL approach between curriculum content. This becomes an external systemic barrier for them when implementing integrated STEM lessons (Asghar et al. 2012). Meanwhile, in primary education, Gresnigt et al. (2014) said they were concerned about curriculum goals. This is because curriculum changes (STEM) naturally affect teaching and learning and evaluation in national examinations (Bahrum, Wahid & Ibrahim 2017). As well known, the implementation of an integrated STEM approach in an educational system with a very well-established segregated and disciplinary structure requires a profound restructuring of curriculum and lessons (Nadelson & Seifert 2017). So, any curriculum changes affect not only the teacher's teaching but also the students' achievement.

### 3.1 Materials and Resources

Materials and resources are other issues that arise (Coppola & Schnedeker 2015; Shernoff, Sinha, Bressler & Ginsburg 2017). Integrated STEM education often requires numerous materials, resources and training for students like building tools, electronic materials, and other design materials (Coppola & Schnedeker 2015; Mcfadden & Roehrig 2017; Stohlmann, Moore & Roehrig 2012), but the cost of providing STEM teaching and learning materials and resources is expensive (Asghar et al. 2012). Lack of knowledge, skills, materials and resources (Coppola & Schnedeker 2015; Shernoff et al. 2017; Wang et al. 2011) makes teachers feel untrustworthy and unwilling to teach integrated STEM especially by integrating technology into STEM lessons (Ayres 2016). It is clear that among the key elements for ensuring the smooth implementation of STEM integration education are materials and resources. Lack of resources and materials as well as adequate training will affect STEM integration effectiveness.

### 3.4 Teacher

The finding showed that teacher is the core issue in implementing integrated STEM education (36/60%). Meanwhile, this study also revealed that teachers’ pedagogy (17/28%) is the main challenge for teachers.

#### 3.4.1 Teacher Understanding

In implementing integrated STEM lessons, there were only two articles that talked about the issue of teacher understanding. The findings are based on the results of several studies done in Arab Saudi (H. El-Deghaidy & Mansour 2016; Heba El-Deghaidy, Mansour, Alzaghibi & Alhammad 2017). Arab Saudi teachers do not have sufficient understanding of the T in STEM and may not have a sufficient understanding of the nature of science and technology as well as the interactions between these two disciplines. Research results also showed that their teachers were unprepared to implement integrated STEM for their lesson. Integrating T into the lesson was a challenge due to the lack of knowledge and technology skills among teachers.

#### 3.4.2 Teacher knowledge

Knowledge of teachers is the key to implementing integrated STEM education, but STEM teachers still lack knowledge of STEM content (H. El-Deghaidy & Mansour 2016; Heba El-Deghaidy et al. 2017; Margot & Kettler 2019; Nadelson & Seifert 2017; Shernoff et al. 2017). The STEM teachers urgently need to have in-depth knowledge of the content of science, technology, engineering and mathematics to ensure a successful implementation of integrated STEM (Eckman, Williams & Silver-thorn 2016). Without STEM knowledge, the integrated STEM reform will slow down (Ayres 2016). According to Guzey et al. (2016), teachers need opportunities to learn new knowledge and skills to implement an integrated program (Asghar et al., 2012; Heba El-Deghaidy et al., 2017; Stohlmann et al., 2012) employing integrated approaches and new curriculum materials. Therefore, to ensure the success of integrated STEM, the knowledge of STEM teachers must be enhanced.

#### 3.4.3 Teacher self-efficacy

The findings showed that one of the problems in implementing STEM integration is the self-efficacy of teachers (Asghar et al. 2012; Capobianco 2011; Heba El-Deghaidy et al. 2017; Gresnigt et al. 2014; Stohlmann et al. 2012).

According to Capobianco (2011) and Gresnigt et al. (2014), STEM teachers' low self-efficacy leads to less motivation and uncertainty in the education of STEM integration. Reports by H. El-Deghaidy & Mansour (2016) and Heba El-Deghaidy et al. (2017) demonstrated the same issue with STEM teachers in Saudi Arabia where weak self-efficacy was also linked to lack of self-esteem confidence and inadequate STEM content knowledge.

#### 3.4.4 Teacher pedagogy

Teacher pedagogy is the most widely reported issue by researchers. According to Margot and Kettler (2019), Stohlmann et al. (2012) and Wang et al. (2011), teachers have problems with pedagogy in implementing STEM integration. This problem is also related to self-efficacy of teachers, knowledge of STEM content, time, skills, curriculum and evaluation (Bahrum et al. 2017a; Guzey et al. 2016; Stohlmann et al. 2012; Thibaut et al. 2018). A change in the curriculum requires not only pedagogical changes but also the enhancement of skills, mindset and teacher knowledge (Eckman et al. 2016; Shernoff et al. 2017). This change also requires enough time to allow teachers to plan and select suitable approaches (Asghar et al. 2012). Lack of skills including effective pedagogy, in particular, will slow down the STEM reform (Ayres 2016).

### 3.5 Assessment

Assessment is another issue reported by researchers. Evaluation is needed as a guideline for their students to conduct an evaluation (Gresnigt et al. 2014; Margot & Kettler 2019; Shernoff et al. 2017). However, there is no such guideline available at the moment. Gresnigt et al. (2014) said that integrated curriculum assessment is becoming an issue for STEM teachers.

### 3.6 Time

Empirical study shows a lack of time to plan a lesson and teach an integrated STEM lesson among teachers (Asghar et al. 2012; Coppola & Schnedeker 2015; Gresnigt et al. 2014; Nadelson & Seifert 2017). This is because the current curricula and timetables lack time/space as well as teacher preparation time (Mc Mullin & Reeve 2014). The results of research by Asghar et al. (2012) also revealed that an integrative PBL approach between curriculum content and time has external systemic barriers.

This study also analysed the reported issues in detail as shown in Table 5. In this table, the reported issues are presented based on researcher reports.

**Table 5.** Number of reported issues based on researcher reports

| Number | Researcher | Number of reported issues/ (%) |
|---|---|---|
| 1 | Capobianco (2010) | 3(5%) |
| 2 | (Wang, 2011) | 6(5%) |
| 3 | (Stohlmann et al., 2012) | 4(7%) |
| 4 | (Asghar et al., 2012 | 6(10%) |
| 5 | (McMullin and Reeve 2014) | 2(3%) |
| 6 | Gresnight et al. 2014 | 7(12%) |
| 7 | (Coppola & Schnedeker, 2015) | 7(12%) |
| 8 | Eckman et al., 2016 | 2(3%) |
| 9 | (Ayres, 2016) | 6(10%) |
| 10 | (Guzey et al., 2016) | 3(5%) |
| 11 | (Nadelson & Seifert, 2017) | 8(13%) |
| 12 | (Estapa & Tank, 2017) | 6(10%) |
| 13 | (Bahrum, Wahid, & Ibrahim, 2017b) | 3(5%) |
| 14 | (Shernoff et al., 2017) | 9(15%) |
| 15 | (Thibaut et al., 2018) | 3(5%) |
| 16 | (Margot & Kettler, 2019) | 10(17%) |
| 17 | El-Deghaidy and Mansour (2015 & 2017) | 4(7%) |
| | Total | 60(100%) |

Based on Table 5, Margot and Kettler (2019) reported the highest issues (10/17%) about integrated STEM, followed by Shernoff et al. (2017) with 9/15% issues and Nadelson and Seifert (2017) with 8/13% issues. Meanwhile, Gresnigt et al. (2014), as well as Coppola and Schnedeker (2015), reported 7/12% issues each. Studies by Asghar et al. (2012), Ayres (2016), Estapa and Tank (2017) and Wang et al. (2011) also reported the same number of 6/10% reported issues. 4/7% reported issues were mentioned by El-Deghaidy and Mansour (2015 & 2017) and Stohlmann et al. (2012). Meanwhile, Bahrum et al. (2017), Capobianco (2011) and Guzey et al. (2016) reported 3/5% issues. The least of the reported problems was 2/3% reported by McMullin and Reeve (2014) and

Eckman et al. (2016). To make it clearer, the issues were clustered into eight main issues. The reported number and their percentages are shown in Fig. 2.

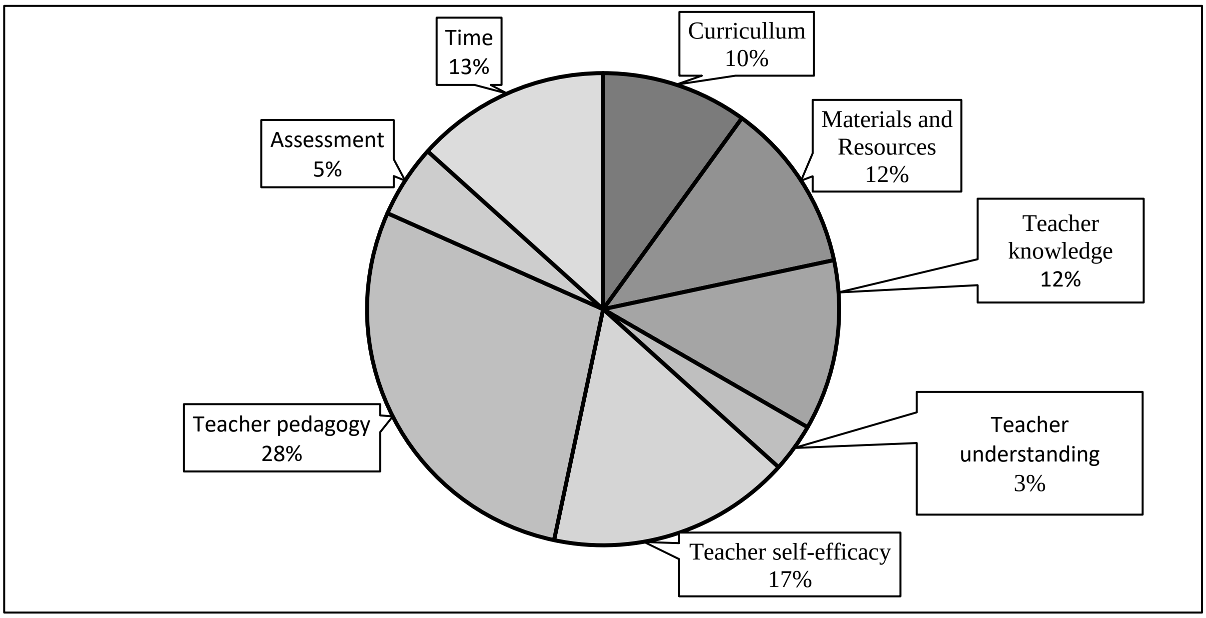


**Fig. 2.** Reported number of issues based on researcher

Based on Fig. 2, eight main issues constituted the implementation of STEM integration in education were reported by researchers namely curriculum (6/10%), materials and resources (7/12%), teacher knowledge (7/12%), teacher understanding (2/3%), teacher self-efficacy (10/17%), teacher pedagogy (17/28%), assessment (3/5%), as well as time (8/13%). The highest issue was teacher pedagogy and the lowest issue was assessment. Then, these issues were classified into five categories as shown in Table 7.

**Table 7**. Reported number category of issues

| Category of Issues | Reported number | Percentage |
|---|---|---|
| Curriculum | 6 | 10% |
| Materials and Resources | 7 | 12% |
| Teacher | 36 | 60% |
| Assessment | 3 | 5% |
| Time | 8 | 13% |
| Total | 60 | 100% |

Based on the results in Table 7, the eight issues were categorised into five categories namely curriculum, materials and resources, teacher assessment, as well as time. The analysis showed that the highest category of issue was teacher (36/60%). This study also analysed the frequency for the category of issues reported by researchers based on year as illustrated by the bar graph in Fig. 3.

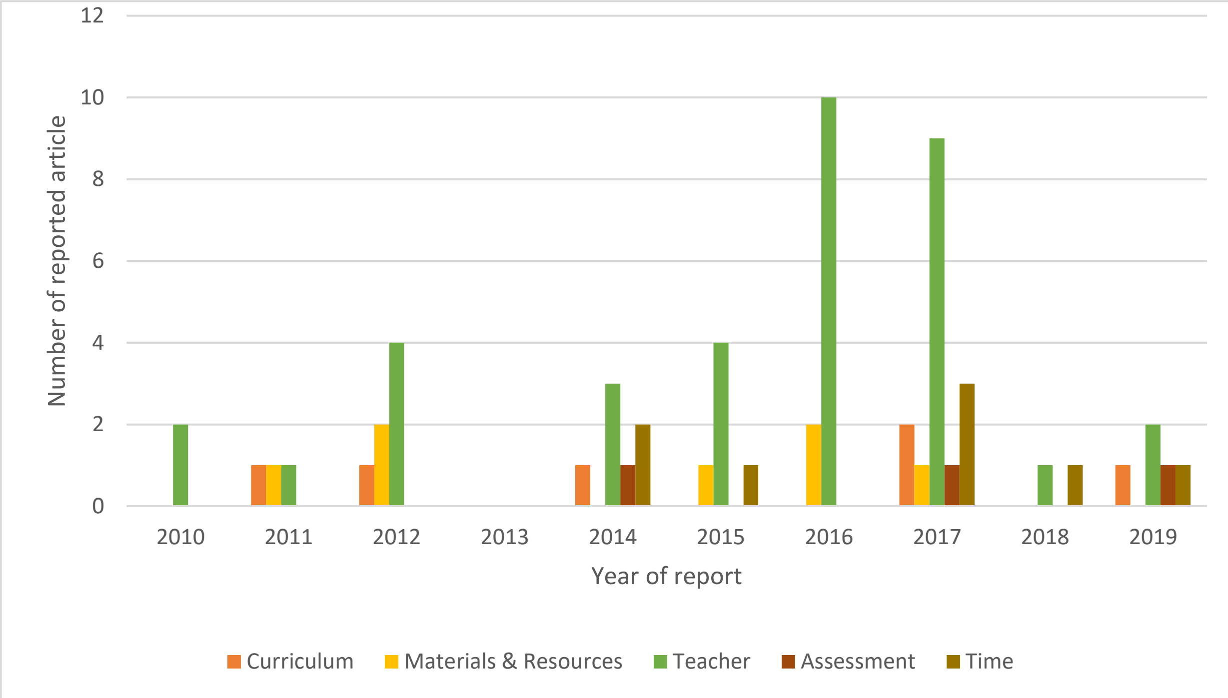


**Fig. 3.** Number of reported articles based on category

According to the graphs as shown in Fig. 3, the highest number of reports issues (16/27%) was in 2017, followed by 12 (20%) in 2016. The lowest report was in 2013 (0/0%). Details of the reported number of articles are shown in Table 6.

**Table 6.** Year of reported issues based on category

| Category | Year of report | | | | | | | | | | Num (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | |
| Curriculum | | 1 | 1 | | 1 | | | 2 | | 1 | 6(10%) |
| Materials and Resources | | 1 | 2 | | | 1 | 2 | 1 | | | 7(12%) |
| Teachers | | | | | | | | | | | |
| (a) | | | | | | | 5 | 2 | | | 7(12%) |
| (b) | | | | | | | | 2 | | | 2(3%) |
| (c) | 1 | | 2 | | 1 | 2 | 2 | 1 | | 1 | 10(17%) |
| (d) | 1 | 1 | 2 | | 2 | 2 | 3 | 4 | 1 | 1 | 17(28%) |
| Assessment | | | | | 1 | | | 1 | | 1 | 3(5%) |
| Time | | | | | 2 | 1 | | 3 | 1 | 1 | 8(13%) |
| Total | 2 | 3 | 7 | | 7 | 6 | 12 | 16 | 2 | 5 | 60(100%) |

(a)teacher understanding, (b)teacher knowledge, (c)teacher self-efficacy and (d)teacher pedagogy

Table 6 shows the years of reported issues based on category from the year 2010 until the year 2019. Based on the analysis in Table 6, the highest reported number for curriculum was in the year 2017 (2/3%). Meanwhile, for materials and resources, the highest reported number was in the year 2012 and 2016 (2/3%). For teacher and time category, the highest reported number for these two categories were in the year 2017 (9/15%) and (3/5%).

However, for the assessment category, the highest reported number was in the year 2014, 2017 and 2019 (1/2%). Analysis of the reported issues also showed the lowest reported number for curriculum, materials and resources, teacher and time, which was 1 (1/2%). The years reported for curriculum were 2011, 2012, 2014 and 2019. While for materials and resources, there were three years reported, which were 2011, 2015 and 2017. For teacher category, only two years (2011 and 2018) were reported with one issue.

## 4. Conclusion

It can be concluded that teacher is the core issue in the implementation of integrated STEM. Since STEM teachers are trained only based on their specific expertise or by specialised subjects (major, minor), this implies the limited knowledge of STEM disciplines beyond their expertise. However, to ensure the effectiveness of the STEM teaching process, skilled and knowledgeable teachers are required, in particular, to link different disciplines throughout the curriculum (Li, 2014). Teacher pedagogy is another important thing (Shernoff et al. 2017). Previous studies showed that less effective method of teaching was found as the cause of student interest in the phenomenon of deterioration. The learning process through STEM is not limited in the classroom alone but can also be linked to the real world as a major component of problem-solving (Baker & Galanti 2017; Howes, Kaneva, Swanson & Williams 2013). Therefore, skilled and knowledgeable teachers are needed to ensure the effectiveness of STEM teaching process to link different disciplines throughout the curriculum (Adnan et al. 2016; Li 2014). However, previous studies discovered that less effective method of teaching is the cause of the student interest in deterioration phenomenon (Shernoff et al. 2017). The low level of teachers' skills towards STEM and less skilled teachers also contributed to students' deteriorating interest (Ejiwale 2013). It is crucial that the government and policymakers resolve this problem in order to achieve integrated STEM education success.

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