Perusing the Past to Propel the Future: A Systematic Review of STEM Learning Activity Based on Activity Theory

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Abstract: Education is the road to sustainability, creating the appropriate environment for learners to socialize and acquire knowledge and skills for the 21st century. This study reviews 53 studies on Science, Technology, Engineering, and Mathematics (STEM) learning activities from 2011 to 2020. In the past last 10 years, STEM education has gained attention, and little is known about how researchers designed and implemented learning activities. This systematic review based on activity theory reveals that STEM learning activities mostly involved elementary students in all STEM disciplines, with a sample size from 1 to 50. STEM learning activities emphasize mixed tasks, evaluating mixed learning outcomes with three STEM disciplines. Researchers mostly preferred project-based learning and problem-based learning methods, lasting from 9 to 24 weeks under teacher guidance with no rewards. This study revealed that most STEM activities were implemented in the classroom. Finally, the most often-used tools were mixed hardware. The quiz is the most often utilized in STEM activity. Major understudied areas that can be investigated by future studies are also revealed in depth. The results and implications for future studies are also discussed in detail.

Keywords: STEM education; science; technology; engineering; mathematics; systematic review; activity theory

1. Introduction

School is the best environment for learners to socialize and develop numerous abilities and competencies significant for sustainable development [1]. Sustainable development can be achieved through education as a learning domain, which is considered significant and fundamental for achieving the sustainable development goals (SDGs) [2]. Therefore, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) recommends teaching Science, Technology, Engineering, and Mathematics (STEM)-related subjects in the 21st century for sustainable development [3]. The goal of education is to guarantee that students obtain the theoretical and practical knowledge for sustainable development by 2030 [4]. The SDGs seek to address and overcome global challenges and hence require that everyone possess the skills and competencies that can be engaged for current transformations [3].

The skills required in the 21st century include not only knowledge in school subjects but also all-around knowledge and skills of human development [5]. These skills include critical thinking, communication, creativity, and collaboration [3,5]. These are required skills to make students effective workers. Skills such as creativity, critical thinking, collaboration, computer thinking, and problem-solving [6] are for learning that is focused on helping students develop their mental processes [2]. Literacy skills such as reading and writing also include understanding of digital usage with skills such as information literacy, technology literacy, consuming information, and life skills such as leadership, productivity, flexibility, and social skills. These competencies and skills can be achieved by engaging students in Science, Technology, Engineering, and Mathematics (STEM) learning activities.
STEM education has become crucial for social, cultural, and economic development in the 21st century. It has led to the rising interest in research, and stakeholders are interested in incorporating STEM into education [7,8]. STEM education can be referred to as a means to integrate all the four disciplines into learning [9]. Similarly, Sanders [10] also suggests that STEM learning activities should include at least two of the subject domains or compare one of the STEM subjects to other subject domains. STEM education involves student inquiry and problem-based, and project-based learning approaches that allow instructors to help learners improve their skills for the 21st century [11]. According to Freeman and colleagues [12], STEM education focuses on advancing students’ problem-solving skills, knowledge, and creative abilities. The purpose of STEM education is closely related to education for sustainable development. Both STEM education and sustainability hinge on education that is aimed at critical thinking, problem-solving skills, and knowledge from a local to global perspective [13,14]. The skills acquired through STEM education are referred to as the measurement of countries’ preparedness for the future [7]. Skill development is one of the major aims of education. Even though there are numerous studies on STEM education, it would be valuable to have up-to-date knowledge on how researchers design and implement STEM learning activities.

The learning materials and methods implemented in STEM activities are significant to arouse student interests, engagement, and learning outcomes. Donmez [15] posits that determining which learning tools or materials to employ in STEM activities is confusing for educators, such as whether to use simple materials or robotic kits. However, it is important but challenging to sustain students’ interest and positive emotions towards STEM learning and career. Designing activities based on content and pedagogy can be a challenging task, as determining the right materials to help students solve real-life problems [16], and the activity design process is sometimes time-consuming [17]. However, this is dependent on the availability of teaching and learning materials, student levels, and the goals of the STEM activity.

Furthermore, there is limited literature concerning the appropriate time for STEM activities [15]. For instance, a review on augmented reality (AR) in science, technology, engineering, and mathematics indicated that preparing materials created challenges for teachers due to its time-consuming nature [18]. Due to these challenges, different frameworks have been proposed such as botSTEM by Dufranc [7] for inquiry and engineering. Therefore, there is a need to investigate the trends in duration used in STEM literature. In addition, to the best of our knowledge, there is a lack of studies that adopted activity theory as a framework to analyze STEM learning activities. Activity theory includes duration as part of an activity design.

Activity theory (AT) is a framework based on the idea that “doing precedes thinking, goals, images, cognitive models, intentions, and abstract notions like definition and determinant”, which develop as a result of practical engagement [19]. The original AT framework is an analytical framework where the entire work of activity is broken into components of subject, tool, object, rules, community, and division of labor by Engeström [20]. The revised AT framework of Sung et al. [21] includes the following components: the subject is the participant in the study, the object is the intended activity, the rule is the standards or conditions that regulate the activity, the tool is the mediating device, the context is the learning setting, and interaction/communication is how the subjects interact during the activity.

Most of the existing STEM literature reviews have focused on instructional methods or learning outcomes. Other studies report trends in several publications according to journals, subject areas, or specific educational levels (such as K-12, college, and/or graduate). However, there is no systematic review on how STEM education activities were implemented. There is a lack of studies giving a systematic review of the current growth rate of STEM education activities in the last 10 years. Moreover, there is no comprehensive review of STEM activity that covers all educational levels. Our literature search found that no STEM review study adopted activity theory as a framework. Therefore, this study
aims to conduct a comprehensive and systematic review of the current status of STEM learning activities based on activity theory. STEM education activities are usually focused on solving real-life problems that are necessary for sustainable development.

Due to the lack of systematic analysis of STEM education activities in the last 10 years, this study has the following goals: (a) to provide a systematic analysis and statistical information about how STEM education activities from 2011 to 2020 were designed and implemented; (b) to propose a STEM education activity framework based on activity theory; (c) to provide comprehensive information on the main elements of activities in STEM education based on an activity theory-based framework; (d) to identify areas in the last 10 years research concerning STEM education disciplines and variables that are understudied; and (e) to suggest areas of STEM education activity research and practices for further investigation. With the above purpose, this review identified the different elements in STEM activities based on the activity theory framework. Through the growth rate analysis, this review discovered STEM education disciplines and areas that received less attention from 2011 to 2020. The question is, how were STEM education activities conducted in the last 10 years? To answer this question, six sub-questions were formed:

RQ1: Who participated in STEM activities during the last 10 years?
RQ2: What objects were investigated in STEM activities during the last 10 years?
RQ3: What kinds of rules were employed in STEM activities during the last 10 years?
RQ4: What were the major learning contexts in STEM activities during the last 10 years?
RQ5: How do learners interact in STEM activities during the last 10 years?
RQ6: What kinds of tools were mainly utilized in STEM activities during the last 10 years?

By answering the above research questions, this systematic review presents trends in STEM learning activities to accelerate the sustainability of STEM education at all education levels. The findings could reinforce educators in developing more learning strategies to engage students to increase sustainable learning perceptions. Moreover, STEM processes could be adopted in other learning subjects such as science in sports [22], language learning [23], and business management [24], to mention a few. Consequently, learners will become global problem solvers and agents of change as they are trained through learning methods such as inquiry-based learning and frameworks such as Education for Sustainability Development (ESD).

The rest of the paper is as follows. Section 2 describes the systematic process from data collection to analysis. Section 3 reports the results of the retrieved research sample based on the adopted activity-theory-based framework. Section 4 discusses the results of the study by expounding the research subjects, learning domain, the activity rules, learning contexts, mode of interaction, and the tools or materials used for the STEM learning activities. Section 5 summarizes the main findings, contributions, limitations, and recommendations for future studies.

2. Methods
The systematic review procedure was used for retrieving and analyzing the research foci for this review [19]. The review process involved data collection, selecting main the literature, quality assessment of the literature, data extraction, and synthesis.

2.1. Data Collection
To achieve the purpose of this study, a systematic review process began with a literature search by querying Scopus and Web of Science Core Collection databases [25]. We limited our search to STEM education activities (search date: 2 to 28 January 2021). The keywords and connectors applied to the literature searches included “STEM AND Learning activities”, “STEM education”, and “STEM education AND Science, Technology, Engineering, and Mathematics learning activities”. The period of studies examined [26] was from
2011 to 2020. A search result of 7546 papers in total was found, of which 4474 papers were retrieved from Web of Science and 3072 papers were obtained from Scopus.

2.2. Inclusion and Exclusion Criteria

The next stage involved the following exclusion and selection criteria to identify studies that engaged learners in a STEM learning activity. All three authors collaborated to apply the criteria adopted from Yeh et al. [25]: (a) exclusion of papers not related to STEM education ($n = 4016$); (b) exclusion of STEM education literature that did report learning activities ($n = 3100$); (c) removal duplicate papers that were found ($n = 24$); (d) removal of non-journal articles (literature review, meta-analysis, conference papers, editorials, commentaries, and position papers, $n = 88$); and (e) inclusion of journal research papers that describe a designed STEM education activity. This stage of the review process reduced the number of papers from 7546 to 318 papers. The entire paper selection process is presented in Figure 1.

![Figure 1. Diagram for the sample selection process.](image)

2.3. Quality Criteria

The next step of the process involved examining the quality of the remaining 318 papers. Quality in this study is defined as how well the research was designed and executed [25]. Further screening of the remaining papers resulted in discarding 265 papers. These were STEM education papers that did not report how the learning activity was designed and how it was executed [27]. At the end of this stage, 53 articles were retrieved. Among the 53 research papers retrieved based on the inclusion criteria, there was no study found for the year 2013. The distribution of the selected 53 literature studies from 2011 to 2020 is illustrated in Figure 2 and the analytical data is presented in Appendix A.
2.4. Data Analysis Framework

The selected 53 papers were analyzed based on the activity theory framework, which was developed as a guide for the data analysis. The activity theory framework for this study has been adopted in previous studies such as [19,28]. The framework was revised further to suit the purpose of this study and can be seen in Figure 3. Table 1 shows the coding scheme. The six elements included:

- The research, subjects being the sample for the selected studies, include sample level and sample size.
- Objects, being the goal of STEM activity, include learning domains, task types (e.g., inquiry, simulation, and problem-solving), and learning outcomes.
- The rules or norms that were utilized for effective facilitation of STEM learning activity include methods, teacher involvement, duration, and reward method.
- The context of the STEM activities refers to the learning setting.
- The interaction includes interactive types and participant interaction.
- The tools that were used include software, hardware, and functionalities.

![Figure 2](image2.png)

**Figure 2.** The distribution of 53 retrieved literature studies from 2011 to 2020.

![Figure 3](image3.png)

**Figure 3.** A framework for STEM learning activity based on activity theory.
Table 1. The coding scheme.

| Elements       | Super-Dimensions                                                                 | Sub-Dimensions                                                                 |
|----------------|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Sample level   | Subjects                                                                         |                                                                               |
|                | Sample size                                                                      |                                                                               |
| Subjects       | 1. Kindergarten (3–6)                                                            | 1. 1–50                                                                        |
|                | 2. Elementary school (6–12)                                                      | 2. 51–100                                                                      |
|                | 3. Middle school (12–15)                                                         | 3. 101–300                                                                     |
|                | 4. High school (15–18)                                                           | 4. More than 300                                                                |
|                | 5. College/University (18–22)                                                     | 5. Not Specified                                                                |
| Learning domains| Learning domains                                                                 |                                                                               |
|                | 1. Science                                                                       | 1. Inquiry                                                                      |
|                | 2. Technology                                                                     | 2. Simulation                                                                   |
|                | 3. Engineering                                                                    | 3. Investigation                                                                |
|                | 4. Mathematics                                                                    | 4. Issue Discussion                                                             |
|                | 5. Two disciplines                                                                | 5. Problem-solving                                                              |
|                | 6. Three disciplines                                                              | 6. Engineering design                                                           |
|                | 7. More than three disciplines                                                    | 7. Knowledge acquisition                                                        |
|                |                                                                                   | 8. Mixed                                                                        |
| Objects        | Task types                                                                       |                                                                               |
|                | Learning outcomes                                                                 |                                                                               |
|                | 1. Learning achievements                                                          | 1. Learning achievements                                                        |
|                | 2. Thinking skills                                                                | 2. Thinking skills                                                              |
|                | 3. Spatial skills                                                                 | 3. Spatial skills                                                               |
|                | 4. Learning perceptions (such as satisfaction/attitudes/motivation)               | 4. Learning perceptions (such as satisfaction/attitudes/motivation) |
|                | 5. Learning engagement                                                            | 5. Learning engagement                                                           |
|                | 6. Self-learning ability                                                           | 6. Self-learning ability                                                         |
|                | 7. Mixed                                                                         | 7. Mixed                                                                        |
| Methods        |                                                                                   |                                                                               |
| Teachers’ involvement | 1. Guidance                                                                         | 1. Guidance                                                                     |
|                | 2. Without guidance                                                               | 2. Without guidance                                                             |
| Rules          |                                                                                   |                                                                               |
| Duration       | 1. Less than one day                                                              | 1. Individual rewards                                                           |
|                | 2. 1–7 day                                                                        | 2. Group rewards                                                                |
|                | 3. 2–4 weeks                                                                      | 3. No rewards                                                                   |
|                | 4. 5–8 weeks                                                                      |                                                                               |
|                | 5. 9–24 weeks                                                                     |                                                                               |
|                | 6. More than 24 weeks                                                             |                                                                               |
|                | 7. Not Specified                                                                  |                                                                               |
| Reward methods |                                                                                   |                                                                               |
| Elements     | Super-Dimensions                                                                 | Sub-Dimensions                                                                 |
|-------------|---------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Context     | Learning setting                                                                | 1. Museum/Science center/theatre                                               |
|             |                                                                                 | 2. In classroom                                                                |
|             |                                                                                 | 3. After-school club/program                                                   |
|             |                                                                                 | 4. Lab                                                                        |
|             |                                                                                 | 5. Workplace                                                                   |
|             |                                                                                 | 6. Summer camp                                                                 |
|             |                                                                                 | 7. Out-door place                                                              |
| Interaction | Interaction types                                                               | 1. Face-to-face interaction                                                    |
|             |                                                                                 | 2. Technology-mediated interaction                                             |
|             |                                                                                 | 3. Blended interaction                                                         |
|             |                                                                                 | 4. Exhibit-mediated interaction                                                 |
|             | Participant interaction                                                         | 1. With teachers                                                               |
|             |                                                                                 | 2. With family members                                                         |
|             |                                                                                 | 3. With group members                                                          |
|             |                                                                                 | 4. With group members + With teachers                                          |
|             |                                                                                 | 5. Mixed                                                                      |

| Hardware    |                                                                                   | 1. Electrical Materials                                                        |
|             |                                                                                   | 2. Recyclable Materials                                                         |
|             |                                                                                   | 3. Computers                                                                   |
|             |                                                                                   | 4. Booklets/workbooks                                                          |
|             |                                                                                   | 5. Smart phones                                                                |
|             |                                                                                   | 6. Mixed                                                                       |
|             |                                                                                   | 7. No hardware                                                                 |

| Tools       |                                                                                   | 1. Online learning platform or website                                          |
|             |                                                                                   | 2. Arduino                                                                     |
|             |                                                                                   | 3. Arduino + Scratch                                                           |
|             |                                                                                   | 4. 3D design software + Arduino                                               |
|             |                                                                                   | 5. VR + AR + Arduino. Simulation software (such as PhET)                       |
|             |                                                                                   | 6. 3D design software (such as Tinkercad, CAD)                                |
|             |                                                                                   | 7. Game                                                                        |
|             |                                                                                   | 8. No software                                                                 |
|             |                                                                                   | 9. Unspecified                                                                 |

| Functionalities |                                                                 | 1. Collaborative creation                                                    |
|                |                                                                 | 2. Scaffold                                                                  |
|                |                                                                 | 3. Quiz + scaffold                                                           |
|                |                                                                 | 4. Quiz                                                                      |

In addition, the current review included the growth rate of the 53 research papers retrieved from 2011 to 2020. To obtain the initial value and ending value for the growth rate of 10 years period, we analyzed the number of studies in first five years (2011 to 2015) and second five years (2016 to 2017) [29].

2.5. Inter-Rater Reliability

To ensure that the reliability of the data coding and results, two researchers were involved to analyze 53 papers. The Fleiss’ Kappa [30] statistics were used to calculate the inter-rater reliability between two raters and it achieved 0.89, indicating a high reliability.
3. Results

3.1. Who Participated in STEM Activities during the Last 10 Years?

Table 2 shows the proportions of sample level and sample size from 2011 to 2020. It was found that the number of studies that focused on learners from the elementary level was the greatest from 2011 to 2020. The majority of the studies that involved elementary students were published in 2019 and 2020. Next to the elementary level were studies that involved middle school students, forming the second largest component of the total sample, followed by mixed participants. For instance, Jesionkowska et al. [31] involved both elementary and middle school level students in STEM learning activities. Within the category of studies that involved mixed student levels, most involved were elementary and middle school students, followed by middle and high school students, and only one study involved elementary, middle, and high school students. As shown in Table 2, it was interesting to discover that kindergarten and college students were the least engaged in STEM activities. In addition, most papers (51%) employed a sample size in a range of 1 to 50, followed by 101–300. Only 6 out of the 53 articles reported studies employed a number greater than 300.

Table 2. The proportions of sample level and sample size from 2011 to 2020.

| Variable           | Category          | No. of Studies | Proportion of Studies |
|--------------------|-------------------|----------------|-----------------------|
| Sample level       | Kindergarten      | 1              | 2%                    |
| -                  | Elementary school | 20             | 38%                   |
| -                  | Middle school     | 11             | 21%                   |
| -                  | High school       | 8              | 15%                   |
| -                  | College/University| 3              | 6%                    |
| -                  | Mixed             | 10             | 18%                   |
| Sample size        | 1–50              | 27             | 51%                   |
| -                  | 51–100            | 9              | 17%                   |
| -                  | 101–300           | 11             | 21%                   |
| -                  | More than 300     | 6              | 11%                   |

The growth rates of sample level and sample size are shown in Table 3. It was found that studies that involved middle school students reached the highest growth rate (900%), followed by mixed participants (300%) and elementary school students (200%). In addition, studies that involved a sample size of 1 to 50 achieved the highest growth rate (700%), followed by the sample size range of 101 to 300 (350%), and then studies that involved the sample range of 51 to 100 (250%).

Table 3. The growth rate of sample level and sample size from 2011 to 2020.

| Variable           | Category          | 2011–2015 | 2016–2020 | Growth Rate   |
|--------------------|-------------------|-----------|-----------|---------------|
| Sample level       | Kindergarten      | 0         | 1         | NA            |
| -                  | Elementary school | 5         | 15        | 200%          |
| -                  | Middle school     | 1         | 10        | 900%          |
| -                  | High school       | 3         | 5         | 66.67%        |
| -                  | College/University| 0         | 3         | NA            |
| -                  | Mixed             | 2         | 8         | 300.00%       |
| Sample size        | 1–50              | 3         | 24        | 700%          |
| -                  | 51–100            | 2         | 7         | 250%          |
| -                  | 101–300           | 2         | 9         | 350%          |
| -                  | More than 300     | 3         | 3         | 0             |

3.2. What Objects Were Investigated in STEM Activities during the Last 10 Years?

To answer the second research question, the learning domains, task types, and learning outcomes of STEM activities are analyzed in depth. As shown in Table 4, a popular trend in the past 10 years was to integrate subjects from all the STEM domains (59%).
This was followed by studies that integrated subjects from three STEM domains such as integrating science, engineering, and technology found in [32]. Other studies also integrated subjects from one or two STEM domains. For instance, Boeve-de Pauw and colleagues [33] integrated technology-related subjects for elementary school students in a study to determine their attitudes towards technology. Furthermore, Table 5 shows the growth rate from 2011 to 2020. It was found that STEM activities with three disciplines achieved the highest growth rate (600%), followed by more than three disciplines (420%).

Table 4. The proportions of objects in STEM education activities from 2011 to 2020.

| Variable          | Category         | No. of Studies | Proportion of Studies |
|-------------------|------------------|----------------|-----------------------|
| Learning domains  | Science          | 6              | 11%                   |
| - Technology      | 1                | 2%             |
| - Engineering     | 1                | 2%             |
| - Mathematics     | 0                | 0%             |
| - 2 Disciplines  | 6                | 11%            |
| - 3 Disciplines  | 8                | 15%            |
| - More than three| 31               | 59%            |
| Task types        | Inquiry          | 2              | 4%                    |
| - Simulation      | 8                | 15%            |
| - Investigation   | 0                | 0%             |
| - Issue discussion| 0                | 0%             |
| - Problem-solving| 2                | 4%             |
| - Engineering design| 14              | 26%            |
| - Knowledge acquisition | 3        | 6%             |
| - Mixed           | 24               | 45%            |
| Learning outcomes | Learning achievements | 10 | 19% |
| - Thinking Skills | 6                | 11%            |
| - Spatial skills  | 1                | 2%             |
| - Learning perceptions | 8        | 15%            |
| - Learning engagement | 0    | 0%             |
| - Self-learning ability | 3     | 6%             |
| - Mixed           | 25               | 47%            |

Table 5. The growth rate from 2011 to 2020.

| Variable          | Category         | 2011–2015 | 2016–2020 | Growth Rate |
|-------------------|------------------|-----------|-----------|-------------|
| Learning domains  | Science          | 3         | 3         | 0           |
| - Technology      | 0                | 1         | NA        |
| - Engineering     | 0                | 1         | NA        |
| - Mathematics     | 0                | 0         | NA        |
| - 2 Disciplines  | 1                | 5         | 400%      |
| - 3 Disciplines  | 1                | 7         | 600%      |
| - More than three| 5                | 26        | 420%      |
| Task types        | Inquiry          | 1         | 1         | 0           |
| - Simulation      | 1                | 7         | 600%      |
| - Investigation   | 0                | 0         | NA        |
| - Issue Discussion| 0                | 0         | NA        |
| - Problem-solving| 0                | 2         | NA        |
| - Engineering design| 2              | 12        | 500.00%   |
| - Knowledge acquisition | 1        | 2         | 100.00%   |
| - Mixed           | 3                | 21        | 600.00%   |
| Learning outcomes | Learning achievements | 2 | 8 | 300.00% |
| - Thinking Skills | 0                | 6         | NA        |
| - Spatial skills  | 0                | 1         | NA        |
| - Learning perceptions | 2          | 6         | 200.00%   |
| - Learning engagement | 0    | 0         | NA        |
| - Self-learning ability | 0      | 3         | NA        |
| - Mixed           | 6                | 19        | 216.67%   |
With respect to task types, the majority of studies employed mixed learning tasks (45%), followed by engineering design (26%), then simulation (15%). Furthermore, the results indicated that from 2011 to 2020, only a few of the studies had the primary objective of involving learners in problem-solving and knowledge acquisition tasks. Lastly, studies with inquiry tasks were the least common of the sample literature reviewed in this study. Furthermore, the growth rate of simulation and mixed tasks achieved the highest (600%), followed by engineering design (500%).

With regard to learning outcomes, the results indicated that mixed learning outcomes accounted for the largest proportion (47%), followed by learning achievements (19%). For instance, Kuo and colleagues [34] involved university students in mixed subjects and investigated learning motivation, self-efficacy, joyfulness of learning, and creativity as learning outcomes. However, no studies have been conducted to investigate learning engagement in STEM activities. Furthermore, the growth rate of learning achievements reached the highest (300%), followed by mixed learning outcomes (216.67%).

3.3. What Kinds of Rules Were Employed in STEM Activities during the Last 10 Years?

As shown in Table 6, the adopted learning methods included program-based learning, project-based learning, problem-based learning, inquiry-based learning, research-based learning, and mixed learning methods. It was found that most studies implemented project-based learning method (49%), most of which were in the second 5 years or 10 years, followed by problem-based learning, then inquiry-based learning. Lastly, minimal frequencies of studies were found to implement research-based learning methods (4%). Table 7 shows the growth rate of rules from 2011 to 2020. It was found that the project-based learning method achieved the highest growth rate (450%), followed by problem-based learning (350%).

Table 6. The proportions of rules implemented in STEM educational Activities from 2011 to 2020.

| Variable Category                  | No. of Studies | Proportion of Studies |
|-----------------------------------|----------------|----------------------|
| Methods                           | Program-based learning | 3 | 5% |
| - Project-Based Learning          | 26 | 49% |
| - Problem-based learning          | 11 | 21% |
| - Inquiry-based Learning          | 8 | 15% |
| - Research-Based Learning         | 2 | 4% |
| - Mixed                           | 3 | 6% |
| Teacher involvement               | Guidance       | 52 | 98% |
| - No guidance                     | 1 | 2% |
| Durations                         | Less than one day | 9 | 17% |
| - 1–7 days                        | 9 | 17% |
| - 2–4 weeks                       | 4 | 8% |
| - 5–8 weeks                       | 9 | 17% |
| - 9–24 weeks                      | 14 | 26% |
| - More than 24 weeks              | 3 | 6% |
| - Not Specified                   | 5 | 9% |
| Reward methods                    | Individual rewards | 0 | 0% |
| - Group rewards                   | 1 | 2% |
| - No rewards                      | 52 | 98% |

With respect to teacher involvement, the results revealed that almost all studies involved teacher guidance. Hence, 98% of studies were found to involve guidance, and only 2% did not include teacher guidance. An in-depth analysis revealed that studies with teacher guidance surged from 2016 to 2020, and the growth rate achieved was 377.78%.

Concerning durations, the majority of studies engaged students for 9 to 24 weeks, such as [32,35,36]. Next were studies that engaged learners in STEM activities within a day and 1 to 7 days. For example, Ozcan et al. [37] engaged 33 middle school participants in a program-based activity for 12 lesson hours. Few studies were found to implement STEM activities for 2 to 4 weeks or more than 24 weeks. In terms of the growth rates associated
with different durations, the findings revealed that less than one day reached the highest growth rate (700%), followed by 9–24 weeks (500%). Regarding the reward methods, it was found that only one study adopted group reward.

### Table 7. The growth rate of rules from 2011 to 2020.

| Variable                  | Category                      | 2011–2015 | 2016–2020 | Growth Rate |
|---------------------------|-------------------------------|-----------|-----------|-------------|
| Methods                   | Program-based learning        | 0         | 3         | NA          |
|                           | Project-Based Learning        | 4         | 22        | 450%        |
|                           | Problem-based learning        | 2         | 9         | 350%        |
|                           | Inquiry-based Learning        | 3         | 5         | 66.67%      |
|                           | Research-Based Learning       | 0         | 2         | NA          |
|                           | Mixed                         | 0         | 3         | NA          |
| Teacher involvement       | Guidance                      | 9         | 43        | 377.78%     |
|                           | No guidance                   | 1         | 0         | −100%       |
| Durations                 | Less than one day             | 1         | 8         | 700%        |
|                           | 1–7 days                      | 0         | 9         | NA          |
|                           | 2–4 weeks                     | 2         | 2         | 0           |
|                           | 5–8 weeks                     | 3         | 6         | 100%        |
|                           | 9–24 weeks                    | 2         | 12        | 500%        |
|                           | More than 24 weeks            | 0         | 3         | NA          |
|                           | Not Specified                 | 2         | 3         | 50%         |
| Reward methods            | Individual rewards            | 0         | 0         | NA          |
|                           | Group rewards                 | 1         | 0         | NA          |
|                           | No rewards                    | 10        | 42        | 320%        |

#### 3.4. What Were the Major Learning Contexts in STEM Activities during the Last 10 Years?

To analyze the learning contexts employed in STEM activities, learning settings were investigated in depth. As shown in Tables 8 and 9, the results revealed that most STEM activities were implemented in the classroom, which was found in 69% of the literature with a growth rate of 725%. Few studies reported out-of-school programs such as after-school programs or clubs or summer camps or workplaces, which have gained researchers' attention in the last 5 years, such as [38–41].

### Table 8. The proportions of learning settings from 2011 to 2020.

| Variable                  | Category                              | No. of Studies | Proportion of Studies |
|---------------------------|---------------------------------------|----------------|-----------------------|
| Learning settings         | Museum or Science center or theatre   | 2              | 4%                    |
|                           | In classroom                          | 37             | 69%                   |
|                           | After-school club or program          | 7              | 13%                   |
|                           | Lab                                   | 3              | 6%                    |
|                           | Workplace                             | 1              | 2%                    |
|                           | Summer camp                           | 2              | 4%                    |
|                           | Outdoor place                         | 1              | 2%                    |

### Table 9. The growth rate of settings implemented in STEM education activities from 2011 to 2020.

| Variable                  | Category                              | 2011–2015 | 2016–2020 | Growth Rate |
|---------------------------|---------------------------------------|-----------|-----------|-------------|
| Learning setting          | Museum or science center or theater  | 1         | 1         | 0           |
|                           | In classroom                          | 4         | 33        | 725%        |
|                           | After-school club or program          | 4         | 3         | −25%        |
|                           | Lab                                   | 0         | 3         | NA          |
|                           | Workplace                             | 0         | 1         | NA          |
|                           | Summer camp                           | 1         | 1         | 0           |
|                           | Outdoor place                         | 0         | 1         | NA          |
3.5. How Have Learners in STEM Activities Interacted during the Last 10 Years?

Tables 10 and 11 show the proportions and the growth rates, respectively, of how participants interacted from 2011 to 2020. With regard to interaction types, it was found that a great number of the studies adopted face-to-face interaction (81%). For example, Li et al. [8] engaged elementary students in a face-to-face interaction activity with a mixed task type. Furthermore, face-to-face interaction achieved the highest growth rate (875%). In addition, a few studies employed blended interaction in STEM activities [42–44]. Only Master et al. [45] implemented a technology-mediated interaction with elementary-level participants.

Table 10. The proportions of how participants interact from 2011 to 2020.

| Variable                | Category                        | No. of Studies | Proportion of Studies |
|-------------------------|---------------------------------|----------------|-----------------------|
| Interaction types       | Face-to-face interaction        | 43             | 81%                   |
|                        | Technology-mediated interaction | 1              | 2%                    |
|                        | Blended interaction             | 9              | 17%                   |
| Participant interaction | With teachers                   | 5              | 9%                    |
|                        | With group members              | 8              | 15%                   |
|                        | With group members and teachers | 40             | 75%                   |

Table 11. The growth rate of how participants interacted from 2011 to 2020.

| Variable                | Category                        | 2011–2015 | 2016–2020 | Growth Rate |
|-------------------------|---------------------------------|-----------|-----------|-------------|
| Interaction type        | Face-to-face interaction        | 4         | 39        | 875%        |
|                        | Technology-mediated interaction | 0         | 1         | NA          |
|                        | Blended interaction             | 6         | 3         | −50%        |
| Participant interaction | With teachers                   | 3         | 2         | −33.33%     |
|                        | With group members              | 1         | 7         | 600%        |
|                        | With group members and teachers | 6         | 34        | 466.67%     |

According to the results, the majority of STEM activities involved both student-to-student interaction and student-to-teacher interaction (75%). For example, a study by Adriyawati and colleagues [46] engaged elementary-level participants in a project-based learning activity that allowed students to interact with each other and the teacher(s) as support. In addition, few studies involved only student-to-student interaction at a high school level [47,48]. However, the growth rate of student-to-student interaction achieved the highest one (600%), followed by both student-to-student interaction and student-to-teacher interaction (466.67%). The lowest participant interaction strategy used was students interacting with a teacher such as [35]. Most of the interactions with only teachers were elementary level students, except in [44], which involved high school students.

3.6. What Kinds of Tools Were Mainly Utilized in STEM Activities during the Last 10 Years?

Tables 12 and 13 show, respectively, the proportions and growth rate of tools utilized in STEM activities from 2011 to 2020. The findings revealed that most employed mixed hardware such as electric, recyclable tools, and natural materials (e.g., magnets, solar panels, consumables) and electrical materials. To illustrate, [49] utilized regular textile materials (such as fabric, thread, and markers) and conductive/computational materials (such as LEDs, conductive thread, sewable microcontroller with sensors and sound buzzer) in an engineering design that involved high school participants. Few studies were found to use computers, booklets/workbooks, smartphones, or no hardware. In addition, recyclable materials achieved the highest growth rate (1000%), followed by mixed hardware (600%).
Table 12. The proportions of tools utilized in STEM activities from 2011 to 2020.

| Variable | Category                        | No. of Studies | Proportion of Studies |
|----------|---------------------------------|----------------|-----------------------|
| Hardware | Electrical Materials            | 15             | 28%                   |
|          | Recyclable Materials            | 12             | 22%                   |
|          | Computers                       | 3              | 6%                    |
|          | Booklets/workbooks              | 3              | 6%                    |
|          | Smart phones                    | 1              | 2%                    |
|          | Mixed                           | 16             | 30%                   |
|          | No hardware                     | 3              | 6%                    |
| Software | Online learning platform/website | 6              | 11%                   |
|          | Arduino                         | 2              | 4%                    |
|          | Arduino + Scratch               | 1              | 2%                    |
|          | 3D design software + Arduino    | 1              | 2%                    |
|          | VR + AR + Arduino               | 1              | 2%                    |
|          | Simulation software (such as PhET) | 5               | 9%                    |
|          | 3D design software (such as CAD) | 7             | 13%                   |
|          | Game                            | 1              | 2%                    |
|          | No hardware                     | 27             | 51%                   |
|          | Not specified                   | 2              | 4%                    |
| Functionality | Collaborative creation        | 1              | 2%                    |
|          | Scaffold                        | 7              | 13%                   |
|          | Quiz + scaffold                 | 1              | 2%                    |
|          | Quiz                            | 43             | 81%                   |
|          | Not specified                   | 1              | 2%                    |

Table 13. The growth rate of tools utilized in STEM activities from 2011 to 2020.

| Variable | Category                        | 2011–2015 | 2016–2020 | Growth Rate |
|----------|---------------------------------|-----------|-----------|-------------|
| Hardware | Electrical Materials            | 3         | 12        | 300%        |
|          | Recyclable Materials            | 1         | 11        | 1000%       |
|          | Computers                       | 2         | 1         | -50%        |
|          | Booklets/workbooks              | 1         | 2         | 100%        |
|          | Smart phones                    | 0         | 1         | NA          |
|          | Mixed                           | 2         | 14        | 600%        |
|          | No hardware                     | 0         | 3         | NA          |
| Software | Online learning platform/website | 4         | 2         | -50%        |
|          | Arduino                         | 0         | 2         | NA          |
|          | Arduino + Scratch               | 0         | 1         | NA          |
|          | 3D design software + Arduino    | 0         | 1         | NA          |
|          | VR + AR + Arduino               | 0         | 1         | NA          |
|          | Simulation software (such as PhET) | 1       | 4         | 300%        |
|          | 3D design software (such as CAD) | 0     | 7         | NA          |
|          | Game                            | 1         | 0         | -100.00%    |
|          | No software                     | 2         | 25        | 1150.00%    |
|          | Not specified                   | 2         | 0         | -100%       |
| Functionality | Collaborative creation        | 0         | 1         | NA          |
|          | Scaffold                        | 1         | 6         | 500.00%     |
|          | Quiz + scaffold                 | 0         | 1         | NA          |
|          | Quiz                            | 8         | 35        | 337.50%     |
|          | Not specified                   | 0         | 1         | NA          |

As shown in Table 12, the majority of the studies did not utilize any software. It should be noted that most studies that did not employ software were found in the last 5 years, such as [42,50]. Next was 3D design software (such as Tinkercad, CAD), then online learning platform/website, and simulation software (such as PhET). Studies such as Ridlo, Dafik, and Nugroho [51] utilized an online learning platform to implement STEM activities. Lastly, it was discovered that only a few studies utilized software such as CAD, Arduino, augmented reality, and 3D design software in the last 5 years (2016 to 2020).
Studies that did not engage students with software increased tremendously in the last 5 years at a growth rate of 1150%.

Concerning functionalities of the tools, it was found that a significant number of studies employed a quiz, especially in the last 5 years. The second highest was studies that employed tools for scaffolding purposes, which obtained the highest growth rate in the last 5 years (500%). Scaffolding was a key element for motivating students’ interest in STEM education activity [52]. The functionality least employed by researchers was collaboration creation as well as quiz and scaffolding, which were published in the year 2020. For example, collaborative creation was used in [53] to identify different roles and distinctive ways of participation in group activities.

4. Discussion

This review addresses the status and trend of the activity design and implementation in the STEM education field in the last 10 years from a sample of 53 research papers. The design of STEM education activities that engage learners increased towards the end of the study period compared to the beginning. This section discusses the findings and their implications.

4.1. Discussion of Main Findings

It is significant to note that most studies involved students from the elementary level. This indicated the rise in interest in introducing STEM education at a younger age to prevent elementary students from losing interest in STEM-related subjects [54,55]. The findings in this study contrast with [56], which stated that elementary students were incapable of engineering design. For instance, some researchers [57] posited that the engineering behavior of elementary school learners could be increased through engineering design. Science and engineering education activities are paramount to preparing students for the 21st-century industrial revolution termed Industry 4.0. STEM education and training plays a significant role for well-trained engineers and in the successful implementation of Industry 4.0 [58]. The small number of middle school and high school participants indicated that teachers focused on preparing students for the national exam, which is required before enrolling into a tertiary institution in most countries [53,59]. On the other hand, STEM at the university level received minimal attention. This indicated a reduction in interest and a low number of students enrolled in STEM undergraduate programs in the last 10 years [60]. Furthermore, another reason could be a lack of funds for interdisciplinary research [61]. The findings confirm that universities need to invest more efforts in training and exposing students to the benefits of Industry 4.0 [62]. On the other hand, there was been a rise in studies that involved middle school and high school participants in the last 5 years. This might be because middle school level is a crucial stage leading to higher education level. For sample size, the majority of the studies used 1 to 50 students. A possible explanation is that a small sample will be easy to manage and supervise. Learning outcomes as part of the STEM activity goals were in line with the aims of STEM sustainability education, which seeks to make everyone an agent of change through methods that develop skills for the 21st century. From the sample literature, the activities were aimed at mixed or multiple skills and competencies, learning attitudes, and behaviors towards STEM, learning achievement, critical thinking, creative skills, self-learning ability, and spatial skills. This confirms the UNESCO (2015) argument that these skills are obtained through STEM learning domains and that other forms of education are necessary for sustainable development [63]. Through the findings from this review, we confirm that the main goals of STEM activities were achieved through frameworks such as project-based learning, inquiry-based learning, and problem-based learning, which engage learners through scientific processes. Consequently, these practices help develop students’ skills for the 21st century and create a sustainability mindset.

In the present study, it was found that there is a lack of studies on problem discussion and investigation tasks. Studies that employed mixed tasks mostly included investigation
and discussion with other tasks such as investigation, discussion, simulation, and projects. This reveals that when integrating learning domains, it is significant to incorporate different tasks. Most studies reported mixed learning outcomes [31,64]. The more that STEM activity designers integrate the disciplines, the more likely they are to adopt different tasks and investigate different learning outcomes. Integrated STEM disciplinary activities are deemed promising and therefore have been promoted by the UN for “sustainable development education” [65]. The findings revealed that researchers in the last 10 years did not focus on integrating STEM-related concepts in other disciplines.

The most often used learning methods include project-based and problem-based learning methods. This indicated that STEM activities in the last 10 years were more practical and directed towards creativity and solving real-world problems. Most STEM education researchers preferred project-based learning, problem-based learning, and inquiry-based methods, which were highly practical for improving behavior, attitude, interest, and skills [66,67]. It should be noted that a trend in program-based, research-based, and mixed methods in 2020 gained researchers’ attention. Almost all these methods were administered under teacher guidance except for one study in 2011. This finding indicated that effective teacher guidance was critical for students’ engagement [68] since STEM activities usually are complex and difficult. Furthermore, most studies lasted for 9–24 weeks, indicating that recent STEM activities were designed for a long duration [69]. The more demanding a project or problem-designed activity, the more duration will be needed. Finally, it was surprising to discover that almost all of the studies provided any reward to learners. According to the findings, most of the studies engaged students in a school setting, while out-of-school settings such as the museum, workplace, outdoor place, and summer camp were understudied. In addition, there was also a lack of STEM studies with learners and their families, which confirmed the claim by [70,71] that families in the domain of STEM education remained unexploited.

Most researchers preferred face-to-face interaction due to the practicality of STEM studies and students’ characteristics [72]. Consequently, the interest increased in the last two to three years while blended interaction decreased. This denoted a gradual decline in preference for blended interaction among STEM activity designers. Students were allowed to interact with other students and teachers in most of the studies. This was related to the high level of guidance given to students in the classroom setting. On the other hand, few studies either engaged students with only teachers or students only. More so, there is a lack of studies on interaction with family, human–computer interaction, or mixed.

Most studies engaged students with mixed hardware, which included recyclable materials, natural or perishable materials, and computers. Furthermore, from 2016 to 2020, most studies utilized electrical materials such as 3D printers, recyclable materials such as Lego, rubber bands, and wood. However, studies that administered computers, smartphones, booklets, or no hardware were minimal. Regarding software, a total of 40% of studies adopted online learning platforms, Arduino, CAD and Arduino, VR, AR, simulation software (such as PhET), 3D design software (such as Tinkercad, CAD), or games. Arduino is an open-source electronic hardware and software prototyping platform that is inexpensive, making it highly useful for education purposes. However, the use of VR or AR is understudied, but it is expected to increase in the years ahead due to its ability to boost interest in STEM [73]. The results confirmed previous findings that blended learning in STEM increases performance and reduces dropout [74]. Advanced learning technologies have a major role to play in STEM education. Therefore, teachers need to be trained and motivated for the use of advanced technologies to improve students’ skills for the 21st-century necessary for sustainable development. Sustainability-related problems such as climate change require global skills not limited to one discipline [23,24]. STEM learning activities that are designed for learners to generate innovative solutions enable the integration of STEM disciplines and multidisciplinary learning. Engaging learners in well-designed STEM activities and creating sustainability awareness among learners could promote development that meet the needs of current and future challenges.
4.2. Implications

This study revealed some prospects for future studies. It sheds more light on the understudied areas that need to be explored. With regards to participants in the last ten years, a suggestion is to involve more college or university students into multidisciplinary STEM subjects. Science and engineering activities should be increased to equip students with the necessary skills for Industry 4.0. Knowledge acquisition, problem-solving, inquiry, and simulation tasks need to be explored further from the different learning environments. There is a requisite to explore metacognitive processes, knowledge elaboration, and knowledge-building processes in STEM education activities, especially in informal learning settings. Furthermore, researchers should note that previous studies have well-explored methods such as project-based and problem-based learning. However, other methods such as research-based, program-based, and group investigation methods are recently gaining researchers’ attention. Future STEM studies should explore learning settings and learning methods that would be more effective to sustain learners’ interest at all education levels. Furthermore, the sustainability of both students’ and educators’ interest in the area of STEM and the knowledge gained through STEM learning activities is significant. Educators need to create awareness of how students can apply their knowledge to solve real-world environmental, social, economic, and psychological problems through STEM learning activities. Moreover, it is necessary to explore opportunities and the role of machine learning and artificial intelligence tools. For instance, future studies could explore machine learning tools for personalized STEM learning activities. In addition, it is recommended that future studies can adopt the proposed STEM activity design framework in this paper as a guide to design and implement STEM learning activities. Longitudinal studies to determine why students lose interest along the education ladder will add to the knowledge base.

Future studies should focus on training more teachers in the area of STEM disciplines and STEM sustainability curriculums. The sustainability of teacher’s emotions and motivation should be explored, since it is important for training more learners for the social, cultural, environmental, and economic development of every nation. This contributes to STEM education for sustainability by revealing understudied methods, which researchers and educators could utilize in future studies. STEM activities should not only aim at learning achievements but towards sustainability awareness, mindset, and development. Lastly, science, technology, engineering, and mathematics learning activities designed were aimed at solving problems through different methods related to the sustainable development goals of the United Nations.

5. Conclusions

This systematic review of STEM activity from 2011 to 2020 accumulates evidence of the subjects, objectives, rules, interaction, setting, and tools utilized in such activities. This study contributes to displaying the current status, trends, and directions in the STEM field. A significant contribution is to shed light on the design and implementation of STEM activities for future studies to investigate. The findings of this review reveal how integrated STEM disciplinary activities were designed and implemented to train learners of different education levels to solve problems relating to sustainability. It also proposes a significant framework to serve as a guide for designing STEM activities.

However, this study was constrained by several limitations. First, only 53 studies met the criteria in this study. Future studies will expand the data sources to conduct a more comprehensive analysis. Second, this study reviewed the literature based on six elements of activity theory. Future studies will examine the effects of STEM activities on higher-order thinking skills.
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| Appendix A |
|------------|

| 1. | Evaluating the effect of differentiated inquiry-based science lesson modules on gifted students' scientific process skills | Elementary school | 1–50 | Science | Inquiry | Self-learningability | Inquiry-basedlearning | Guidance | 9–24 weeks | No rewards | In classroom | Face-to-face interaction | With teachers | No hardware | No software | Quiz |
| 2. | An interdisciplinary approach to investigate preschool children's implicit inferential reasoning in scientific activities | Kindergarten | 1–50 | Engineering | Engineering design | Self-learningability | Program-basedlearning | Guidance | 1–7 day | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Recyclable materials | No software | Not Specified |
| 3. | Building engineering awareness: problem-based learning approach for STEM integration | Elementary school | 51–100 | More than three | Mixed | Mixed | Problem-basedlearning | Guidance | 9–24 weeks | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Mixed | No software | Quiz |
| 4. | Promoting college students' learning motivation and creativity through a STEM interdisciplinary PBL human-computer interaction system design and development course | College/University | 1–50 | More than three | Problem solving | Mixed | Project-basedlearning | Guidance | 9–24 weeks | Group rewards | In classroom | Face-to-face interaction | With group members and teachers | Mixed | VR + AR + Arduino | Quiz |
| 5. | HOTS profile of physics education students in STEM-based classes using PhET media | College/University | 1–50 | Science | Simulation | Thinking skills | Inquiry-basedlearning | Guidance | 9–24 weeks | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Computers | Simulations software | Quiz |
| 6. | A case study exploring non-dominant youths' attitudes toward science through making and scientific argumentation | Elementary school | 1–50 | More than three | Engineering design | Learning perceptions | Project-basedlearning | Guidance | 9–24 weeks | No rewards | After-school club program | Face-to-face interaction | With group members and teachers | Electrical Materials | 3D design software | Quiz |
| 7. | Exploring changes in primary students' attitudes toward science, technology, engineering, and mathematics (STEM) across genders and grade levels | Elementary school | 101–300 | More than three | Project-based | Learning perceptions | Mixed | Guidance | 9–24 weeks | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Mixed | No software | Quiz |
| 8. | Teachers co-designing and implementing career-related instruction | Middle school | 1–50 | Science | Mixed | Mixed | Project-basedlearning | Guidance | Less than one day | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Mixed | No software | Quiz |
| Paper Title | Sample Level | Sample Size | Learning Domains | Task Types | Learning Outcomes | Methods | Teachers’ Involvement | Duration | Reward Methods | Learning Setting | Interaction Types | Participant Interaction | Hardware | Software | Functionalities |
|-------------|--------------|-------------|------------------|------------|------------------|---------|----------------------|----------|----------------|------------------|------------------|------------------------|----------|----------|----------------|
| 9. The dream performance—case study of young girls’ development of interest in STEM and 21st century skills, when activities in a makerspace were combined with drama | Elementary school | 1–50 | More than three | Mixed | Mixed | Project-based learning | Guidance | 9–24 weeks | No rewards | Museum or Sciencecenter or theatre | Face-to-face interaction | With group members and teachers | Mixed | 3D design software | Quiz |
| 10. STEM Integration in sixth grade: designing and constructing paper bridges | Elementary school | 101–300 | 3 Disciplines | Mixed | Mixed | Project-based learning | Guidance | 1–7 day | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Mixed | No software | Scaffold supported |
| 11. STEM learning through engineering design: Impact on middle secondary students’ interest towards STEM | Middle school | 51–100 | More than three | Engineering design | Learningachievement | Problem-based learning | Guidance | 1–7 day | No rewards | After-school club or program | Face-to-face interaction | With group members and teachers | Mixed | No software | Quiz |
| 12. Integration of media design processes in Science, Technology, Engineering, and Mathematics (STEM) education | Middle school | 1–50 | 2 Disciplines | Mixed | Mixed | Project-based learning | Guidance | 9–24 weeks | No rewards | After-school club or program | Face-to-face interaction | With group members and teachers | Computers | Not Specified | Quiz |
| 13. The effect of hands-on ‘energy-saving house’ learning activities on elementary school students’ knowledge, attitudes, and behavior regarding energy saving and carbon-emissions reduction | Elementary school | 101–300 | Science | Mixed | Mixed | Project-based learning | Guidance | Not Specified | No rewards | In classroom | Face-to-face interaction | With teachers | Mixed | No software | Quiz |
| 14. An elective course to engage student pharmacists in elementary school science education | Elementary school | More than 300 | Science | Inquiry | Mixed | Inquiry-based learning | Guidance | 5–8 weeks | No rewards | In classroom | Blended interaction | With teachers | Computers | Online learning platform/website | Quiz |
| 15. Assessing the effectiveness of using fab lab-based learning in schools on k–12 students’ attitude toward STEAM | Mixed | 1–50 | More than three | Mixed | Mixed | Problem-based learning | Guidance | 1–7 day | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Electrical Materials | 3D design software | Quiz |
| 16. How creativity in STEAM modules intervenes with self-efficacy and motivation | Mixed | More than 300 | More than three | Mixed | Mixed | Guidance | More than 24 weeks | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Electrical Materials | No software | Quiz |
| Paper Title                                                                 | Sample Level       | Sample Size | Learning Domains | Task Types       | Learning Outcomes | Methods                | Teachers' Involvement | Duration  | Reward Methods | Learning Setting | Interaction Types | Participant Interaction | Hardware       | Software       | Functionalities |
|---------------------------------------------------------------------------|--------------------|-------------|------------------|------------------|-------------------|----------------------|------------------------|-----------|----------------|------------------|-------------------|-------------------------|----------------|---------------|----------------|
| 17. Investigating the effectiveness of STEAM education on students' conceptual understanding of force and energy topics | Middle school      | 51–100      | More than three  | Mixed            | Thinking skills   | Project-based learning | Guidance              | 9–24 weeks | No rewards     | In classroom    | Face-to-face interaction | With group members and teachers | No hardware | No software | Quiz            |
| 18. STEAM teaching professional development works: effects on students' creativity and motivation | Elementary school | More than 300 | More than three  | Knowledge acquisition | Mixed            | Inquiry-based learning | Guidance              | More than 24 weeks | No rewards | In classroom    | Face-to-face interaction | With group members and teachers | Mixed         | No software | Quiz            |
| 19. Short and long term impact of a high-tech STEM intervention on pupils' attitudes towards technology | Elementary school | More than 300 | Technology       | Mixed            | Learning perceptions | Project-based learning | Guidance              | Less than one day | No rewards | In classroom    | Face-to-face interaction | With group members and teachers | Mixed         | No software | Quiz            |
| 20. "I just do what the boys tell me": Exploring small group student interactions in an integrated STEM unit | Elementary school | 1–50        | 2 Disciplines    | Engineering design | Mixed            | Problem-based learning | Guidance              | 2–4 weeks | No rewards     | In classroom    | Face-to-face interaction | With group members | Electrical Materials | No software | Collaborative creation |
| 21. Active learning augmented reality for steam education—a case study       | Mixed              | 1–50        | 3 Disciplines    | Engineering design | Mixed            | Project-based learning | Guidance              | 1–7 day    | No rewards     | Workplace       | Face-to-face interaction | With group members and teachers | Electrical Materials | 3D design software | Quiz            |
| 22. Developing students' critical thinking: A steam project for chemistry learning | High school       | 1–50        | More than three  | Mixed            | Thinking skills   | Project-based learning | Guidance              | 5–8 weeks | No rewards     | In classroom    | Face-to-face interaction | With group members and teachers | Mixed         | No software | Quiz            |
| 23. Report and recommendation of implementation research-based learning in improving computational thinking skills embedded in STEM parachute design activities assisted by CCR (cloud classroom) | College/University | 51–100      | More than three  | Engineering design | Learning achievement | Research-based learning | Guidance              | Not Specified | No rewards     | In classroom    | Face-to-face interaction | With group members and teachers | Recyclable materials | Online learning platform/website | Quiz + scaffold |
| 24. STEAM maker education: conceal/reveal of personal, artistic and computational dimensions in high school student projects | High school       | 1–50        | 3 Disciplines    | Engineering design | Learning achievement | Project-based learning | Guidance              | 9–24 weeks | No rewards     | In classroom    | Face-to-face interaction | With group members | Arduino         | Quiz            |
| Paper Title                                                                 | Sample Level | Sample Size | Learning Domains | Task Types | Learning Outcomes                | Methods | Teachers’ Involvement | Duration | Reward Methods | Learning Setting | Interaction Types | Participant Interaction | Hardware | Software | Functionality |
|---------------------------------------------------------------------------|--------------|-------------|------------------|------------|----------------------------------|---------|-----------------------|----------|-----------------|-----------------|-------------------|-------------------------|-----------|----------|--------------|
| 25. STEAM-project-based learning integration to improve elementary school students’ scientific literacy on alternative energy learning | Elementary school | 1–50 | More than three | Mixed | Learning achievement | Project-based learning | Guidance | 5–8 weeks | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Mixed | No software | Quiz |
| 26. Teachers and STEM education: collaboration across disciplines and implementation of lessons in two subject areas | Middle school | Not Specified | 2 Disciplines | Engineering design | Learning perceptions | Project-based learning | Guidance | Not Specified | No rewards | In classroom | Face-to-face interaction | With group members | Booklets/workbooks | No software | Quiz |
| 27. From STEM to STEAM: cracking the code? How creativity & motivation interacts with inquiry-based learning | Elementary school | 101–300 | More than three | Mixed | Mixed | Inquiry-based learning | Guidance | Less than one day | No rewards | In classroom | Face-to-face interaction | With group members and teachers | No hardware | No software | Quiz |
| 28. Exploring the effectiveness of STEAM design processes on middle school students’ creativity | Middle school | 51–100 | More than three | Engineering design | Thinking skills | Project-based learning | Guidance | 9–24 weeks | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Mixed | No software | Scaffold supported |
| 29. Investigating the affordances of a CAD enabled learning environment for promoting integrated STEM learning | Mixed | More than 300 | 3 Disciplines | Simulation | Mixed | Project-based learning | Guidance | 2–4 weeks | No rewards | In classroom | face-to-face interaction | With group members and teachers | Mixed | 3D Design software | Scaffold supported |
| 30. Learning as Making: Using 3D computer-aided design to enhance the learning of shape and space in STEM-integrated ways | Mixed | 101–300 | More than three | Mixed | Spatial skills | Research-based learning | Guidance | 1–7 day | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Electrical Materials | 3D Design software | Scaffold supported |
| 31. The effect of project-based Arduino educational robot applications on students’ computational thinking skills and their perception of basic stem skill levels | Elementary school | 1–50 | More than three | Simulation | Mixed | Project-based learning | Guidance | 9–24 weeks | No rewards | In classroom | Blended interaction | With group members and teachers | Recyclable materials | Arduino + Scratch | Quiz |
| 32. The effect of STEM-based activities on 7th grade students’ academic achievement in force and energy unit and students’ opinions about these activities | Middle school | 51–100 | More than three | Engineering design | Learning achievement | Program-based learning | Guidance | 5–8 weeks | No rewards | In classroom | Blended interaction | With group members and teachers | Recyclable materials | Simulation software | Quiz |
| Paper Title                                                                 | Sample Level | Sample Size  | Learning Domains | Task Types | Learning Outcomes | Methods | Teachers’ Involvement | Duration | Reward Methods | Learning Setting | Interaction Types | Participant Interaction | Hardware | Software | Functionalities |
|----------------------------------------------------------------------------|--------------|--------------|------------------|------------|-------------------|---------|----------------------|----------|-----------------|----------------|-----------------|------------------------|-----------|----------|-----------------|
| 33. The impact of teaching the subject “pressure” with STEM approach on the  | Middle school | 1–50         | More than three  | Simulation | Mixed             | Program-based learning | Guidance | Less than one day     | No rewards | In classroom | Face-to-face interaction | With group members | Recyclable materials | No software | Quiz |
| 34. Enhancing spatial ability and mechanical reasoning through a STEM course | Mixed        | 1–50         | More than three  | Mixed      | Mixed             | Problem-based learning | Guidance | More than 24 weeks   | No rewards | Lab             | Face-to-face interaction | With group members and teachers | Electrical Materials | Simulation software | Quiz |
| 35. Robotics and STEM learning: Students’ achievements in assignments according to the P3 Task Taxonomy—practice, problem solving, and projects | Middle school | 1–50         | 3 Disciplines    | Simulation | Learning perceptions | Project-based learning | Guidance | 9–24 weeks          | No rewards | Lab             | Face-to-face interaction | With group members and teachers | Electrical Materials | Simulation software | Quiz |
| 36. Analysis of students’ critical thinking skill of middle school through   | Middle school | 101–300      | More than three  | Engineering design | Thinking skills | Project-based learning | Guidance | Not Specified      | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Recyclable materials | No software | Quiz |
| 37. Impacts of the Project Based (PBL) Science, Technology, Engineering and  | High School  | 1–50         | More than three  | Simulation | Mixed             | Project-based learning | Guidance | 5–8 weeks           | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Recyclable materials | No software | Quiz |
| 38. Co-robotics hands-on activities: A gateway to engineering design and     | Mixed        | 101–300      | 3 Disciplines    | Mixed      | Learning perceptions | Project-based learning | Guidance | 1–7 day             | No rewards | Summer camp     | Face-to-face interaction | With group members and teachers | Electrical Materials | 3D design software | Sketchup supported |
| 39. Advancing integrated STEM learning through engineering design: Sixth-grade | Elementary school | 101–300      | 3 Disciplines    | Engineering design | Learning achievement | Problem-based learning | Guidance | Less than one day   | No rewards | In classroom | Face-to-face interaction | With group members | Booklets/workbooks | No software | Quiz |
| 40. Programming experience promotes higher STEM motivation among first-grade girls | Elementary school | 51–100       | 2 Disciplines    | Mixed      | Learning perceptions | Project-based learning | Guidance | Less than one day   | No rewards | Lab             | Technology-mediated interaction | With teachers | Smart phones | Not Specified | Quiz |
| Paper Title                                                                 | Sample Level | Sample Size | Learning Domains | Task Types | Learning Outcomes | Methods       | Teachers’ Involvement | Duration  | Reward Methods | Learning Setting | Interaction Types | Participant Interaction | Hardware | Software | Functionalities |
|----------------------------------------------------------------------------|--------------|-------------|------------------|------------|-------------------|---------------|----------------------|------------|----------------|------------------|-------------------|------------------------|-----------|----------|----------------|
| 41. The effects of an afterschool STEM program on students’ motivation and engagement | Mixed        | 101–300     | More than three  | Knowledge acquisition | Learning perceptions | Problem-based learning | Guidance | 5–8 weeks | No rewards | After-school club or program | Face-to-face interaction | With group members and teachers | Recyclable materials | No software | Quiz           |
| 42. STEM learning through engineering design: fourth-grade students’ investigations in aerospace | Elementary school | 51–100      | 3 Disciplines    | Engineering design | Learning achievement | Problem-based learning | Guidance | Less than one day | No rewards | In classroom | Face-to-face interaction | With group members and teachers | Booklets/ workbooks | Online learning platform/website | Quiz           |
| 43. Effects of implementing STEM project-based learning activities for female high school students | High school  | 51–100      | More than three  | Engineering design | Mixed             | Project-based learning | Guidance | 5–8 weeks | No rewards | After-school club or program | Blended interaction | With group members and teachers | Mixed | Online learning platform/website | Scaffold supported |
| 44. Meteorology meets engineering: an interdisciplinary STEM module for middle and early secondary school students | Mixed        | 101–300     | 2 Disciplines    | Knowledge acquisition | Learning achievement | Inquiry-based learning | Guidance | 2–4 weeks | No rewards | Summer camp | Face-to-face interaction | With group members and teachers | Recyclable materials | No software | Quiz           |
| 45. The impact of problem-based learning strategies on STEM knowledge integration and attitudes: An exploratory study among female Taiwanese senior high school students | High school  | 1–50        | More than three  | Mixed             | Mixed             | Project-based learning | Guidance | 5–8 weeks | No rewards | After-school club or program | Blended interaction | With group members | Electrical Materials | Online learning platform/website | Quiz           |
| 46. Mars mission program for primary students: Building student and teacher skills in science, technology, engineering and mathematics | Elementary school | More than 300 | 2 Disciplines    | Simulation       | Mixed             | Problem-based learning | No guidance | Not Specified | No rewards | Museum or Science center or theatre | Blended interaction | With group members and teachers | Electrical Materials | Game | Scaffold supported |
| 47. Reflections on iCODE: Using web technology and hands-on projects to engage urban youth in computer science and engineering | Mixed        | 101–300     | More than three  | Mixed             | Mixed             | Project-based learning | Guidance | 2–4 weeks | No rewards | After-school club or program | Blended interaction | With group members and teachers | Electrical Materials | Simulation software | Quiz           |
| 48. A science, technology, engineering and mathematics course with computer-assisted remedial learning system support for vocational high school students | High school  | 1–50        | Science          | Mixed             | Mixed             | Inquiry-based learning | Guidance | 9–24 weeks | No rewards | In classroom | Blended interaction | With teachers | Electrical Materials | Online learning platform/website | Quiz           |
| Paper Title                                                                 | Sample Level     | Sample Size | Learning Domains | Task Types        | Learning Outcomes | Methods                          | Teachers’ Involvement | Duration | Reward Methods | Learning Setting | Interaction Types | Participant Interaction | Hardware                | Software           | Functionalities |
|-----------------------------------------------------------------------------|------------------|-------------|------------------|-------------------|-------------------|----------------------------------|------------------------|----------|----------------|------------------|---------------------|------------------------|-------------------------|-----------------|------------------|
| 49. The effect on pupils’ science performance and problem-solving ability through Lego: An engineering design-based modeling approach | Elementary school | 1–50        | More than three  | Mixed             | Mixed             | Inquiry-based learning          | Guidance              | 5–8 weeks | No rewards      | In classroom   | Face-to-face interaction | With group members and teachers | Recyclable materials | No software     | Quiz             |
| 50. Fostering students’ scientific imagination in stem through an engineering design process | High school      | 1–50        | More than three  | Mixed             | Thinking skills   | Project-based learning          | Guidance              | Less than one day | No rewards     | In classroom   | Face-to-face interaction | With group members and teachers | Recyclable materials | No software     | Quiz             |
| 51. A design-oriented STEM activity for students’ using and improving their engineering skills: the balance model with 3D printer | Middle school    | 1–50        | More than three  | Simulation        | Self-learning ability | Project-based learning          | Guidance              | Less than one day | No rewards     | Out-door place | Face-to-face interaction | With group members | Electrical Materials | 3D Design software | Quiz             |
| 52. Stop bridge collapse: a STEM activity about preventing corrosion of metals | High school      | 1–50        | More than three  | Mixed             | Learning achievement | Project-based learning          | Guidance              | 1–7 day         | No rewards     | In classroom   | Face-to-face interaction | With group members and teachers | Mixed                  | No software     | Quiz             |
| 53. Curriculum analysis and design, implementation, and validation of a STEAM project through educational robotics in primary education | Elementary school | 1–50        | More than three  | Mixed             | Learning achievement | Mixed                          | Guidance              | 1–7 day         | No rewards     | In classroom   | Blended interaction | With group members | Electrical Materials | Arduino           | Quiz             |
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