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Review

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

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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 Engestrom [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.

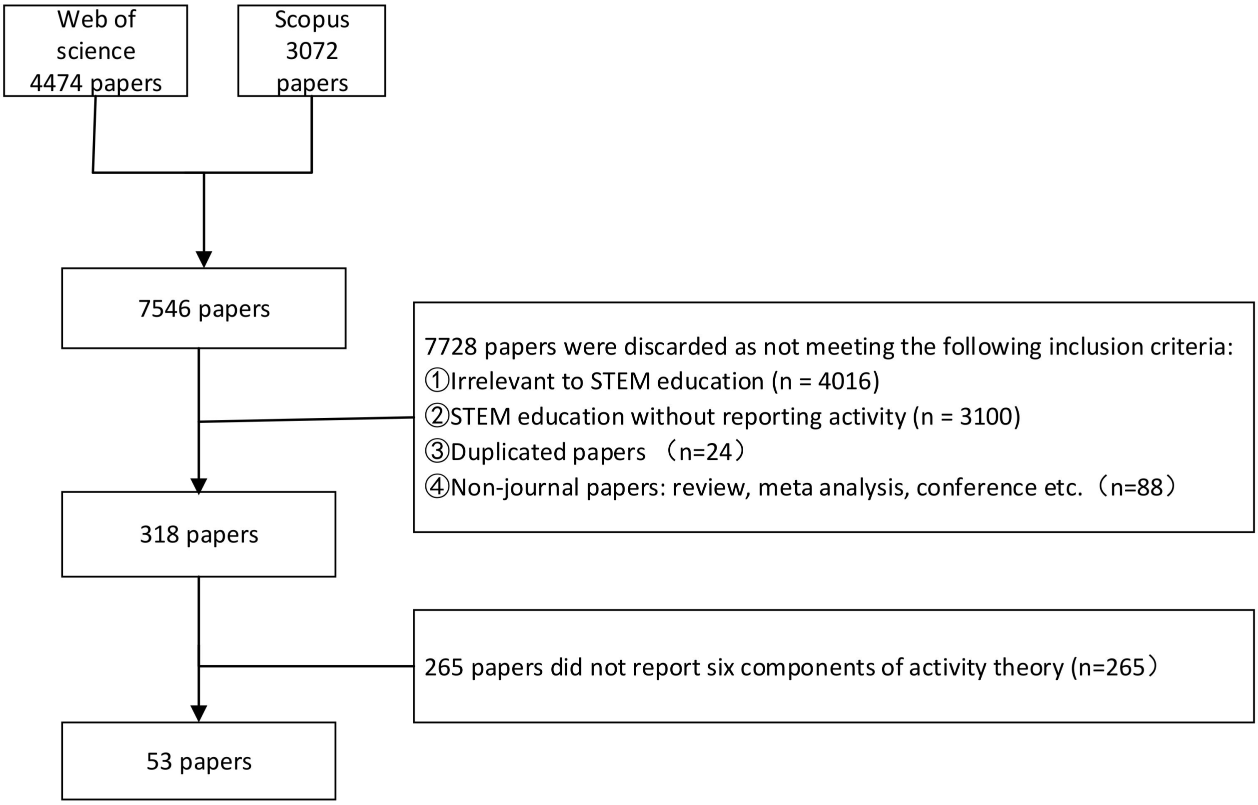

Figure 1. Diagram for the sample selection process.

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.

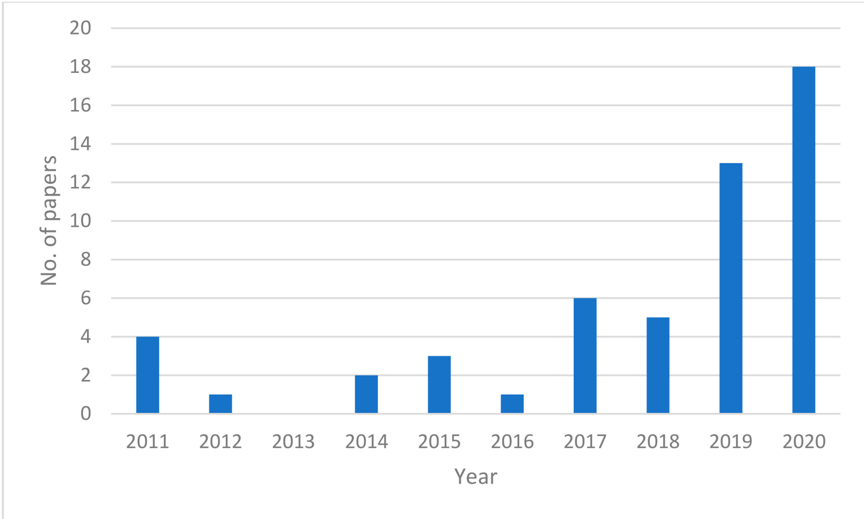

Figure 2. The distribution of 53 retrieved literature studies from 2011 to 2020.

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.

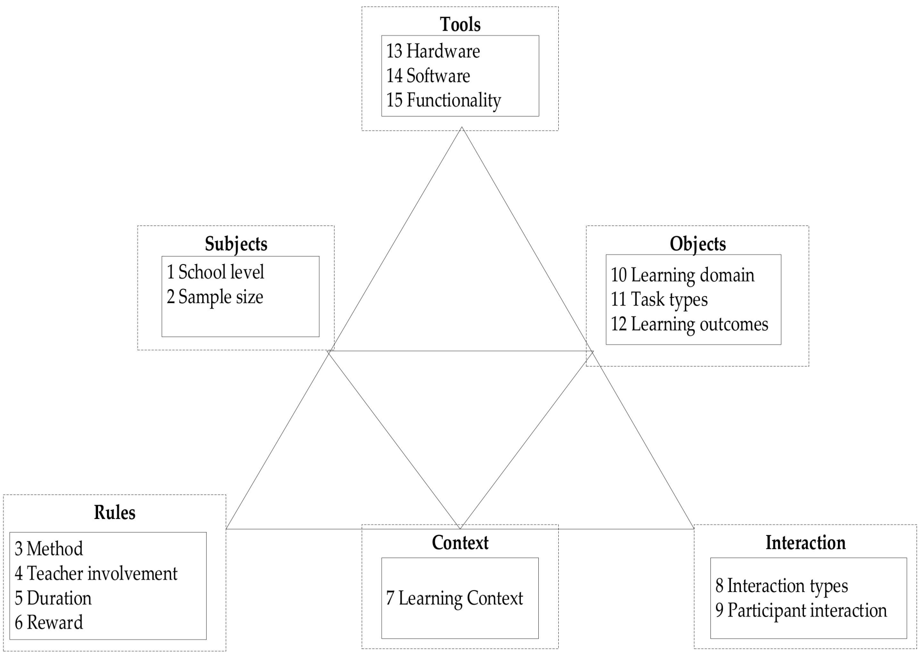

Figure 3. A framework for STEM learning activity based on activity theory.

Table 1. The coding scheme.

Elements	Super-Dimensions	Sub-Dimensions
Subjects	Sample level	1. Kindergarten (3–6) 2. Elementary school (6–12) 3. Middle school (12–15) 4. High school (15–18) 5. College/University (18–22) 6. Mixed
	Sample size	1. 1–50 2. 51–100 3. 101–300 4. More than 300 5. Not Specified
Objects	Learning domains	1. Science 2. Technology 3. Engineering 4. Mathematics 5. Two disciplines 6. Three disciplines 7. More than three disciplines
	Task types	1. Inquiry 2. Simulation 3. Investigation 4. Issue Discussion 5. Problem-solving 6. Engineering design 7. Knowledge acquisition 8. Mixed
	Learning outcomes	1. Learning achievements 2. Thinking Skills 3. Spatial skills 4. Learning perceptioins (such as satisfaction/attitudes/motivation) 5. Learning engagement 6. Self-learning ability 7. Mixed
Rules	Methods	1. Program-based learning 2. Project-Based Learning 3. Problem-based learning 4. Inquiry-based Learning 5. Research-Based Learning 6. Mixed
	Teachers' involvement	1. Guidance 2. Without guidance
	Duration	1. Less than one day 2. 1–7 day 3. 2–4 weeks 4. 5–8 weeks 5. 9–24 weeks 6. More than 24 weeks 7. Not Specified
	Reward methods	1. Individual rewards 2. Group rewards 3. No rewards

Table 1. *Cont.*

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
Tools	Hardware	1. Electrical Materials 2. Recyclable Materials 3. Computers 4. Booklets/workbooks 5. Smart phones 6. Mixed 7. No hardware
	Software	1. Online learning platform orwebsite 2. Arduino 3. Arduino + Scratch 4. 3D design software +Arduino 5. VR + AR + Arduino6. 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 or 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 software	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 eduation 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

	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
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-faceinteraction	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-faceinteraction	With group membersand teachers	Recyclablematerials	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-faceinteraction	With group membersand teachers	Mixed	No software	Quiz
4.	Promoting college student's 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-faceinteraction	With group membersand 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-faceinteraction	With group membersand teachers	Computers	Simulationsoftware	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	Learningperceptions	Project-basedlearning	Guidance	9–24 weeks	No rewards	After-school clubor program	Face-to-faceinteraction	With group membersand teachers	Electrical Materials	3D design software	Quiz
7.	Exploring changes in primary students' attitudes towards science, technology, engineering and mathematics (stem) across genders and grade levels	Elementary school	101–300	More than three	Project-based	Learningperceptions	Mixed	Guidance	9–24 weeks	No rewards	In classroom	Face-to-faceinteraction	With group membersand 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-faceinteraction	With group membersand 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-basedlearning	Guidance	9–24 weeks	No rewards	Museum or Sciencecen-ter or theatre	Face-to-faceinteraction	With group membersand 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-basedlearning	Guidance	1–7 day	No rewards	In classroom	Face-to-faceinteraction	With group membersand 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-basedlearning	Guidance	1–7 day	No rewards	After-school clubor program	Face-to-faceinteraction	With group membersand 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 clubor program	Face-to-faceinteraction	With group membersand 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 plat-form/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	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 combinatorial 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	Mixed	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	Functionalities
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 Speci-fied	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 academic achievements of the secondary school 7th grade students and their attitudes towards STEM	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 stem education project-based learning	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 Mathematics (STEM) education on academic achievement and career interests of vocational high school students	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 STEM learning	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 +Arduino	Scaffold supported
39.	Advancing integrated STEM learning through engineering design: Sixth-grade students' design and construction of earthquake resistant buildings	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	Problem-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 plat-form/website	Quiz
43.	Effects of implementing STEM-I 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 plat-form/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	Problem-based learning	Guidance	5–8 weeks	No rewards	After-school club or program	Blended interaction	With group members	Electrical Materials	Online learning plat-form/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 plat-form/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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