Inovasi Kurikulum
https://ejournal.upi.edu/index.php/JIK

Curriculum and instructional designs on SDGs STEM learning

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ABSTRACT

Few studies have investigated the latest findings about curriculum design for STEM learning. This study collected the latest evidence related to the curriculum design used in STEM learning. The Systematic Literature Review method with PRISMA Guidelines on empirical SSCI research articles based on the WOS database was employed to guide the review process and avoid bias in data analysis. After quality assessment, 27 articles were selected for analysis using the thematic analysis technique. The results showed three categories of curriculum designs, including mono, inter, and transdisciplinary subjects. Most studies focus on SDGs agenda No. 4, quality of education; apart from that, some explore weather and climate change, energy availability, clean water, sanitation, and peaceful societies. The most reported learning methods are research-based, program-based, problem and project-based, inquiry-based, and using tools and platforms to support the STEM learning process. Moreover, the types of assessments employed in the SDGs STEM learning are questionnaires, surveys, standardized tests, written tests, comprehension tests, and mixed tests. Future research could emphasize the development of empirically based research designs on other related SDGs topic issues, not only in the natural science domain but also in the socio-economic dimension.

ARTICLE INFO

Article History:
Received: 17 March 2024
Revised: 20 May 2024
Accepted: 23 May 2024
Available online: 26 May 2024
Publish: 30 May 2024

Keyword:
curriculum design; instructional design; SDGs based education; STEM learning

Open access
Inovasi Kurikulum is a peer-reviewed open-access journal.

ABSTRAK

Hanya sedikit penelitian yang menyelidiki temuan terbaru tentang desain kurikulum untuk pembelajaran STEM. Penelitian ini fokus pada pengumpulan bukti-bukti terkini terkait desain kurikulum yang digunakan dalam pembelajaran STEM. Metode Tinjauan Pustaka Sistematis dengan Pedoman PRISMA pada artikel penelitian empiris SSCI berbasis database WOS digunakan untuk memandu proses peninjauan dan menghindari bias dalam analisis data. Setelah dilakukan penilaian kualitas, dipilih 27 artikel untuk dianalisis menggunakan teknik analisis tematik. Hasil penelitian menunjukkan bahwa terdapat tiga kategori desain kurikulum yang meliputi mata pelajaran mono, interdisipliner, dan transdisipliner. Sebagian besar penelitian berfokus pada agenda SDGs No. 4, kualitas pendidikan, selain itu ada juga yang mengeksplorasi cuaca dan perubahan iklim, ketersediaan energi, air bersih dan sanitasi, termasuk masyarakat yang damai. Metode pembelajaran yang paling banyak dilaporkan adalah pembelajaran berbasis penelitian, pembelajaran berbasis program, pembelajaran berbasis masalah dan proyek, pembelajaran berbasis inkuiri, serta penggunaan alat dan platform untuk mendukung proses pembelajaran STEM. Selain itu, jenis penilaian yang paling banyak digunakan dalam pembelajaran STEM SDGs adalah angket, survei, tes terstandar, tes tertulis, tes pemahaman, dan tes campuran. Penelitian di masa depan dapat menekankan pengembangan desain penelitian berbasis empiris pada isu-isu topik SDGs terkait lainnya, tidak hanya pada domain ilmu pengetahuan alam, tetapi juga pada dimensi sosial-ekonomi.

Kata Kunci: *desain kurikulum; desain pembelajaran; pendidikan berbasis SDGs; pembelajaran STEM*

How to cite (APA 7)
Surahman, E. (2024). Curriculum and instructional designs on SDGs STEM learning. *Inovasi Kurikulum, 21*(2), 1177-1192.
Peer review
This article has been peer-reviewed through the journal’s standard double-blind peer review, where both the reviewers and authors are anonymised during review.

https://doi.org/10.17509/jik.v21i2.69620

INTRODUCTION

To produce educational graduates who are literate in theory, practice, and the development of science, technology, engineering, and mathematics (STEM), STEM is developed and integrated into the curriculum (Margot & Kettler, 2019). STEM is a learning approach model that combines the subject areas of science, technology, engineering, and mathematics in problem-based, project-based, and research-based learning modes (Hendriana, 2023). The STEM program is defined as an example of a catalyst for a learning environment for students (Margot & Kettler, 2019). The availability of quality STEM programs can help students develop their talents in science, technology, engineering, and mathematics (MacFarlane, 2016). Thus, in general, the purpose of implementing a sustainable STEM education program is to prepare people who are STEM literate when they enter the world of work or when continuing their studies in college. According to NRC from its book titled "*STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*", STEM literacy means awareness of the role of science, technology, engineering, and mathematics in the needs of modern society, a basic understanding of basic concepts in each area, and basic skills in basic level applications such as accuracy in critically evaluating content. Science in news reports, performing mathematical operations for daily needs, and solving problems using technology (Margot & Kettler, 2019).

To realize successful STEM learning requires various efforts from education stakeholders, streamlining the STEM-oriented curriculum, changing the learning paradigm from teacher-centered to student-centered, and using project-based, problem-based, and research-based models (Gyasi et al., 2021). In addition, teachers not only master the material according to their field but also have to understand other disciplines that are summarized in STEM (Margot & Kettler, 2019). So, preparing prospective teachers for higher education levels also requires the design of a STEM-based curriculum. In addition, teachers must increase their self-development to develop their professional and pedagogical competencies in designing learning, guiding students to solve problems, encouraging students not to give up, and designing teaching materials and evaluations following the needs of STEM learning.

STEM learning, in principle, consists of all general learning components such as learning objectives, subject matter, methods, processes, and evaluation of the learning itself. However, the difference with non-STEM learning is the integration of cross-subject lessons that are usually separate and partial to be integrated into interdisciplinary designs. One of the challenges to realizing good STEM learning is the lack of attention to curriculum design and STEM learning activities in schools (Gyasi et al., 2021). The division of teachers and subject-based teaching has been too entrenched for a long time. It is like a thick wall that must be broken down so that the sectoral ego in each subject can be reduced and increase the awareness of teachers, curriculum designers, and teaching materials designers to combine cross-materials and subjects in one STEM learning design consciously.

This research is being conducted immediately due to the lack of attention given by earlier researchers to the review of learning activities (Gyasi et al., 2021). According to the search results in the WOS SSCI paper database, a greater number of literature reviews specifically examine teachers' perspectives on the incorporation of STEM into education (Margot & Kettler, 2019). However, few studies explore the curriculum and instructional design in SDGs STEM learning.

To find out what practitioners and researchers have done to design successful STEM learning, researchers are encouraged to conduct a systematic literature review of recent studies that focus on research on instructional design in sustainable STEM learning. This study, by reviewing, synthesizing, and critically and comprehensively analyzing several existing studies, hopes to contribute a complete summary of what is known about the curriculum and instructional design models used in STEM education in line with the SDGs concept.

https://doi.org/10.17509/jik.v21i2.69620

The purpose of this study was to examine the existing literature on instructional design models in STEM learning that are in line with the concept of SDGs. This study seeks to understand what the research community already knows regarding learning objectives, learning methods, learning assessments, and future research directions in STEM education that align with the SDGs concept. To test what already exists in the literature, the following research questions have been used: 1) how is the existing research on curriculum and instructional design in SDGs STEM learning?; 2) what types of learning objectives in SGDs STEM education?; 3) what learning methods are most used by SDGs STEM learning?; 4) what types of learning assessment in SDGs STEM education?; and 5) what are the future research directions on SDGs STEM education?

LITERATURE REVIEW

Investigate studies in an important area to capture the existing conditions and provide guidance for future studies (Sirakaya & Alsancak Sirakaya, 2018). This research is urgently carried out because a review of learning activities still does not get the attention of previous researchers (Gyasi et al., 2021). Based on the search results in the WOS SSCI paper database, more literature review results focus on teachers' perceptions of the integration of STEM and education (Margot & Kettler, 2019), the use of augmented reality in STEM education (Ibáñez & Delgado-Kloos, 2018; Sirakaya & Alsancak, 2018), immersive virtual reality in STEM education (Pellas et al., 2020), the use of mobile game-based learning in STEM learning (Gao et al., 2020), game-based learning in virtual world (Pellas & Mystakidis, 2020), use of robotic programming (Çetin & Demircan, 2020), computational thinking in science classroom (Ogegbo & Ramnarain, 2021), interdisciplinary assessment in STEM education (Gao et al., 2020), cross-cultural issue in STEM education (Rodriguez & Shim, 2020), training mentors (Stelter et al., 2021), and evidence of the effectiveness of the application of STEM on student learning outcomes (Wahono & Chang, 2019).

The literature review reports above do not focus on reviewing the results of the latest research on instructional and curriculum design used in STEM education based on SDGs. So, this study seeks to solve these problems to assist practitioners, teachers, and stakeholders in selecting and using them in an effective and efficient STEM learning process.

In coding and analyzing the data from the review results, the author refers to research describes the data comprehensively, including learning context, learning design, learning objectives, learning methods, learning assessment, learner, and media tools used in the research report (Gyasi et al., 2021). Then, it will be adapted for the review of this study. The author refers to the 2020 Sustainable Development Goals (SDGs) report on the SDGs variable. The United Nations (UN) 2030 Agenda highlights that efforts to ensure inclusive, equitable, and quality education and promote lifelong learning for all (SDGs 4) are at the core of the agenda concerned by the author, but also includes 16 other agendas outlined by the United Nations such as eradicating poverty, eliminating hunger, promoting good health and well-being, achieving gender equality, ensuring access to clean water and sanitation, promoting affordable and clean energy, fostering economic growth and decent work, developing industry, innovation, and infrastructure, reducing inequalities, creating sustainable cities and communities, promoting responsible consumption and production, taking action on climate change, protecting life below water and life on land, promoting peace, justice, and strong institutions, and fostering partnerships to achieve these goals.

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METHOD

This study conducted a systematic literature review using the criteria of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). PRISMA was developed by 29 review authors in 2005 (Page et al., 2021). The PRISMA guideline contains 27 checklist items and four phased diagrams for transparency in a literature review (Page et al., 2021). The review process involves data collection, selection of the primary literature, assessment of the quality of the literature, data extraction, and synthesis.

Data Collection

To achieve the objectives of this study, the systematic review process begins with the search for research data carried out in an electronic database using the Web of Science database (see: https://www.webofscience.com/wos/woscc/basic-search). The search process was carried out on August 3, 2023. The keywords and connectors used in the referral search were "STEM education" AND "sustainable development" OR "STEM learning" AND "sustainable development". All searches were conducted using the all-field option, which aims to search for candidate papers comprehensively on all types of literature without being limited by the year of publication. The search results were 72 papers obtained from the Web of Science.

Inclusion and Exclusion Criteria

Table 1. Inclusion and Exclusion Criteria in Selecting Review Studies

No	Inclusion Criteria	Exclusion Criteria
1	Published in all the years	-
2	Published in SSCI WOS indexed journal	Not indexed by WoS database
3	Empirical and peer-reviewed research articles	Proceedings, books, review articles, conference reviews, book chapters
4	Articles in English	In another language
5	The topic of the article discusses about SDGs STEM Education	The topic of the article is not related to the SDGs STEM education agenda
6	File articles are available online	Not available to access

Source: Surahman & Wang (2023)

The next stage involves several selection criteria to identify research reporting on the practice of STEM learning or STEM education related to the concept of the 4th SDGs agenda (see **Table 1**), namely quality education and other SDGs agendas. All authors collaborated to apply the defined criteria (see Table 1). To be included in this review, research requires peer review and publication in a scientific journal (n = 55) (books, conference papers, magazines, newspapers excluded, and non-English papers, n = 17). The included articles were indexed on the SSCI databases (n = 37). Articles not indexed on the SSCI were excluded (n = 18). Articles can be reported at all levels of education, including early childhood education, primary education, secondary schools, high schools, college and university students, professional development programs, and workers training programs, including those related to student disabilities. The research reviewed should discuss the relationship with the topic of the 4th SDGs agenda for educational equity. In addition, the extracted data aligned with the research questions so that 27 articles were fulfilled that met all the criteria. The diagram of the study search process carried out can be seen in **Figure 1**.

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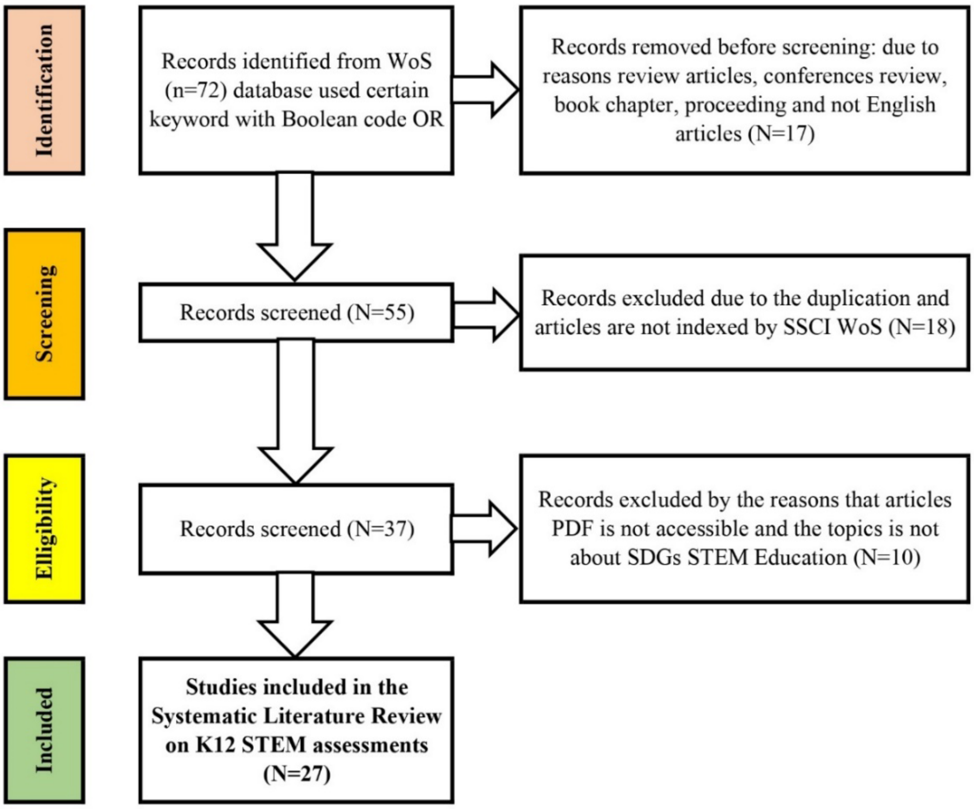

Figure 1. Systematic Review Process Based on the PRISMA Framework
Source: Author's data 2024

Figure 2 shows the data for the 27 articles were distributed in 2010-2014 (3.70%), 2015-2019 (14.81%), 2020-2023 (81.48%), where the increase in 2021-2023 is very significant, each by 11, 5 and 3 articles. At the beginning of its development, it was still fluctuating; for example, in 2010-2014 and 2015-2019, only five studies were found that matched our research criteria, but since 2020-2023, the trend has tended to increase. Furthermore, based on the source journal title, these review studies are spread across 14 reputable international journals.

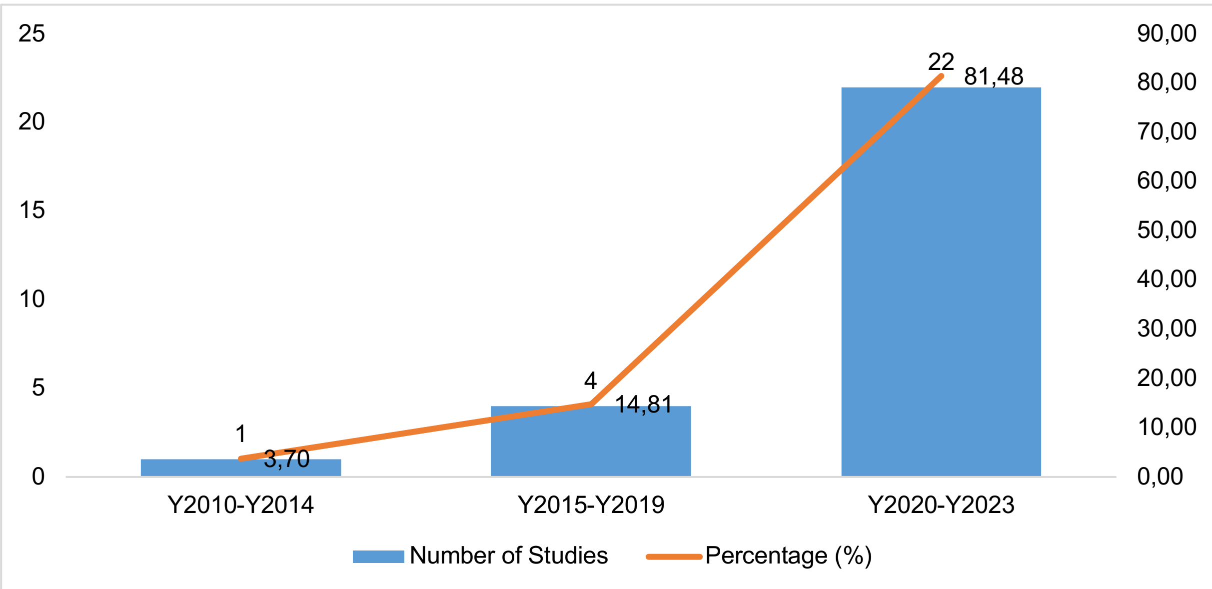

Figure 2. Distribution of 27 Reviewed Literature Studies Based on Year
Source: Author's data 2024

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The sustainability journal ranks first with 51.9%, and the remaining 13 have 3.7% **(Figure 3)**.

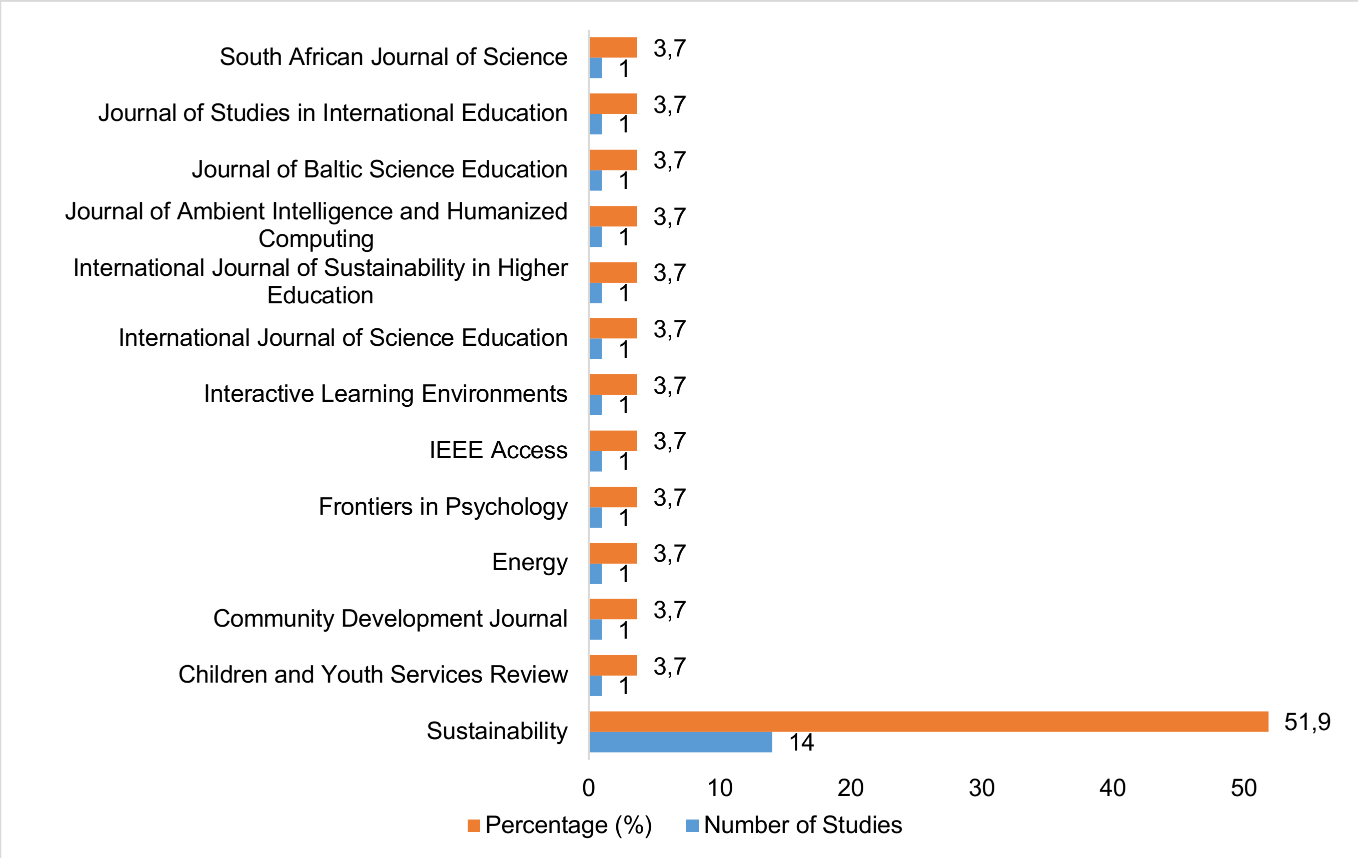

Figure 3. Distribution of 27 Reviewed Literature Studies Based on Journal Sources
Source: Author's Data 2024

Data Analysis

The author used the thematic analysis method to analyze each retained article based on the inclusion and exclusion criteria. Thematic analysis methods are carried out to identify, analyze, and report themes or patterns in the data. Each theme is defined to capture important information about the collected data. There are six phases of thematic analysis, including data introduction, initial coding, the initial search for themes by compiling code, examining each theme or reviewing to ensure that code extracts have been carried out, defining and naming each theme, and finally, generating a report from the theme and linking it back with all research questions (Clarke & Braun, 2014).

Both authors read all retained articles to establish a rating protocol for coding the findings. They agreed to the previously defined coding protocol regarding the study (Gyasi et al., 2021). In this study, the author used the monodisciplinary, interdisciplinary, and transdisciplinary subject categories to identify the instructional design of STEM learning for SDGs. While in the learning method, the author used program-based learning, research-based learning, project-based learning, problem-based learning, and inquiry-based learning (Zheng et al., 2019). In addition to using tools or platforms to support the SDGs STEM learning process. Meanwhile, to identify the SDGs agenda reported by our researchers, the author used the guidelines outlined by the United Nations, such as eradicating poverty, eliminating hunger, promoting good health and well-being, achieving gender equality, ensuring access to clean water and sanitation, promoting affordable and clean energy, fostering economic growth and decent work, developing industry, innovation, and infrastructure, reducing inequalities, creating sustainable cities and communities,

https://doi.org/10.17509/jik.v21i2.69620

promoting responsible consumption and production, taking action on climate change, protecting life below water and life on land, promoting peace, justice, and strong institutions, and fostering partnerships to achieve these goals. After the coding has been agreed upon, the next step is to synthesize the essence of each finding in each coding category to be presented in the results and discussion section.

RESULTS AND DISCUSSION

In this section, the author presents the data from our review of 27 peer-reviewed journal papers that have met the inclusion criteria. The author presents the findings based on four research questions about instructional and curriculum design in STEM learning, types of learning theories and principles in the development of learning models, instruction and curriculum design that are widely adopted for STEM learning with STEM SDGs, and future research direction on the topic of instructional and curriculum design. On STEM education, the theme of SDGs.

SDGs Agenda, Sample Size Covered in Studies

Based on the results of data analysis in articles that were included for review, 45.71% of studies discussed the 4 SDGs agenda (quality education), followed by an agenda on clean and affordable energy, clean water and sanitation, climate change, oceans, seas and marines, and peaceful societies by each 5.71%, and the remaining 2.86% each for other issues, as shown in **Figure 4**.

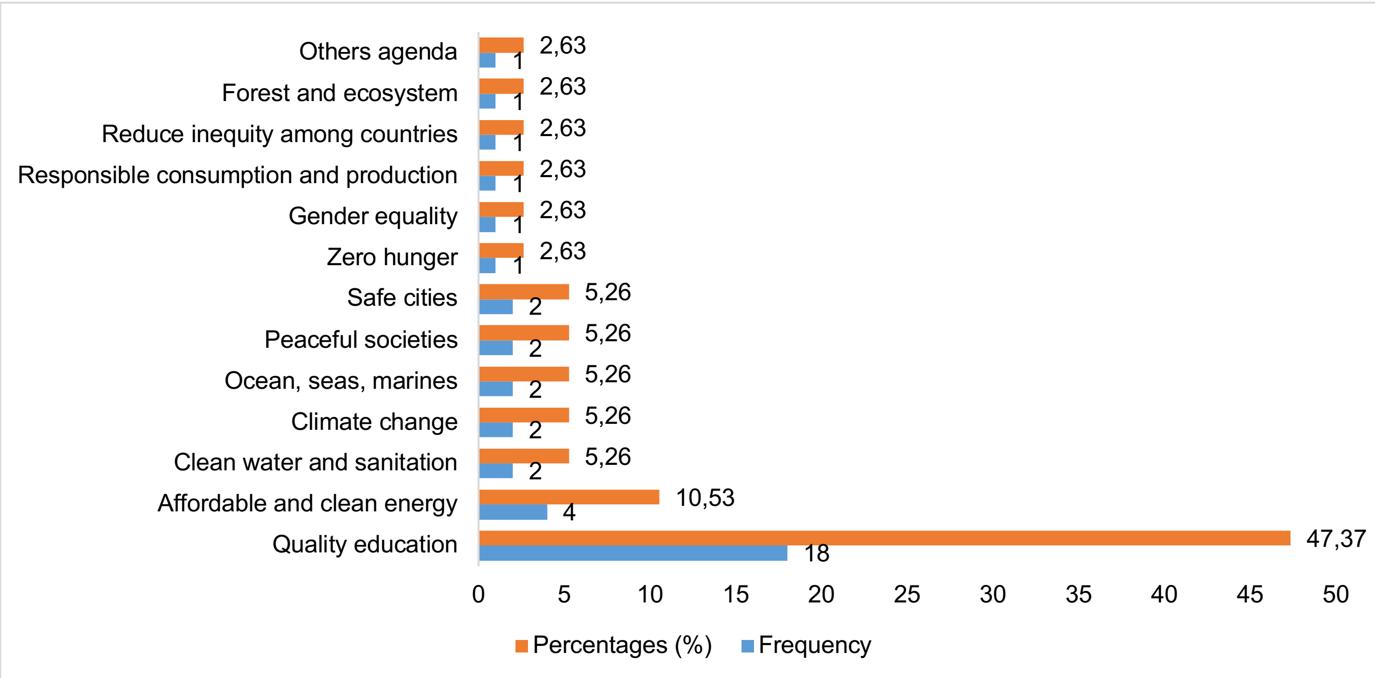

Figure 4. Distribution of SDGs Agenda in STEM Education
Source: Author's data 2024

Meanwhile, it is seen from the sample variables and research participants covered in the articles reviewed. As many as 41.7% were reported in college education, including reguler student and preservice teachers, then 20.8% in teacher professional development programs in the STEM field, middle school, high school, and informal learning, with 8.3% each. Meanwhile, no reports have been found in elementary school. While the number of samples that were most involved was in the range of 1-50,101-300 and more than 300 samples respectively 20.8%, and the remaining 50-100 samples 12.5%, more no reported sample size for about 25% (**Table 2**).

https://doi.org/10.17509/jik.v21i2.69620

Table 2. Distribution of Sample Levels and Sample Size in SDGs STEM Learning Research

Variable	Category	Number of studies	Proportion of studies
Sample level	Kindergarten	1	3.70%
	Elementary school	2	7.41%
	Midle school	2	7.41%
	High school	2	7.41%
	College/University	10	37.04%
	Professional development	6	22.22%
	Mixed	1	3.70%
	Non-formal education	1	3.70%
	Not mentioned	2	7.41%
Sample size	1-50 sample	5	18.52%
	51-100 sample	4	14.81%
	101-300 sample	6	22.22%
	More than 300	5	18.52%
	No reported	7	25.93%

Source: Research 2024

Instructional and Curriculum Design Models in SDGs STEM Learning

Figure 5 shows data on the distribution of STEM learning instructional design categories associated with the SDGs agenda for educational equity. Predominantly transdisciplinary learning designs are reported more. This means that researchers are more likely to design STEM learning that is associated with the SDGs by involving more than three areas of STEM learning such as science, engineering, engineering, and mathematics, as reported by the researchers (Nguyen et al., 2020; Nguyen et al., 2020; Wahono & Chang, 2019). However, some studies are also conducted in a monodisciplinary manner, meaning that they only involve one topic, such as research on science (Araya & Collanqui, 2021), physics (Chapman et al., 2015), science-energy (Mylonas et al., 2021), Zoology (Kulshreshtha et al., 2022), as well as in social science (Marcone, 2022). This research inspires practitioners to be able to choose whether the model is mono, interns, or transdisciplinary in promoting SDGs issues in STEM learning.

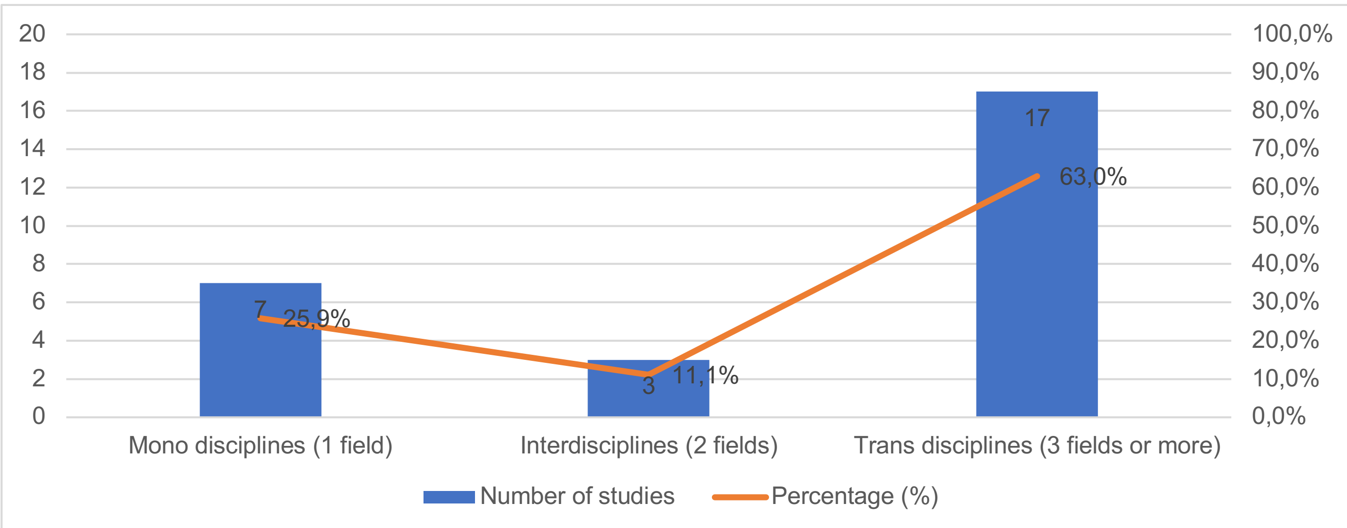

Figure 5. Distribution of Instructional Design Categories on SDGs STEM learning
Source: Author's Data 2024

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Learning Objectives in SGDs STEM Education

Based on the findings in the articles reviewed, most of them were more focused on promoting the 4 SDGs agenda in STEM-based learning. The primary purpose of learning is to encourage students, prospective teachers, and teachers to realize the importance of quality education as part of a continuing education development program (Nguyen et al., 2020; Wahono & Chang, 2019). Explaining the essence of education for human survival in the long term (Suh & Han, 2019). Introducing STEM for cross-country students to understand air quality issues (Rico et al., 2021). Another goal is to promote awareness about eco-farming (Pajk et al., 2021), climate change, air condition, and energy availability (Chiang, 2021; Melton et al., 2022), understand the greatness of the universe (Dieck-Assad et al., 2021), and adopting STEM education during and post COVID-19 pandemic (Jeong & González-Gómez, 2021). Apart from that, some encourage increased student motivation to explore STEM learning and have a career in the STEM field (Sharma, 2021). Other learning objectives are looking for the best practice of STEM learning on social humanities in a sustainable manner (Marcone, 2022) and educating about environmental and social issues (Campbell et al., 2022). Based on some of the learning objectives mentioned, it is clear that the emphasis on STEM education related to the SDGs agenda is still limited. More massive assessment is needed in future studies.

Learning methods and models are most used in STEM learning for SDGs.

Figure 6 depicts a summary of the distribution of learning methods and models that are widely used in the studies reviewed. The research-based learning model is the most dominant n=9, 33.3%; program-based learning n=7, 25.9%; project and problem-based learning (n=5, 18.5% and n=4, 14.8% respectively); the last one is inquiry-based learning n=2, 7.4%. Research-based learning can be understood as a learning process that promotes the SDGs agenda in STEM learning through research designed by researchers and teachers. Researchers use research schemes to measure awareness, understanding, and interest in STEM learning with SDGs agendas (Nguyen et al., 2020; Nguyen et al., 2020; Wahono & Chang, 2019).

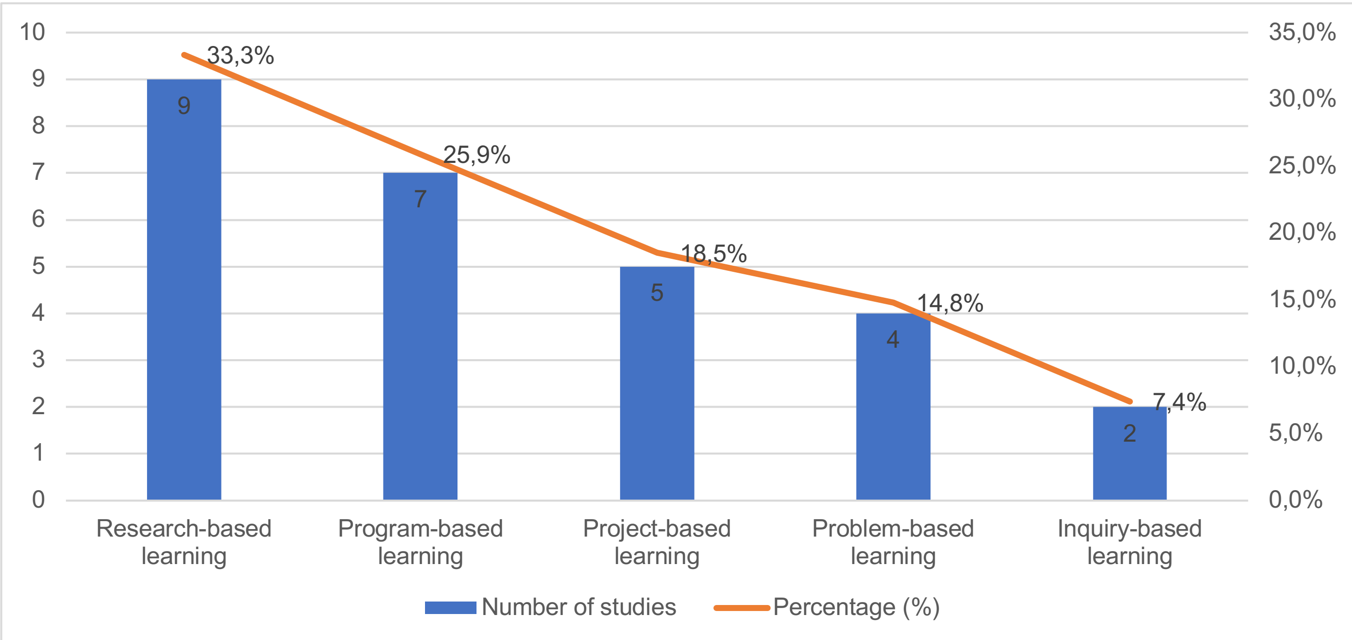

Figure 6. Distribution of Learning Methods and Models on SDGs STEM Learning
Source: Author's Data 2024

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On the other hand, learning-based programs mean that researchers and practitioners report their studies, a series of STEM learning programs under an affiliate funder (Rico et al., 2021; Timko et al., 2022). Usually, there is a period from the implementation of a program. Meanwhile, problem-based learning means learning in the form of problem-solving related to the SDGs agenda and issues such as energy consumption and saving (Amoako & Insaidoo, 2021; Araya & Collanqui, 2021), climate, environment (Melton et al., 2022; Rico et al., 2021), and gender issues (Ho et al., 2020; Sharma, 2021).

Learning Assessment in SDGs STEM Education

Based on the results of the analysis of the study of STEM learning related to the SDGs agenda as examined. Some of the assessment models and methods are presented in **Figure 7**. Questionnaires, surveys, and mixed methods are the most widely reported assessment methods, with 29.6% and 18.5%, respectively. This follows the context of the learning objectives, which are more focused on increasing understanding of the SDGs agenda in STEm learning. Meanwhile, the pre-test, post-test, standardized test, and conceptual knowledge of STEM material in relation to the SDGs agenda were 7.4% each. The rest are written answers, concept maps, and EEG at 3.7%.

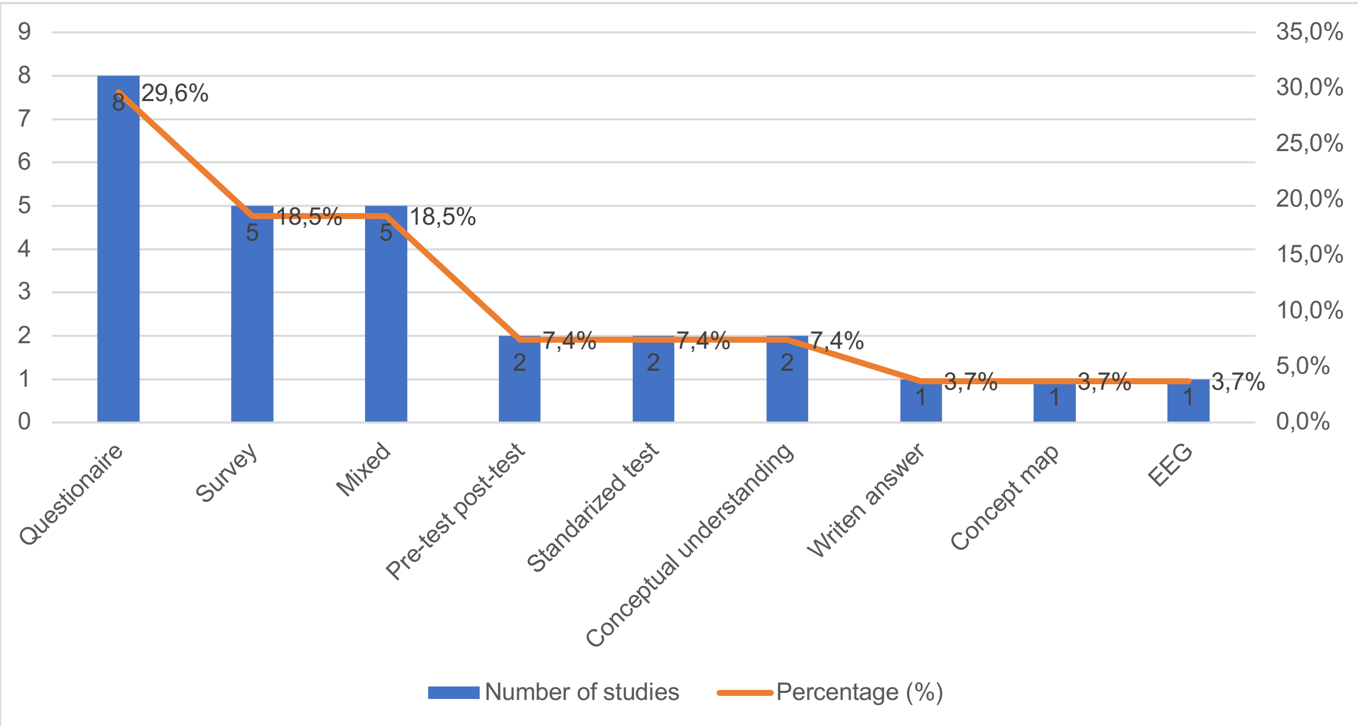

Figure 7. Distribution of Assessment Forms on SDGs STEM Learning
Source: Author's Data 2024

Discussion

The Learning outside the classroom (LOtC) activities method to teach students about Chemistry and SDGs, including through industrial visits. The results found positive perceptions of industrial visits, more interest in class materials, and increased understanding of learning materials. In principle, the LotC method can be implemented in other categories of subjects related to industrial fields, such as engineering and science (González-Peña et al., 2021). Another widely reported model in STEM education is learning through robotic competition activities, computational problem-solving, and real societal problems. For example, a research report on the research results between electronic engineering classes using partner

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training with Challenge-Based Learning Oriented to Sustainable Development Goals with traditional classes (Dieck-Assad et al., 2021). In the context of globalization, research from the past has reported the results of research involving two countries in the student education process related to energy saving and socioeconomic problems (Araya & Collanqui, 2021). The results found the level of engagement of the student learning process through the interaction between students in overcoming energy and CO2 problems. Climate issues are closely related to STEM lessons and SDGs. Another research reported the results of his research on the development of virtual climate change applications to increase students' awareness of the impact of climate change on the world; through 10-minute VR media, the author reported positive changes related to student awareness (Pimentel & Kalyanaraman, 2021).

Sustainability in Algebra mathematics class with mathematical model material. As a result, students can perceive mathematics material positively. This research has not specifically examined the concept of SDGs in the context of mathematics. Still, at least the students have been introduced to the basic principles of the SDGs from a mathematical perspective (Suh & Han, 2019).

In the context of teacher professional development in STEM education and SDGs, research revealed teachers' average positive perception of STEM education, especially when viewed from their educational background (Khuyen et al., 2020). However, in practice, they are still not very confident due to a lack of experience, so continuous training and assistance are needed regarding lesson plans and learning materials (Khuyen et al., 2020). This needs to get support from governments, managers of educational institutions, and parents so that teachers have adequate competence in designing SDGs-based STEM learning. In line with that, research reported that pre-service teacher programs using the face-to-face model differ significantly in perception and emotion compared to face-to-screen (F2S). Meanwhile, to increase interactivity in virtual learning, active learning methods are needed to attract students to be involved in the learning process (Jeong & González-Gómez, 2021).

The development of technological innovation in the field of education has a significant impact both in supporting the learning process and in preparing the competence of prospective teachers. Using gamification, comparative, and IoT-based educational activities has proven effective in increasing student participation in learning and their awareness of energy saving (Mylonas et al., 2021). Energy saving is one of the important issues in the SDGs that needs serious attention, especially in the school curriculum. Teachers and students need to know the importance of saving energy, considering that all humans depend highly on energy sources. Giving self-understanding to students can increase their awareness of how life patterns should be carried out.

Implications for Future Studies

Based on the analysis and synthesis results of the review study, some practical implications and recommendations for our future studies are described below. In preparing for continuous STEM learning, it is recommended to develop more massive teaching materials on various subjects and gamification-based and IoT-based education levels to measure their impact on learning (Mylonas et al., 2021). This ensures that STEM education is not just a short-term routine program but can become a long-term program that can promote the principles of continuing education outlined by UNESCO.

In the context of students in sustainable STEM learning, investigating in detail the additional determinants of student STEM learning outcomes, for instance, non-STEM disciplines and training, as well as internal factors like students' reading habits or personal hobbies, may influence their performance in STEM topics (Ho et al., 2020). Investigating the dynamics of student group interactions during the study of sustainability in STEM courses. Considering that sustainability primarily concerns society and the tangible world, students' backgrounds may exert a more significant influence when they engage in concrete STEM projects. This is also important to investigate in the future (Suh & Han, 2019). Meanwhile (Chiang, 2021)

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emphasizes the importance of studying students' future participation and makes several stages of data to estimate learning efficiency. This means that students are involved in how learning is measured from the start, so the main role of controlling the quality of learning is for teachers and each student, encouraging self-regulated learning.

In the aspect of using technology to support sustainable STEM learning, researchers focus on studying the application of technology, optimizing industrial structures as well as Science, Technology, Engineering, and Mathematics (STEM) education and tax concessions to increase public understanding (Amoako & Insaidoo, 2021). Applying the right technology helps educators design STEM learning that facilitates students in achieving sustainable learning goals effectively and efficiently. For example, researchers could explore the effect of virtual scientists on STEM interest in the context of more neutral STEM topics (e.g., physics) in addition to other subjects (Pimentel & Kalyanaraman, 2021). This is not impossible if, in the metaverse era, the role of the STEM teacher can be strengthened with the help of a virtual STEM teacher and instructor.

It is necessary to conduct an in-depth analysis of the performance and affective domains in the F2S PST program and to study the differences in the results based on gender. It also recommends further studies on appropriate adoption and transitions to promote preservice teacher performance and affective domains. Thus, it will enable pre-service teachers to be more interactive in virtual and online contexts to implement active teaching methodologies to educate future students to teach STEM content (Jeong & González-Gómez, 2021). One model that can be developed to prepare educators for STEM-based learning is DDMT. This model contains four main stages: Discover, Define, Model & Modeling, and Transfer (DDMT). This model is not tied to a particular subject but can be used in every field, including sciences, technology, engineering, art, math, and many more (Lam et al., 2019).

In implementing sustainable STEM education at the tertiary level, educational institutions strengthen the evaluation and validation of disciplinary competencies in all engineering/science study programs that support the achievement of STEM and SDGs fields (Dieck-Assad et al., 2021). This is to maintain the quality standards of processes and graduates. Meanwhile, Chapman et al. (2015) recommend explicit research toward a more rigorous impact assessment of the impact of astronomy programs. So that the long-term impact of programs implemented in continuing education can be measured. In addition, it is necessary to spread the concept of STEM learning in other fields, such as language, art, and social humanities.

CONCLUSION

This study concludes that portraits of the implementation of curriculum design in the context of sustainable STEM learning have been reported at every level of education: preschool, K-12, higher education, professional development, and non-formal education. Although still dominated at the level of higher education and professional development. This shows that the practice of STEM learning based on continuing education in the K-12 context still needs to be massive. However, the good news is that the program for preparing teacher candidates and developing the profession of STEM educators has begun to be developed. This promises massive distribution in the future. Meanwhile, the SDGs categories widely reported in the studies are education and environment: energy consumption, climate change and social and gender issues. The STEM subjects reported are dominated by STEM disciplines, mathematics, science, physics, chemistry, and biology, a small part of which is noted in universities' social science, humanities, economics, and sustainability courses.

https://doi.org/10.17509/jik.v21i2.69620

Meanwhile, research topics that are widely reported include knowledge, attitudes, motivation, and skills related to STEM, social equality, SDGs, eco-farming, energy, astronomy, algebra, material science, and applications in civil engineering. Meanwhile, the learning methods that are widely used in sustainable STEM learning include the incorporation of STEM disciplines, inquiry-based on real-world contexts, problem-based learning, design-based learning, cooperative learning approaches, case studies, virtual learning, didactic model, with and without industry training, learning outside the classroom (LotC) activities, VR, gamification competition, and IoT based educational activities, and F2F vs F2S in a flipped classroom. Meanwhile, the forms of continuous STEM learning evaluation that have been reported include questionnaires, surveys, standard STEM tests, EEG, mobile applications, pre-test and post-tests, conceptual understanding, and procedural and attitudinal contents to solve contextual problems.

The study's limitations are due to the limited number of referrals that match the criteria for our review of studies. It needs to be investigated more massively by expanding the inclusion of the database used to get a more comprehensive picture of how continuing education is promoted in the practice of STEM learning. In addition, it is also necessary to study the latest reports on STEM learning practices due to the COVID-19 pandemic and the potential development of virtual scientists in the metaverse era. The focus of future research, emphasizing the development of empirically based research designs on topics related to SDGs issues, must be more evenly distributed, not only on natural issues but also regarding the socio-economic dimension. This is the challenge because, as far as researchers observe, STEM teachers are more dominated by teachers in science, engineering, and mathematics. Meanwhile, the SDGs issue concerns economics, sociology, politics, law, and state governance.

AUTHOR'S NOTES

The author declare that there is no potential conflict of interest. The author affirms that the data and substance of the essay are devoid of any instances of plagiarism. This research did not get any dedicated grant from any governmental, commercial, or nonprofit funding body.

REFERENCES

Amoako, S., & Insaidoo, M. (2021). Symmetric impact of FDI on energy consumption: Evidence from Ghana. *Energy, 223*, 1-14.

Araya, R., & Collanqui, P. (2021). Are cross-border classes feasible for students to collaborate in the analysis of energy efficiency strategies for socioeconomic development while keeping CO2 concentration controlled?. *Sustainability, 13*(3), 1584-1604.

Campbell, C., Hobbs, L., Xu, L., McKinnon, J., & Speldewinde, C. (2022). Girls in STEM: Addressing SDG 4 in context. *Sustainability*, *14*(9), 4897-4914.

Çetin, M., & Demircan, H. Ö. (2020). Empowering technology and engineering for STEM education through programming robots: A systematic literature review. *Early Child Development and Care*, *190*(9), 1323-1335.

Chapman, S., Catala, L., Mauduit, J. C., Govender, K., & Louw-Potgieter, J. (2015). Monitoring and evaluating astronomy outreach programmes: Challenges and solutions. *South African Journal of Science*, *111*(5-6), 1-9.

Chiang, T. (2021). A Fuzzy-Based Hybrid approach for estimating interdisciplinary learning efficiency. *IEEE Access*, *9*(1), 143275-143283.

https://doi.org/10.17509/jik.v21i2.69620

Clarke, V., & Braun, V. (2017). Thematic analysis. *The journal of positive psychology, 12*(3), 297-298.

Dieck-Assad, G., Ávila-Ortega, A., & González Peña, O. I. (2021). Comparing competency assessment in electronics engineering education with and without industry training partner by challenge-based learning oriented to sustainable development goals. *Sustainability, 13*(19), 10721-10750.

Gao, F., Li, L., & Sun, Y. (2020). A systematic review of mobile game-based learning in STEM education. *Educational Technology Research and Development*, *68*(4), 1791-1827.

Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. *International Journal of STEM Education*, *7*(1), 1-14.

González-Peña, O. I., Peña-Ortiz, M. O., & Morán-Soto, G. (2021). Is it a good idea for chemistry and sustainability classes to include industry visits as learning outside the classroom? An initial perspective. *Sustainability, 13*(2), 752-764.

Gyasi, J. F., Zheng, L., & Zhou, Y. (2021). Perusing the past to propel the future: A systematic review of STEM learning activity based on activity theory. *Sustainability*, *13*(16), 8828-8845.

Hendriana, D. Educational robotics in kurikulum merdeka. *Inovasi Kurikulum, 20*(1), 49-60.

Ho, M. T., La, V. P., Nguyen, M. H., Pham, T. H., Vuong, T. T., Vuong, H. M., Pham, H. H., Hoang, A. D., & Vuong, Q. H. (2020). An analytical view on STEM education and outcomes: Examples of the social gap and gender disparity in Vietnam. *Children and Youth Services Review*, *119*(105650), 1-14.

Ibáñez, M. B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers and Education*, *123*(1), 109-123.

Jeong, J. S., & González-Gómez, D. (2021). A STEM course analysis during COVID-19: A comparison study in performance and affective domain of PSTs between F2F and F2S flipped classroom. *Frontiers in Psychology*,*12*(1), 3352-3365.

Khuyen, N. T. T., Bien, N. v, Lin, P. L., Lin, J., & Chang, C. Y. (2020). Measuring teachers' perceptions to sustain STEM education development. *Sustainability*, *12*(4), 1531-1544.

Kulshreshtha, P., Gupta, S., Shaikh, R., Aggarwal, D., Sharma, D., & Rahi, P. (2022). Foldscope embedded pedagogy in stem education: A case study of SDG4 Promotion in India. *Sustainability*, *14*(20), 13427-13444.

Lam, K. F. T., Wang, T.-H., Vun, Y.-S., & Ku, N. (2019). Using DDMT teaching model to cultivate critical thinking in a STEAM Classroom. *International Congress on Education and Technology in Sciences*, *1I*(1), 47-57.

MacFarlane, B. (2016). Infrastructure of comprehensive STEM programming for advanced learners. *STEM Education for High-Ability Learners, 1*(1), 139-160.

Marcone, G. (2022). Humanities and social sciences in relation to sustainable development goals and STEM education. *Sustainability*, *14*(6), 3279-3290.

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*(1), 1-16.

Melton, J. W., Ali Saiful, J., & Pat Shein, P. (2022). Interdisciplinary STEM program on authentic aerosol science research and students' systems thinking approach in problem-solving. *International Journal of Science Education*, *44*(9), 1419-1439.

https://doi.org/10.17509/jik.v21i2.69620

Mylonas, G., Paganelli, F., Cuffaro, G., Nesi, I., & Karantzis, D. (2023). Using gamification and IoT-based educational tools towards energy savings-some experiences from two schools in Italy and Greece. *Journal of Ambient Intelligence and Humanized Computing, 14*(12), 15725-15744.

Nguyen, T. P. L., Nguyen, T. H., & Tran, T. K. (2020). STEM education in secondary schools: Teachers' perspective towards sustainable development. *Sustainability*, *12*(21), 8865-8881.

Nguyen, T. T. K., van Bien, N., Lin, P. L., Lin, J., & Chang, C. Y. (2020). Measuring teachers' perceptions to sustain STEM education development. *Sustainability*, *12*(4), 1-15.

Ogegbo, A. A., & Ramnarain, U. (2022). A systematic review of computational thinking in science classrooms. *Studies in Science Education, 58*(2), 203-230.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372-381.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. *Journal of Clinical Epidemiology*, *134*(1), 103-112.

Pajk, T., Van Isacker, K., Aberšek, B., & Flogie, A. (2021). STEM education in eco-farming supported by ICT and mobile applications. *Journal of Baltic Science Education, 20*(2), 277-288.

Pellas, N., Dengel, A., & Christopoulos, A. (2020). A scoping review of immersive virtual reality in STEM education. *IEEE Transactions on Learning Technologies*, *13*(4), 748-761.

Pellas, N., & Mystakidis, S. (2020). A systematic review of research about game-based learning in virtual worlds. *Journal Universal Computer Science*, *26*(8), 1017-1042.

Pimentel, D., & Kalyanaraman, S. (2023). Virtual climate scientist: A VR learning experience about paleoclimatology for underrepresented students. *Interactive Learning Environments, 31*(7), 4426-4439.

Rico, A., Agirre-Basurko, E., Ruiz-González, A., Palacios-Agundez, I., & Zuazagoitia, D. (2021). Integrating mathematics and science teaching in the context of education for sustainable development: Design and pilot implementation of a teaching-learning sequence about air quality with pre-service primary teachers. *Sustainability*, *13*(8), 4500-4512.

Rodriguez, A. J., & Shim, S. W. (2021). Addressing critical cross-cultural issues in elementary STEM education research and practice: A critical review essay of Engineering in Elementary STEM Education. *Cultural Studies of Science Education, 16*(1), 1-17.

Sharma, M. (2021). Multiple dimensions of gender (dis)parity: A county-scale analysis of occupational attainment in the USA, 2019. In *Sustainability, 13*(16), 8915-8932.

Sirakaya, M., & Alsancak S., D. (2018). Trends in educational augmented reality studies: A systematic review. *Malaysian Online Journal of Educational Technology, 6*(2), 60-74.

Stelter, R. L., Kupersmidt, J. B., & Stump, K. N. (2021). Establishing effective STEM mentoring relationships through mentor training. *Annals of the New York Academy of Sciences*, *1483*(1), 224-243.

Suh, H., & Han, S. (2019). Promoting sustainability in university classrooms using a STEM project with mathematical modeling. *Sustainability, 11*(11), 3080-3102.

https://doi.org/10.17509/jik.v21i2.69620

Surahman, E., & Wang, T. H. (2023). In-service STEM teachers professional development programmes: A systematic literature review 2018-2022. *Teaching and Teacher Education, 135*, 1-16.

Timko, G., Harris, M., Hayde, D., & Peterman, K. (2023). Sustainable development of community-supported STEM-learning ecosystems in rural areas of the United States. *Community Development Journal, 58*(3), 492-511.

Wahono, B., & Chang, C.-Y. (2019). Assessing teacher's attitude, knowledge, and application (AKA) on STEM: An effort to foster the sustainable development of STEM education. *Sustainability*, *11*(4), 950-968.

Zheng, L., Zhang, X., & Gyasi, J. F. (2019). A literature review of features and trends of technology-supported collaborative learning in informal learning settings from 2007 to 2018. *Journal of Computers in Education*, *6*(4), 529-561.

https://doi.org/10.17509/jik.v21i2.69620