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# Enhancing Students' Abilities and Skills through Science Leaning Integrated STEM: A Systematic Literature Review

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# Enhancing Students' Abilities and Skills through Science Leaning Integrated STEM: A Systematic Literature Review

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**Abstract**

Integrated STEM learning is an appropriate approach to improve students' abilities and skills needed in the 21st century. Therefore, this literature study aims to discuss the effectiveness of integrated STEM implementation in science learning. The focus of this research includes integrated STEM implementation, effectiveness, and analysis of abilities and skills that can be improved through STEM integration. The method used in this literature study is a Systematic Literature Review, which includes several stages, namely Identification, Screening, and Included. The databases used include Springer, Taylor & Francis, ERIC, and Google Scholar. This literature review article is limited to the last 8 years, from 2016 to 2023. After screening, 35 articles were obtained, which were used as literature material regarding the effectiveness of integrated STEM learning in science. The results of the study show that STEM implementation can be integrated with various learning models such as PjBL, PBL, Jigsaw, 5E-EDP, and 6E-Cycle. In addition, it can also be integrated with media, including interactive video, virtual labs, and mobile augmented reality. Integrated STEM has proven to be effective in improving students' abilities and skills. The student's abilities and skills include 4C skills, concept understanding and cognitive abilities, motivation, ICT and computational literacy, spatial and geographic thinking skills, and mathematical thinking skills.

## Introduction

In this era of globalization, the development of science is increasingly rapid and makes a significant contribution to the world of education. As a result of these technological developments, the development of Industry 4.0 focuses a lot on digitizing information, such as Artificial Intelligence (AI), robotics, biotechnology, nanotechnology, and various other disciplines (Sudibjo et al., 2019). Meanwhile, society in Society 5.0 is needed along with the development of Industry 4.0. Society 5.0 aims to create a comfortable world and improve human social welfare and economic growth (Fukuda, 2020). In this increasingly rapid development of science and technology, students must have complete mastery of multidisciplinary integration, namely science, technology, and mathematics (Liliawati et al., 2018). However, the qualification conditions for STEM career skills are getting lower based on TIMSS and PISA results (Knezek et al., 2015). So STEM integration, which can support solving these problems, is needed.

STEM approach aims to compete globally in solving problems through STEM literacy. STEM literacy demonstrates the multidisciplinary integration of science, technology, engineering, and mathematics in living systems. STEM has been widely used in various methods that suit its characteristics, such as inquiry-based learning, cooperative learning, problem-based learning, and project-based learning (Baran et al., 2021). Project-based learning (PjBL) is widely used in integrated STEM learning because it is considered one of the most appropriate methods. Project-based learning includes research activities to give students assignments, such as design, decision-making, and problem-solving. Some literature shows that the PjBL method can increase student success and positively influence student participation, student interest, and 21st-century skills, such as communication, teamwork, critical thinking skills, and problem-solving. Through project-based STEM learning, it can guide students to explore nature so that it can generate interest. STEM is integrated with various effective learning models to improve students' abilities and interests.

This STEM integration can increase the learning efficiency of various scientific disciplines (Faulconer et al., 2020). The integrated STEM approach helps students to increase confidence in solving problems. STEM allows students to be involved in inquiry-based learning, collaboration, and problem-solving in the real world (Ong et al., 2016). Integrated STEM increases students' beliefs or self-confidence regarding their ability to organize, perform tasks, achieve a goal, and implement action. This self-confidence is known as self-efficacy. Students need self-efficacy for learning material before being directly involved in strategic material (Dordinejad & Ahmadabad, 2014). High self-efficacy increases the ability to succeed in doing tasks. Students who have high self-efficacy tend to persist in achieving the desired goals. This is especially important for solving problems encountered in the real world. Self-efficacy correlates with academic performance and self-adjustment (Samsudin et al., 2020).

STEM learning develops student self-efficacy to support students in increasing scientific literacy and 4C skills needed in the 21st century.Science education is part of education that plays a vital role in preparing students to have scientific literacy. (Khaeroningtyas et al., 2016). Scientific literacy must be designed as a reference for scientific thinking in making decisions and solving problems (Ardianto & Rubini, 2016). Science education is used to increase scientific literacy to improve science learning outcomes. Scientific literacy is closely related to science learning. The science learning process must be conveyed through an active learning process where the teacher, as the learning manager, decides on a strategy appropriate to the characteristics of the students, the material, and the learning environment. Science learning not only covers scientific concepts or theories but must also be able to apply them to cognitive processes. The knowledge to use these problem-solving abilities is the definition of scientific literacy. Scientific literacy is defined as the knowledge and skills needed to identify problems, acquire new knowledge, explain natural phenomena, and draw conclusions based on presenting evidence (Ismail et al., 2016).

In addition to having scientific literacy, students must have 4C skills, which must be possessed in the 21st century, including the ability to think critically, communicate, be creative, innovative, and collaborative. These abilities can be developed in STEM learning, which is integrated into science learning. STEM education has become a guideline approach known among educators because it enhances the global technological perspective of the 21st century (Shernoff et al., 2017). Mastery of science and technology is a reference to facing education challenges in the 21st century. An integrated STEM approach to learning has the potential to equip students with 21st-century employability skills through learning outcomes. STEM learning outcomes are combined to provide students with work readiness and career skills (Khoiri, 2019). The STEM-integrated approach will help students develop analytical and problem-solving skills in the world of work.

Based on research conducted by (Samsudin et al., 2020), STEM integrated with Project Based Learning can help students to increase self-efficacy. In addition, (Baran et al., 2021) revealed that Project Based-STEM improves students' 21st-century abilities, including problem-solving skills, critical thinking, and student creativity. Various studies using integrated STEM have proven that this approach can increase students' scientific literacy. Research from (Wahyu et al., 2020) shows that mobile augmented reality-based STEM can increase scientific literacy and student achievement. However, the existing literature study from (Sırakaya & Alsancak Sırakaya, 2022) only examines the use of Augmented Reality in STEM education. In addition, other literature studies discuss student careers in STEM-oriented science (Reinhold et.al, 2018). A literature study (Nurwahyuni, 2021) also shows that the STEM approach can improve the quality of science learning in Indonesia. So, further and extensive literature studies are needed regarding the effectiveness of STEM in science education. This literature study aims to present a systematic review of research mapping regarding integrated STEM in science learning. This research aims to map the effectiveness of STEM integration in science learning to improve students' abilities and skills. This literature study provides recommendations regarding implementing STEM integration in science learning.

## Method

This type of literature study uses the Systematic Literature Review approach. Systematic literature review is guided by the scientific method to minimize errors (bias) in identifying and synthesizing several studies following the problems raised (Patticrew & Roberts, 2006). A systematic review is a scientific method governed by several rules that provide completeness, transparency, limiting errors (bias), and accountability with exclusion and inclusion techniques. A systematic review starts with inclusion criteria, filters out relevant sources, and then provides a mapping with relevant articles. The review process was carried out based on the formulation of the problem and the objectives of the research, namely: i) Explaining the implementation of integrated STEM in science learning; ii) Explaining the effectiveness of integrated STEM in learning science, which can improve students' abilities and skills; (iii) Knowing what students' abilities and skills have increased towards STEM integrated Science learning.

### Identification

At this identification stage, several criteria are used as guidelines in sorting articles according to the research focus. Reviews were conducted from several databases, including Springer, Taylor & Francis, ERIC, and Google Scholar. The keywords used in the search for sources are “STEM Approach in Science,” “STEM PjBL,” and

"STEM Education" to obtain more than 10,000 related articles. There are 4 review criteria to ensure the quality of the paper so that there is no bias. First, there are no duplicate articles obtained from different databases. Sometimes, there are the same articles in several databases. Second, the records article is marked as ineligible by automation; the system automatically excludes this criterion. Third, articles included in this systematic review must be peer-reviewed. Last, this systematic review only focuses on articles within the last 8 years.

**Screening**

The screening process includes several stages: applying inclusion criteria to the title, abstract, and full text. There are two criteria for filtering titles: articles unrelated to STEM and articles needing complete access. The second screening stage is for abstracts with criteria, including STEM, which is not an approach, and articles needing to come from reputable journals. This criterion aims to obtain journal articles that are genuinely high quality and by the research focus. The final stage is filtering through full papers so that the requirements are more detailed, namely articles that focus on something other than the field of science, including physics, chemistry, biology, or integrated science. Apart from the research focus, the entire paper screening stage also selects articles that review effectiveness to suit the research objectives, so the methods used must be quantitative or mixed. The final criteria for articles in this research focused on the effectiveness of the STEM approach on students, so criteria related to students were included. The final results were 35 quality journals that were by the research focus. The steps used in the research are presented in Figure 1.

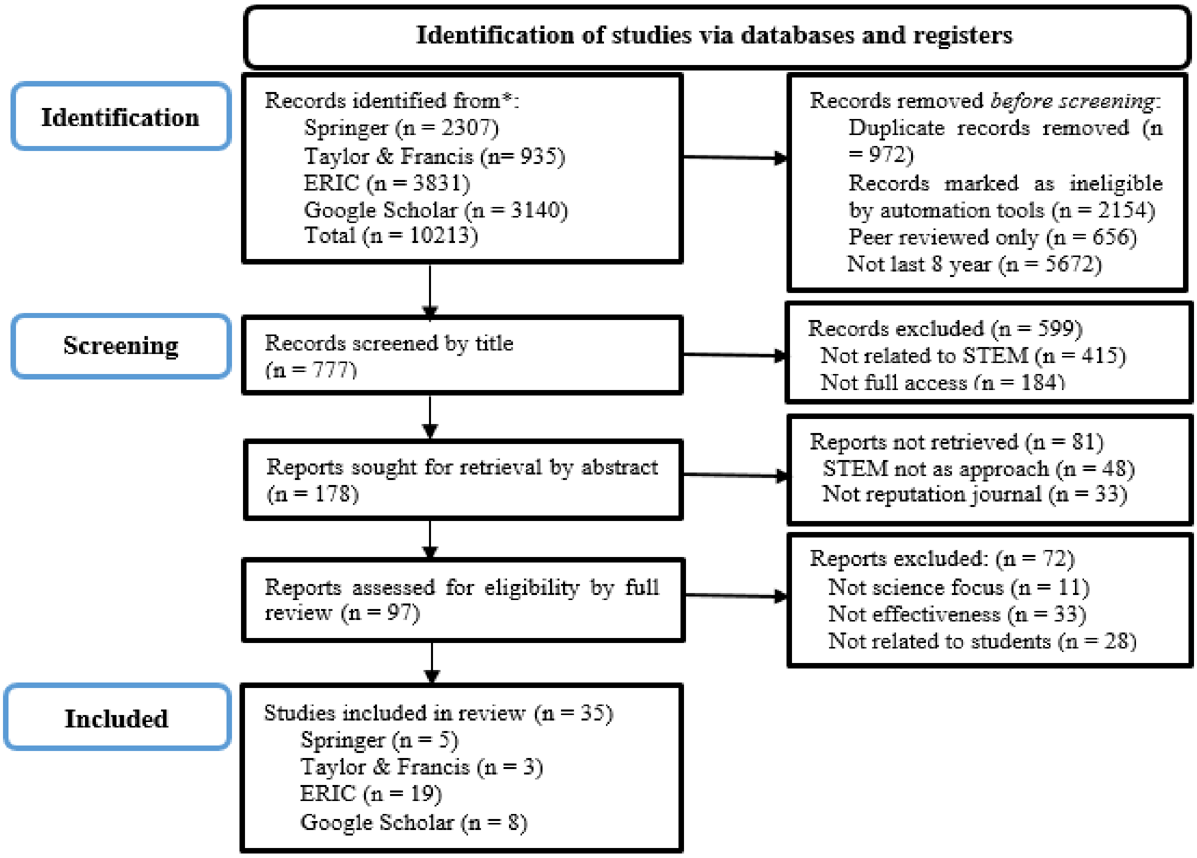


Figure 1. Prism of Systematic Literature Review

**Data Analysis**

This study used narrative synthesis to examine and synthesize findings from all papers according to inclusion criteria. After reading each paper, a focus can be obtained that can be used as a research discussion. Data analysis was carried out to organize and group the results into several categories based on scientific discipline, institute level, research method, and results. The data extraction results are presented in a matrix for evaluation and consideration to produce a conclusion. The matrix describes the findings in an orderly, facilitating the synthesis of findings. Synthesis of literature study findings provides research conclusions and recommendations. The results of article selection can be seen in Table 1.

Table 1. Selected Articles based on A Systematic Literature Review

| No | Author | Journal Name | Database | Index | Year |
|---|---|---|---|---|---|
| 1 | Chin-Sung Chen and Jing-Wen Lin | International Journal of Science and Mathematics Education | Springer | Q1 | 2019 |
| 2 | Kuen-Yi Lin, Ying-Tien Wu, Yi-Ting Hsu, P.John Williams | International Journal of STEM Education | Springer | Q1 | 2021 |
| 3 | Chien-Liang Lin and Chun-Yen Tsai | Journal of Science Education and Technology | Springer | Q1 | 2021 |
| 4 | Fu-Hsing Tsai, et al. | International Journal of Technology and Design Education | Springer | Q1 | 2021 |
| 5 | Shih-Yun Lu, Chih-Cheng Lo, and Jia-Yu Shu | International Journal of Technology and Design Education | Springer | Q1 | 2021 |
| 6 | Bevo Wahono, et al. | International Journal of Science Education | Taylor & Francis | Q1 | 2021 |
| 7 | Akawo Angwal Yaki, et al. | Malaysian Journal of Learning and Instruction | ERIC | Q1 | 2019 |
| 8 | Wichaya Pewkam, Suthida Chamrat | Informatics in Education | ERIC | Q1 | 2022 |
| 9 | Naela Rashad Mater, et al. | Educational Studies | Taylor & Francis | Q2 | 2022 |
| 10 | Shahad Alkair, Ruba Ali, et al. | Applied Environmental Education & Communication | Taylor & Francis | Q2 | 2023 |
| 11 | Shi-Jer Lou, et al. | EURASIA Journal of Mathematics Science and Technology Ed. | ERIC | Q2 | 2016 |
| 12 | Nyet Moi Siew and Norjanah Ambo | Journal of Baltic Science Education | ERIC | Q2 | 2018 |
| 13 | Ayşegül Dedetürk, et al. | Journal of Baltic Science Education | ERIC | Q2 | 2021 |
| 14 | Liang-Ting Tsai, et al. | Journal of Baltic Science Education | ERIC | Q2 | 2021 |

| No | Author | Journal Name | Database | Index | Year |
|---|---|---|---|---|---|
| 15 | Fauziah Sulaiman, et al. | Journal of Baltic Science Education | ERIC | Q2 | 2023 |
| 16 | Yuliana Wahyu, et al. | International Journal of Instruction | ERIC | Q2 | 2020 |
| 17 | Alfyananda K. Putra, et al. | International Journal of Instruction | ERIC | Q2 | 2021 |
| 18 | Mohd. Ali Samsudin, et al. | Journal of Turkish Science Education | ERIC | Q2 | 2020 |
| 19 | Medine Baran, et al. | Journal of Turkish Science Education | ERIC | Q2 | 2021 |
| 20 | Haydée De Loof, et al. | European Journal of STEM Education | ERIC | Q2 | 2022 |
| 21 | Ijirana, Sitti Aminah, Supriadi, Magfirah | Journal of Technology and Science Education | ERIC | Q2 | 2022 |
| 22 | Sudarmin, et al. | Journal of Technology and Science Education | ERIC | Q2 | 2023 |
| 23 | Ismail, A. Permanasari, W.Setiawan | Jurnal Pendidikan IPA Indonesia | Google Scholar | Q3 | 2016 |
| 24 | J. Afriana, A. Purnamasari, A. Fitriani | Jurnal Pendidikan IPA Indonesia | Google Scholar | Q3 | 2016 |
| 25 | N. Khaeroningtyas, A.Purnamasari, I.Hamidah | Jurnal Pendidikan IPA Indonesia | Google Scholar | Q3 | 2016 |
| 26 | L. Mutakinati, I. Anwari, K. Yoshisuke | Jurnal Pendidikan IPA Indonesia | Google Scholar | Q3 | 2018 |
| 27 | Rumadani Sagala, Rofiqul Umam, Andi Thahir | European Journal of Educational Research | ERIC | Q3 | 2019 |
| 28 | H. R. Widarti, D. A. Rokhim, A. B. Syafruddin | Jurnal Pendidikan IPA Indonesia | Google Scholar | Q3 | 2020 |
| 29 | W. Sumarni dan S. Kadarwati | Jurnal Pendidikan IPA Indonesia | Google Scholar | Q3 | 2020 |
| 30 | Parno, L.Yuliati, F.M.Hermanto, M.Ali | Jurnal Pendidikan IPA Indonesia | Google Scholar | Q3 | 2020 |
| 31 | E. Purwaningsih, S.P.Sari, A.M.Sari, A. Suryadi | Jurnal Pendidikan IPA Indonesia | Google Scholar | Q3 | 2020 |
| 32 | Syarifah Rahmiza Muzana, et al. | International Journal of Evaluation and Research in Education | ERIC | Q3 | 2021 |
| 33 | M.Yakob, et al. | International Journal of Evaluation and Research in Education | ERIC | Q3 | 2021 |
| 34 | Mustafa Tevfik Hebebci | Participatory Educational Research | ERIC | Q3 | 2022 |
| 35 | Ngo Hong Diep, et al. | International Journal of Education and Practice | ERIC | Q3 | 2023 |

## Results

In this literature study, 35 articles that are related to the research objectives have been examined. This literature review is used to describe and analyze (i) the implementation of STEM integration in science learning, (ii) the effectiveness of STEM-integrated Science learning in improving students' abilities and skills.

### Implementation of STEM Integrated Science Learning

This literature study focuses on STEM integration applied to science learning. Science is closely related to the STEM approach because it is a part of STEM. The STEM approach can be used in collaboration with various learning models and media. An appropriate learning model can support the effectiveness of STEM-oriented learning. One of the STEM learning models is project-based learning. Multiple studies have shown that project-based learning is very suitable when collaborating with the STEM approach (Afriana et al., 2016; Baran et al., 2021; Ijirana et al., 2022; K. Y. Lin et al., 2021; Lou et al., 2017; Mutakinati et al., 2018; Purwaningsih et al., 2020; Putra et al., 2021; Samsudin et al., 2020; Siew & Ambo, 2018; Sudarmin et al., 2023; Widarti et al., 2020). Project-based learning involves project production and practice-oriented learning to fulfill the "engineering" skills in the STEM approach, so PjBL is considered one of the most appropriate methods (Baran et al., 2021). According to (Siew & Ambo, 2018), project-based and STEM learning designs show students' active interaction with the learning environment. The STEM and PjBL principles included in each activity step provide opportunities for students to design, sketch, and prototype that integrate knowledge of science, engineering, and mathematics. Supporting research is also shown by (Putra et al., 2021), where project-based STEM integration creates conducive learning because it not only learns about technology but also integrates inappropriate instructional steps. According to (Ijirana et al., 2022), STEM PjBL can collaborate further with metacognitive skills, including planning, monitoring, and evaluation skills to assist student performance.

In addition to project-based learning, STEM can be integrated with problem-based learning models that require scientific concepts to solve a problem. Research from (Sulaiman et al., 2023) shows that the STEM-PBL integrated physics module increases students' personal interest, understanding, and effort. The basic science concept can be linked to STEM to create activities designed through technical elements (Parno et al., 2020). Further research shows that STEM can also be integrated with the 6E-Learning model. Research from (Khaeroningtyas et al., 2016) uses the 6E-Learning by Design TM model, which is integrated with STEM. The learning model combines inquiry learning with design-based. Technology and engineering are included in the learning process to become an integrated STEM. STEM can also be integrated with Socio-Scientific Issue (SSI)-based 6E-Learning, which can complement each other (Wahono et al., 2021). SSI can prepare students to face real-world problems and be directly involved in society. In further research, STEM can collaborate with the Stand-Alone engineering design approach, 5E-EDP approach, and Jigsaw learning approach (Diep et al., 2023). This study also showed differences in influencing students' achievement. STEM can also be integrated with learning media to create an exciting learning process. One is STEM-PjBL integration, which is integrated with interactive learning videos. Learning videos have the advantage of being able to visualize concepts to students in an exciting way compared to ineffective text and can overcome the limitations of space and time (Widarti et al., 2020). Apart from that, STEM learning based on virtual lab media was also conveyed by (Ismail et al., 2016), which can visualize abstract concepts in science through technological elements. Furthermore, (Wahyu et al., 2020) show the role of Mobile Augmented Reality, which is integrated with the STEM approach. This media can visualize science concepts into three dimensions in absolute terms that combine technology-based physical and digital.

In addition, this STEM approach can be applied to various scientific disciplines that are growing from year to year. According to the standard classification of science in **Table 2**, it can be seen that integrated STEM learning is carried out in various scientific disciplines, namely integrated science 37.14%, physics 31.43%, chemistry 14.28%, technology & engineering science 5.71%, while in biology, geography, marine science, and computational science each 2.86%. Based on the scientific discipline, the integrated STEM approach is widely used in integrated science. Then, for more specific disciplines, this approach is widely applied to physics and chemistry, where these two sciences are very much in line with the characteristics of STEM. STEM learning is closely related to the characteristics of science (science) material, especially those related to technology, engineering, and mathematics

Table 2. Statistical Data Based on Discipline

| ***Discipline*** | ***Number of Publications*** | ***%*** |
|---|---|---|
| Integrated Science | 13 | 37.14 |
| Physics | 11 | 31.43 |
| Chemistry | 5 | 14.28 |
| Technology | 2 | 5.71 |
| Biology | 1 | 2.86 |
| Geography | 1 | 2.86 |
| Marine Science | 1 | 2.86 |
| Computational Science | 1 | 2.86 |
| **Total** | 35 | 100 |

In addition, according to the article review results, the distribution of countries using an integrated STEM approach can be seen. Most of the journals that discuss the effectiveness of learning with integrated STEM are in Indonesia, with as many as 15 articles. Then followed by Taiwan, as many as 7 articles, and Turkey and Malaysia, 3 articles each. In addition, articles that show the effectiveness of STEM approaches in learning are also carried out in Japan, Palestine, Thailand, Korea, Vietnam, Qatar, Nigeria, and Belgium, each 1 article. Research in Indonesia is quite interested in discussing the effectiveness of the STEM approach in science learning. In addition to area coverage, **Table 3** shows that the sample groups in this study were conducted at various levels of institutions, from elementary schools to universities. Based on the articles that have been reviewed, most of the research was conducted at the high school level. The percentage for each sample is at the institutional level, namely 3 articles in elementary school, 12 articles in junior high school, 14 articles in senior high school, 1 article in vocational high school, and 5 articles in university/college. According to Piaget's development, primary and secondary school students are in the concrete stage (Sırakaya & Alsancak Sırakaya, 2022). Students in the concrete learning stage need learning that can be done with the senses. Integrated STEM learning can facilitate using all the senses to concretize abstract material.

Table 3. Statistical Data Based on Level of the Institute

| *Level of Education* | *Number of Publications* | *%* |
|---|---|---|
| Elementary School | 3 | 8.57 |
| Junior High School | 12 | 34.28 |
| Senior High School | 14 | 40 |
| Vocational High School | 1 | 2.86 |
| University/College | 5 | 14.29 |
| **Total** | 35 | 100 |

STEM-integrated learning is quite significant and provides satisfactory results for overcoming the problems faced by students. Therefore, research on STEM integration in science learning grows every year. From the results of the review conducted, it is known that there were 4 articles in 2016, 2 articles in 2018, 3 articles in 2019, 7 articles in 2020, 10 articles in 2021, 5 articles in 2022, and 4 articles in 2023. The distribution of research years can be seen in Figure 2.

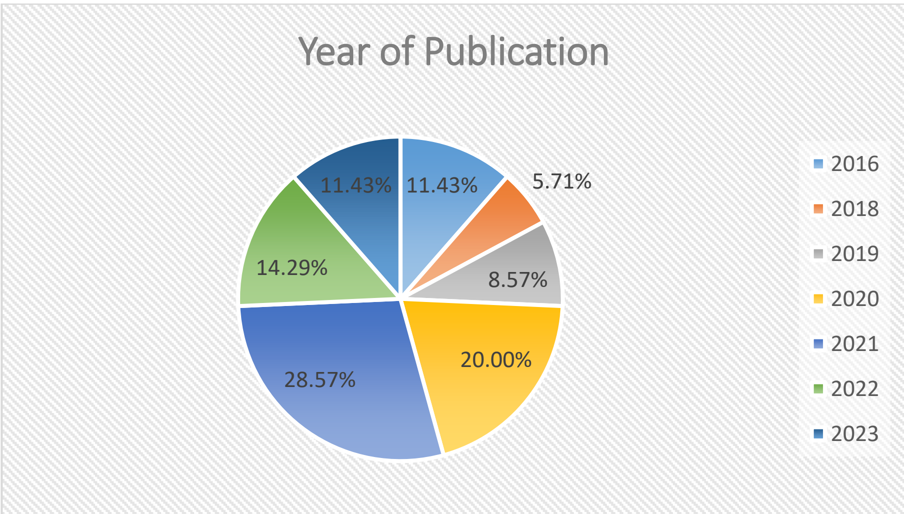


Figure 2. Statistical Data on Year of Publication

### The Effectiveness of Integrated STEM on Students' Abilities and Skills

This literature study aims to identify the influence and effectiveness of integrated STEM implementation on students' abilities and skills, so most articles use quantitative methods. One of the reasons for using the quantitative method is because it is the most appropriate method for testing the effectiveness of STEM implementation. In addition, the quantitative method has the advantage that it is easier to generalize research results and is more accountable because it tends to use large samples. At the same time, the qualitative method is relatively rarely used, especially on the effectiveness of a learning approach. Qualitative methods are not suitable when used to test the efficacy. In **Table 4**, 62.86% of the research used as literature material uses quantitative methods. Quantitative methods can also be followed by qualitative methods to become mixed-method studies, and the results obtained are more comprehensive; as many as 28.57% of studies use mixed methods. Meanwhile, several quantitative studies collaborated with R&D to develop instruments in advance of 8.57%.

Table 4. Statistical Data Based on Research Method

| ***Research Method*** | ***Number of Publications*** | ***%*** |
|---|---|---|
| Quantitative | 22 | 62.86 |
| Mixed-Method | 10 | 28.57 |
| R&D & Quantitative | 3 | 8.57 |
| **Total** | 35 | 100 |

The effectiveness of learning with an integrated STEM approach can be categorized into disciplines and what materials are appropriate to this approach. In addition, effectiveness can also be seen from the integration of STEM to the results achieved, as shown in **Table 5.** Based on systematic analysis, which disciplines and materials are appropriate and effective if delivered through STEM learning can be seen. The material covering multiple disciplines (science, technology, engineering, and mathematics) is usually relevant for this approach, for example, in (Baran et al., 2021) research on physics, namely making miniature hydraulic lifts and bridges. In addition, this approach is also very suitable for learning chemistry, such as making wastewater treatment tools with the principles of colloids, suspensions, and solutions (Mutakinati et al., 2018). The STEM approach is also quite effective when collaborating with various learning models. This is evidenced by multiple studies showing an increase in students' different abilities and skills through science learning that is taught through integrated STEM.

Table 5. Disciplines related to STEM and Research Results

| **No** | ***Author*** | ***STEM Related Discipline*** | ***Result*** |
|---|---|---|---|
| 1 | Chin-Sung Chen and Jing-Wen Lin | Science material | M-STEM project-based learning makes students more active so that learning becomes student-centered |
| 2 | Kuen-Yi Lin, Ying-Tien Wu, et al. | Mousetrap car project | The STEM project-based engineering design process can foster teachers' cognitive structures related to problem-solving, ideas, and feasibility analysis |
| 3 | Chien-Liang Lin and Chun-Yen Tsai | River water pollution and its prevention, bio-indicators | STEAM learning increase project competence, motivation, and self-efficacy |
| 4 | Fu-Hsing Tsai, Hsien-Sheng Hsiao, Kuang-Chao Yu, and Kuen-Yi Lin | Energy material on the introduction of energy sources, energy applications, energy conservation, and new energy | Project-based STEM learning improves teacher candidates' performance in energy knowledge, computational thinking, and programming attitudes |
| 5 | Shih-Yun Lu, Chih-Cheng Lo, and Jia-Yu Shu | Micro-bit paper cutting lamp project | STEAM's integrated project-based learning has a significant influence on student creativity |

| No | *Author* | *STEM Related Discipline* | *Result* |
|---|---|---|---|
| 6 | Bevo Wahono, et al. | Science topics such as genetically modified organisms | STEM-6E learning with socio-scientific issues fosters performance understanding, motivation, and awareness of science learning |
| 7 | Akawo Angwal Yaki, Rohaida Mohd Saat, et al. | Science material | STEM approaches can improve student achievement and reduce academic achievement gaps between students |
| 8 | Wichaya Pewkam, Suthida Chamrat | Computational Science training for science teachers | STEM-based computational science can develop pre-service teachers' computational thinking |
| 9 | Naela Rashad Mater, Muhannad Jamil Haj Hussein, et al. | The concept of motion, velocity, and energy transformation | STEM-based learning shows a positive attitude toward problem-solving, learning concepts, and their application |
| 10 | Shahad Alkair, et al. | Environmental problem material | STEM models with problem-solving approaches significantly improve students' understanding of ecological problems. |
| 11 | Shi-Jer Lou, et al. | Steamship CaC2 Project | STEM project-based learning can enhance students' creativity, as well as interest and curiosity |
| 12 | Nyet Moi Siew and Norjanah Ambo | Physical sciences, materials sciences, and life sciences | The positive effects of STEM-PjBL can increase student creativity |
| 13 | Ayşegül Dedetürk, et al. | Sound matter | Engineering design-oriented STEM activities enhance conceptual understanding |
| 14 | Liang-Ting Tsai, Cheng-Chieh Chang, Hao-Ti Cheng | Marine Science | STEM approaches increase students' success rates and attitudes (motivation and interest) towards subjects. |
| 15 | Fauziah Sulaiman, et al. | Materials of classical mechanics | STEM-PBL learning effectively increases students' interest, understanding, and effort in learning. |
| 16 | Yuliana Wahyu, et al. | Science material | MAR-based STEM-PjBL learning is effective enough to improve science literacy and student achievement |
| 17 | Alfyananda Kurnia Putra, et al. | Population projection, population mobility, population quality, demographic bonus | Project-based STEM learning can develop spatial thinking skills and geographic skills |
| 18 | Mohd. Ali Samsudin, S. M. Jamali, et al. | Pulley system material, simple pendulum | STEM-PjBL can increase students' self-efficacy in solving physics problems |

| No | *Author* | *STEM Related Discipline* | *Result* |
|---|---|---|---|
| 19 | Medine Baran, Mukadder Baran, Ferit K., et al. | Manufacture of hydraulic bridges, drilling machines, and miniature lifts | There has been a significant increase in 21st-century skills due to project based learning |
| 20 | Haydée De Loof, Jelle Boeve-de Pauw, Peter Van Petegem | Physics material integrated mathematics and technology | i-STEM education has a positive effect on performance in terms of knowledge and application of mathematics and technological concepts |
| 21 | Ijirana, Sitti Aminah, Supriadi, Magfirah | Practicum on the basics of analytical chemistry and teaching P3K courses | Team Project Learning STEM-based Metacognitive Skills can develop critical thinking skills |
| 22 | Sudarmin, et al. | Secondary metabolite material of essential oils and terpenes | Project-based chemistry learning with an ethno-STEM approach is feasible and effective in improving the conservation and entrepreneurial character (perseverance, discipline, and creativity) of students |
| 23 | Ismail, et al. | Water pollution material | The application of STEM-based virtual labs can improve students' science literacy |
| 24 | J. Afriana, A. Purnamasari, A. Fitriani | Air pollution in science learning | Students are more enthusiastic about STEM-PjBL, as well as increasing interest, motivation, and science literacy |
| 25 | N. Khaeroningtyas, et al. | Temperature material and its changes | Students who are taught with STEM-6E Learning have better science literacy |
| 26 | L. Mutakinati, I. Anwari, K. Yoshisuke | Wastewater treatment equipment (concept of colloid, suspension, and solution) | Students' critical thinking skills are developed to critique systematic work when STEM-Project based learning is carried out |
| 27 | Rumadani Sagala, Rofiqul Umam, Andi Thahir | Designing spring props | STEM learning is more effective than conventional learning in understanding concepts. |
| 28 | H. R. Widarti, D. A. Rokhim, A. B. Syafruddin | Interactive learning videos about electrolysis | The use of interactive teaching materials based on PjBL-STEM can improve 4C skills, concept understanding, and learning motivation |
| 29 | W. Sumarni dan S. Kadarwati (14) | Colloids, compound nomenclature, solubility, and chemical equilibrium | Ethno-STEM project-based learning can improve critical and creative thinking skills, as well as HOTS |
| 30 | Parno, L.Yuliati, F.M.Hermanto, M.Ali | Optics | The application of STEM-PBL shows significant results in improving science literacy |

| No | *Author* | *STEM Related Discipline* | *Result* |
|---|---|---|---|
| 31 | E. Purwaningsih, et al. | Impulse and momentum subject matter | STEM project based learning trains students to solve real-world problems |
| 32 | Syarifah Rahmiza Muzana, et al. | Science material | Project-based E-STEM learning shows differences in ICT literacy and problem-solving skills |
| 33 | M.Yakob, H.Hamdani, R.P.Sari, A.G.Haji, N.Nahadi | Addictive substances, acid-base, vibration and waves, and plant structure and function | Science learning and STEM-based performance assessment improve students' critical thinking skills. |
| 34 | Mustafa Tevfik Hebebci | Science material | Integrated STEM education positively affects scientific creativity, problem-solving skills, and critical thinking disposition. |
| 35 | Ngo Hong Diep, et al. | Electrical circuit material, the influence of electric current, and its application | STEM approaches with Stand-alone, 5E-EDP, and Jigsaw methods can increase students' scientific knowledge and creativity. |

Most research results from integrating STEM into science learning show that STEM can improve the skills needed in the 21st century. The integrated STEM approach is very suitable for solving problems regarding the lack of skills and students' abilities to face the challenges of the times. As many as 15 articles of research results based on literature reviews show that integrated STEM can improve 4C skills, which are essential competencies that the 21st-century generation must possess. Another ability that combined STEM enhances is students' understanding of concepts and cognitive abilities with many review results of 12 articles. STEM-based games can improve students' knowledge of concepts. In addition, integrating STEM into learning can increase student motivation, self-efficacy, and self-regulated learning, as shown in 6 articles in this literature study. This literature study also shows that the STEM approach effectively increases students' scientific literacy, with several 5 articles. According to (Parno et al., 2020), students' difficulties in understanding concepts are caused by low scientific literacy abilities. STEM also positively impacts ICT literacy and computational thinking, as shown in 3 articles. The literature study results also show that STEM blended project learning can improve spatial abilities and geographic skills (Putra et al., 2021). This study also indicates that i-STEM education positively affects cognitive performance in terms of mathematical application (De Loof et al., 2022). The results of this literature study can be seen in Table 6.

Table 6. Statistical Data on Research Results

| *Research Result* | *Number of Publications* |
|---|---|
| 4C skills, including critical thinking and problem solving, communication, collaboration, and creativity | 15 |
| Concept understanding and cognitive abilities | 12 |
| Motivation, self-efficacy, and self-regulated learning | 6 |
| Scientific literacy | 5 |

| ***Research Result*** | ***Number of Publications*** |
|---|---|
| ICT and computing literacy | 3 |
| Spatial and geographic thinking skills | 1 |
| Mathematical thinking skills | 1 |

## Discussion

This study highlights the implementation of STEM approaches with various learning models and media. The learning model most often integrated with STEM is Project Learning, where this integration can improve different student skills such as improving student-centered learning (Chin Sung Chen), improving cognitive structure (K. Y. Lin et al., 2021), computational literacy (Tsai et al., 2022), creativity and curiosity (Lou et al., 2017), 21st-century skills (Baran et al., 2021), self-efficacy (Samsudin et al., 2020), science literacy (Afriana et al., 2016). In addition, applying STEM PjBL in modules can also increase students' scientific creativity (Siew & Ambo, 2018). Based on the literature results, Project Based Learning integrated STEM learning can improve various abilities and skills students need. STEM is perfect for project-based learning models because of its integration across different science, technology, engineering, and mathematics fields. Project-based learning is a student-centered learning model by solving problems through project assignments. Real-world problem-solving usually involves STEM fields. Therefore, in project-based STEM learning, students can solve interdisciplinary problems according to real-world issues, making them relevant to integration in STEM fields. Other learning models with similar characteristics are also suitable for collaboration with STEM. Some suitable learning models that have a positive impact when integrated with STEM such as problem-based learning, 6E-Circle Inquiry Learning, Jigsaw learning, Stand-Alone engineering design learning, and 5E-EDP learning.

In addition to several learning models that can support STEM-based learning, technology is also needed. Based on the results of literature studies, the learning media used is related to technology, which is one of the fields of science in STEM. Technology makes it easier to explore science materials with a STEM approach and connect different disciplines (Yang & Baldwin, 2020). Technology can also encourage new ways of using mathematical ideas (Beal & Cohen, 2012). Therefore, technology in STEM integration must be used to support learning and address student problems. The STEM approach is also suitable for science in general. However, based on literature studies, it was found that STEM is widely found in physics and chemistry. Both of these subject areas meet the characteristics required in STEM fields. In addition, STEM research is widely used in Asian countries, especially Indonesia. A small percentage of research on the effectiveness of STEM approaches is conducted in Europe and Africa. Outside of Asia, more research shows perceptions and challenges in STEM learning. STEM applications in Science learning are mostly done at the high school level. This can be caused by the need for mature thinking in learning with a STEM approach. However, STEM can still be applied at the elementary school level according to capacity and needs. At primary and secondary levels, students need concrete learning, which can be overcome with the help of STEM approaches.

Based on the findings reviewed from the analysis of 35 articles, it was found that the integration of STEM in science learning can improve students' abilities and skills as follows: (1) 4C skills, including critical thinking and problem-solving, communication, collaboration, and creativity; (2) Concept understanding and cognitive abilities; (3) Motivation, self-efficacy, and self-regulated learning, (4) Scientific literacy; (5) ICT literacy and computational thinking; (6) Spatial and geographical thinking skills; (7) Mathematical thinking skills. The 4C skills include communication, collaboration, critical thinking and problem-solving, creativity, and innovation. According to (Widarti et al., 2020) shows that PjBL STEM learning using interactive learning videos can apply 4C skills. More specifically, integrated STEM can improve problem-solving skills, according to research by (Alkair et al., 2023; Hebebci & Usta, 2022; Muzana et al., 2021; Purwaningsih et al., 2020). This integrated STEM learning can challenge students to solve problems in the real world and accommodate ideas so that they are more interested in the learning process. This learning also creates students who can think critically (Ijirana et al., 2022; Mater et al., 2022; Mutakinati et al., 2018; Sumarni & Kadarwati, 2020). Furthermore, (Sumarni & Kadarwati, 2020) states that you can develop higher-order thinking skills with these critical thinking skills. Students can criticize and evaluate their projects and learning processes with these skills. In addition to necessary thinking skills, integrated STEM improves other 4C skills, namely student creativity (Lu et al., 2022).

In addition, STEM can also eliminate gaps in understanding concepts between students (Yaki et al., 2019). STEM education aims to integrate multidisciplinary knowledge. STEM education based on engineering design allows students to see from various perspectives to achieve competency and performance (Dedetürk et al., 2021). Furthermore, (Sagala et al., 2019) proved that STEM learning is effective for increasing conceptual understanding, and there are differences in the results of understanding concepts for students of different genders. This integrated STEM approach improves students' thinking skills (Yakob et al., 2021). Through mature thinking, understanding of concepts, and good cognitive abilities, students can overcome real-world challenges now and in the future. This model can overcome the constraints on learning science, which includes concepts and their application. Meanwhile, (Zhou et al., 2019) revealed that integrated STEM can enhance an active learning atmosphere. Students who tend to be active in learning will be able to create a student-centered independent learning process. Integrated STEM learning also has a role in increasing students' interest in learning.

Furthermore, there is self-efficacy, which is one of the things students need before engaging in strategic learning. This approach also increases when integrated STEM learning is carried out. When students have high self-efficacy, they will likely complete assignments successfully. According to (Samsudin et al., 2020), project-based STEM learning can increase self-efficacy. Students with a learning environment that links real problems tend to have high self-efficacy. Research from (C. L. Lin & Tsai, 2021) also supports this by stating that this learning increases self-efficacy and student motivation.

Scientific literacy deals with abstract principles, mathematical equations, and the application of technology that helps solve everyday problems. In addition, (Khaeroningtyas et al., 2016) stated that science learning that applies scientific literacy needs to be done. This integrated STEM approach is one of the approaches that can increase students' scientific literacy (Ismail et al., 2016). This research is also supported by (Wahyu et al., 2020), who prove the use of MAR integrated with STEM can increase scientific literacy. In addition to science literacy, STEM can also improve computational thinking in pre-service teachers (Pewkam & Chamrat, 2022) and ICT literacy with the E-STEM project-based learning model (Muzana et al., 2021). The increase in ICT literacy and computational concepts can be due to technological aspects in STEM. The existence of mathematical aspects in STEM can also improve mathematical thinking and technological concepts through i-STEM education (De Loof et al., 2022). The application of STEM in learning can improve various literacy because STEM is an integration of multiple disciplines. In addition, STEM can also improve spatial thinking and geography skills (Putra et al., 2021). Spatial thinking can interpret critical information to make decisions. STEM has many positive impacts on improving students' skills and abilities.

## Conclusion

This paper aims to analyze the application of STEM in science learning through a systematic literature review that synthesizes empirical evidence of learning and the improvement of various abilities and skills required in the 21st century. Based on a review of several articles on the effectiveness of STEM approaches in science learning, it can be concluded that STEM approaches effectively improve students' abilities and skills. Implementing STEM in learning can be integrated with various learning models and media. Several learning models combined with STEM include project-based learning (PjBL), problem-based learning (PBL), Jigsaw learning, 5E-EDP learning, and 6E-Cycle inquiry learning. However, most integrate with project-based learning because they are considered more aligned with STEM characteristics. In addition, learning can also be collaborated with learning media that attract students, such as interactive videos, virtual labs, or Mobile Augmented Reality. This approach can increase interest and motivation to learn, enhancing students' abilities and skills needed in the 21st century. These abilities and skills include 4C skills (critical thinking and problem-solving skills, communication, collaboration, and creativity and innovation), concept understanding and cognitive abilities, motivation (self-efficacy and self-regulated learning), scientific literacy, ICT literacy and computational thinking, spatial and geographic thinking skills, and mathematical thinking skills.

## Recommendations/Implications/Limitations

In various systematic reviews, applying STEM approaches in science can help teachers create student-centered learning and encourage student activeness and multiple skills. Students' abilities and skills are in high demand in the 21st century. In addition, this research is also helpful for other researchers on awareness of collaborating multiple media and learning models with a STEM approach. Future research should analyze teacher and student perceptions of the importance of STEM approaches in learning and teachers' understanding and experience in learning STEM approaches.

Studies that discuss differences in the application of STEM by educators who have good knowledge and are not good are interesting to discuss because, in the application, there should be a need for pedagogy similarity. This systematic review is limited to areas of science but is further being conducted to reveal the impact of STEM in other fields. With application to other fields, whether STEM can be applied in non-science fields can be known. Research also needs to be applied to the abilities and diverse student populations so that they are more useful and can be used as guidelines by educators in various circles. (Moore, 2014) suggests that the application should be done in classrooms with different school environments (urban, rural, and suburban).

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