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An examination of the potential of STEM-based biology learning for improving higher order thinking skills

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ABSTRACT

In 21st-century learning, Higher Order Thinking Skill is a skill that is targeted to be possessed by students, because learning in biology has led to finding solutions to real problems faced by students that require reasoning and analysis to understand them. The purpose of this literature review is to determine the potential of learning with the STEM approach to increase HOTS. The research method used is a systematic literature review of several reputable articles published in recent years through content analysis. From the articles used in this review, it was found that there is an increasing trend of research variations in various learning methods. This study also shows that Environmental Change is the most widely used topic in STEM-related research, both at the high school and university levels. Concerning the findings of this study, several recommendations have been put forward for future research underpinning the STEM approach as the main focus in improving HOTS. Some of these recommendations include increasing the variety of research types and selecting more diverse biology topics.

INTRODUCTION

In learning around the world today 21st century skills are one of the skills that students are targeted to have. The main skills of the 21st century include critical thinking skills, creative, communication, collaboration and problem solving or higher order thinking skills (Thornhill-Miller et al., 2023). These skills can be used as one of the solutions in facing the era of the industrial revolution 4.0 (Hujjatusnaini et al., 2022). As we know from its nature where the industrial revolution 4.0 includes the massive use of artificial intelligence in all sectors, supported by *big data* and information openness so that everyone can access everything or information easily. Thus, a high level of skill is needed to master and use the potential that we have so that we can use it effectively and efficiently.

Critical thinking skills are very important and must be possessed by learners. Learners who have high critical thinking skills will tend to be able to analyze information to find the truth. With high critical thinking skills, students will be able to solve problems and be confident of success in learning. The results of observations on high school students show that the application of biology learning models in schools has not fully trained critical thinking skills which causes critical thinking skills to be low (Jamil et al., 2021). In addition, the challenges faced by teachers are related to the activeness of students during the learning process. Students who are passive in learning will find it difficult to train critical thinking skills such as the ability to analyze, conclude, and evaluate problems. This is due to the low level of confidence of students during the learning process (Allanta & Puspita, 2021). Learning innovation is needed to change teacher-centered learning into learning that activates students. Learning innovation can be done by choosing an innovative and effective learning model that is appropriate for improving learning outcomes and self-efficacy (Amalya et al., 2021).

One of the approaches used to improve the quality of education based on 21st century skills is learning based on Science, Technology, Engineering, and Mathematics (STEM). STEM is considered to be able to increase innovation in the field of learning which allows interaction between students and learning tasks that arise in real life (Nuriyah et al., 2020). With the use of STEM, it is hoped that students can have attitudes and skills that support and match the skills needed to face the industrial era 4.0. STEM is done as an effort to make all or part of the four disciplines in this case Science, Technology, Engineering, and Mathematics into lessons, units, or classes based on the relationship between subjects and real-life problems (Görgülü Arı & Meço, 2021; Shahali et al., 2016).

The STEM approach can help teachers to show students that an integrated combination of science, technology, engineering and math concepts can be applied to develop products, systems and processes that students can use in everyday life. It was further found that STEM-integrated learning, in addition to learning knowledge about science, technology, engineering and math concepts, also plays a role in fostering students' skills in terms of scientific inquiry and problem solving. This STEM approach can also be done in biology subjects as done in Bali Mandara High School (Puspaningsih, 2021).

From the literature review, it is known that the STEM approach is important to be carried out in an effort to improve students' HOTS. Through literature review using content analysis in several scientific journals, this research is intended to answer the following questions in detail: 1) What is the trend and number of STEM research publications in HOTS improvement? 2) What research subjects are the focus of STEM research? 3) What treatments are given in an effort to improve HOTS through STEM? 4) What biology topics or materials are often used to investigate STEM-based HOTS? The study of these aspects can provide an overview of biology learning to improve students' HOTS through the STEM approach.

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METHODS

The method used in this article is a *systematic literature review* by analyzing relevant international articles that focus on STEM in an effort to increase students' HOTS, both at the high school and university levels. The research for this article was conducted systematically in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The utilization of PRISMA 2020 has the potential to benefit many stakeholders. Complete reporting allows readers to assess the appropriateness of the methods, and therefore the findings can be trusted. Complete reporting of all PRISMA 2020 items also facilitates replication and updating of reviews, as well as inclusion of systematic reviews and guidelines, allowing teams to capitalize on the work done and reduce research waste (van Zyl et al., 2024).

The articles examined in this literature review were obtained using Harzing's Publish or Perish software using the Scopus, Pubmed, Google Scholar, Semantic Scholar and Crossref databases by entering several keywords, namely HOTS/critical thinking/STEM. From the search, 358 articles were obtained. After the selection and screening process, 16 reputable articles (Q1-Q3) published from 2017 to 2023 were obtained in accordance with the topic discussed. The process of selecting articles through PRISMA guidelines is explained in stages as can be seen in the Figure 1 below.

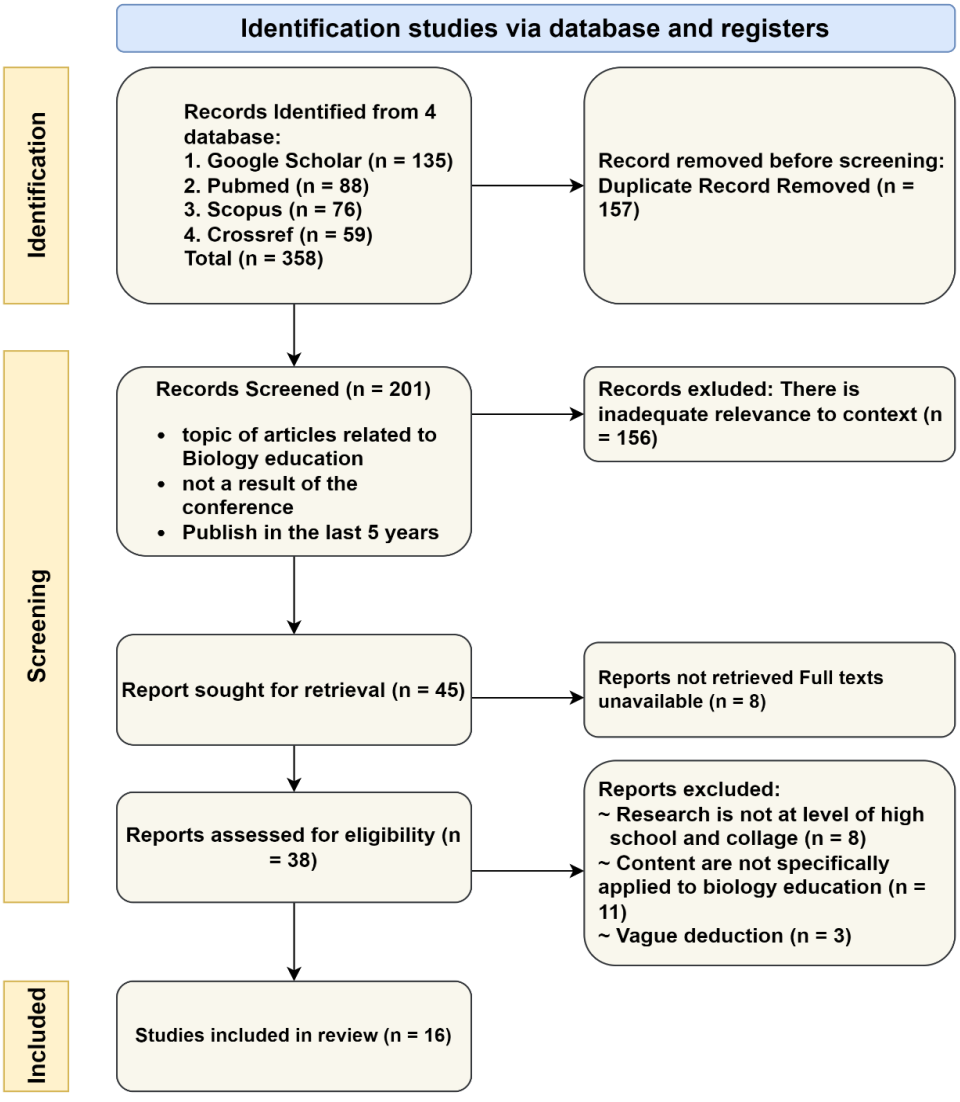

Figure 1. PRISMA flowchart of source search process

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RESULTS AND DISCUSSION

Research trends and number of publications

Based on the results of the literature review search, 16 articles obtained through the PRISMA guidelines were then analyzed. The results of empirical studies related to articles obtained through PRISMA guidelines are presented in Table 1 below.

Table 1. Empirical review of STEM and HOTS research

No.	Author	Journal	Publisher	Country	Methods Research	Research Content
1	Hujjatusnaini et al. (2022)	Indonesia Journal Science Education	State University of Semarang (UNNES)	Indonesia	Mixed-Method	Learning model HOTS
2	Nuriyah et al. (2020)	Journal of Physics: Conference Series	IOP Publishing Ltd.	United Kingdom	Mixed-Method	STEM-based learning
3	Ngabekti et al. (2019)	Indonesia Journal Science Education	State University of Semarang (UNNES)	Indonesia	Research and Development (RnD)	STEM-based learning media
4	Amalya et al. (2021)	Journal Research Science Education	Mataram University	Indonesia	Quasi-experiment	Problem-Based Learning Model
5	Brunelli & Macirella (2021)	F1000Research	F1000Research	United Kingdom	Descriptive: Survey	Learning media STEM
6	Kranzfelder et al. (2019)	International Journal of Science Education	Taylor and Francis Ltd.	United Kingdom	Quasi-experiment	Observation Environment STEM learning
7	Görgülü Arı & Meço (2021)	International Journal of Molecular Sciences	Multidisciplinary Digital Publishing Institute (MDPI)	Switzerland	Quasi-experiment	Learning media STEM
8	Gya & Bjune (2021)	Ecology and Evolution	John Wiley and Sons Ltd	United Kingdom	Quasi-experiment	Model-based learning STEM
9	Rahim et al. (2022)	International Journal of education, Psychology and Counselling	Global Academic Excellence	Malaysia	Quasi-experiment	Learning Model PBL (Problem Based Learning)
10	Puspaningsih (2021)	Puspaningsih Journal of Physics: Conference Series	IOP Publishing Ltd	United Kingdom	Quasi-experiment	Learning model based STEM

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No.	Author	Journal	Publisher	Country	Methods Research	Research Content
11	Tran & Selcen Guzey (2023)	Science Education	John Wiley & Sons inc.	United States	Descriptive: case study	Case Study of STEM learning
12	Rodriguez et al. (2021)	School Science Mathematics	John Wiley & Sons inc.	United States	Descriptive: Survey	Measuring Identity STEM
13	Hasanah et al. (2021)	Journal of Education Science Indonesia	Syah Kuala University	Indonesia	Quasi Experimental	PBL(Problem Based Learning) learning
14	Yaki (2022)	European Journal of STEM Education	Lectito	Netherland	Quasi-experiment	STEM approach Integrated
15	Ernst et al. (2016)	Contempo-rary Issues In Education Research	Clute Institute	United States	Descriptive: Quantitative	Performance-Based Assessment
16	Allanta & Puspita (2021)	Journal of Innovation Education Science	State University of Yogyakarta	Indonesia	Quasi Experiment	PjBL Medel with STEM approach

From the results of the empirical study presented in Table 1, it is known that the research methods used related to STEM-based learning in an effort to increase HOTS in several countries are very diverse. The research used quasi-experimental method (n=9), *mixed-method* (n=2), RnD method (n=1), quantitative descriptive method (n=1), survey descriptive method (n=2), and case study descriptive method (n=1). Each method used is tailored to the research content under study. The distribution of research methods used each year in the 16 articles is presented in the form of a graph in Figure 2 below.

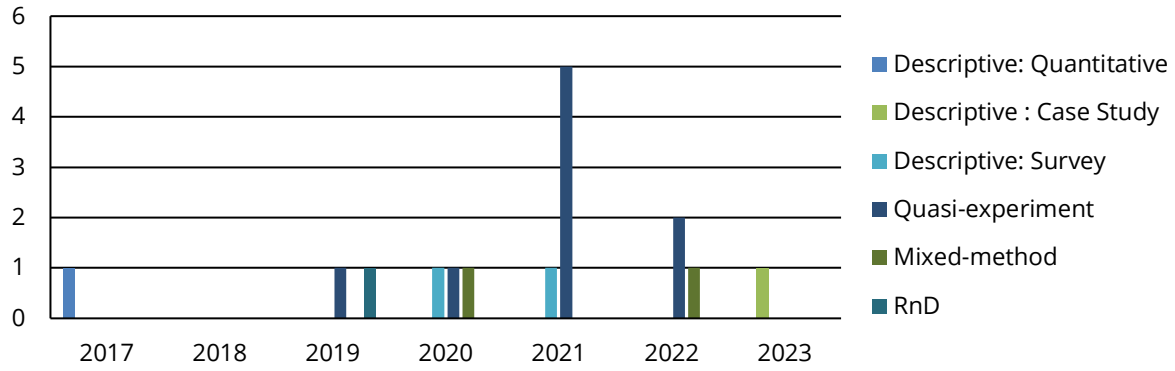

Figure 2. Distribution of research methods used by year

From the diagram above, it can be seen that the use of quasi-experimental research methods is most widely used by researchers in almost every year. The high frequency of using quasi-experimental research methods compared to others illustrates that researchers choose the treatment that best suits their educational concerns. In general, the researchers tried to compare several research methods in empowering the STEM approach in an effort to improve students' HOTS. On the other hand, the *true experimental* research method, which is said to be the most

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difficult design to apply to educational problems, was not found in the publication of research articles with the STEM approach.

Quantitative descriptive research for learning research with a STEM approach was only found in one article and was conducted in 2017. For the following years, this research method was not found. In 2020, the research methods carried out are increasingly varied, for example the use of qualitative research methods of case studies and surveys. The trend of qualitative research has been proven to start increasing and targeting educational research. This condition is closely related to the advantages of the qualitative approach to define a phenomenon in detail and comprehensively. However, RnD and mixed-method research in recent studies are still limited. This lack is a good opportunity for future researchers to use these research methods and focus their research on STEM-based learning.

Research subject

In conducting research, researchers need research subjects to test their hypotheses. The research subjects of STEM-based learning for HOTS improvement are students. This study focuses on the effect of learning with STEM approach at the education level, especially high school and college. To see clearly the distribution of research subjects in this case the level of education of students can be seen from Figure 3.

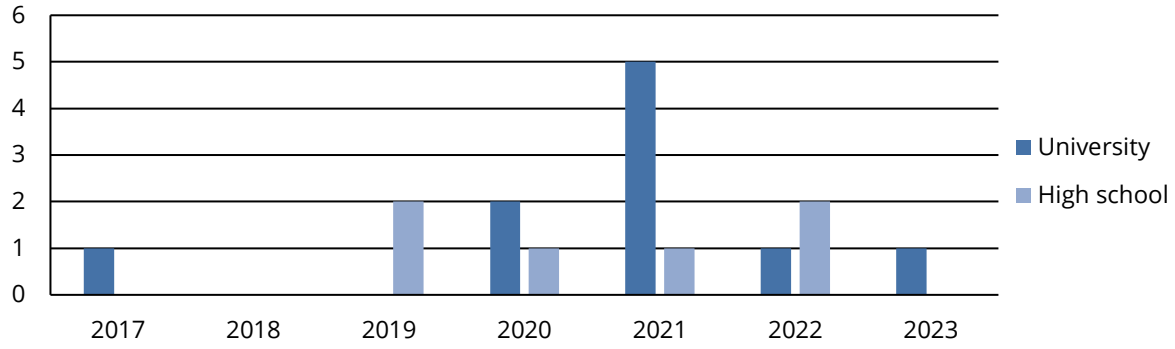

Figure 3. Distribution of research subjects used by year

In Figure 3, it can be seen that the research subjects of STEM-based learning for HOTS improvement are balanced between high schools and universities. This implies that STEM-based learning can be applied to various levels of education. It is known that STEM-based learning can increase student motivation and activeness in the learning process (Nuriyah et al., 2020). Learning motivation and activeness are important assets in participating in the latest learning that requires students to quickly master various applications and *skills* that support participating in learning activities. The use of the internet and technology can overcome the limitations of the learning process such as time and learning materials (Ngabekti et al., 2019).

Implementation of STEM-based learning models and media in an effort to improve HOTS

The treatment aims to test the researcher's hypothesis and/or identify the significance of certain conditions on each parameter under study. From the research that has been conducted, there are several types of research models used in an effort to increase students' HOTS through the STEM approach. The research models used include Problem Based Learning (PBL) with the development of the STEM approach into E-STEM (Environmental STEM) (Amalya et al., 2021). In the context of the STEM-PBL approach, technology is considered as a solution to a problem rather than creating a product (Rahim et al., 2022). Apart from the PBL model from the articles studied, there are also those that use the Project Based Learning (PjBL) model. Project-based learning or directing students to work by doing activities so that they are able to complete a project that involves in-depth investigation, critical thinking, various forms of communication, collaboration between students and teachers (Allanta & Puspita, 2021).

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Besides the two previous learning models, some researchers also developed and modified existing learning models. There are several models applied in research, namely learning materials in the form of cases and *Blended Project-Based Learning* (Hujjatusnaini et al., 2022) which proves that learning models integrated with 21st century skills have a significant effect on HOTS. Then the PBL model combined with STEM-based LKPD is applied in the experimental class and the control class used is conventional learning (Hasanah et al., 2021).

The results of the analysis conducted are learning models that utilize the *Conservation Science and Technology Identity* Instrument (CSTI) as an empirical way to measure STEM identity (Rodriguez, et al., 2020). In addition, the use of technology including using the adruino application in STEM-based learning improves students' ability to establish cause and effect relationships (Görgülü Arı & Meço, 2021). STEM-based learning is also very suitable to be combined with the use of online application technology (Brunelli & Macirella, 2021).

In the STEM approach, the problems faced are global, while the STEM-CP combines the STEM approach with a contextual approach where contextual problems are not global but are real in the environment around students and even experienced by students every day in their lives (Nuriyah et al., 2020). In addition, STEM can also be combined with *do-it-yourself* (DIY) experiments. It is known that experiments like this will be a valuable asset for teaching on campus as well as partly and completely off campus (Gya & Bjune, 2021). Then there is research that examines integrated STEM teaching materials for genetics learning to improve high school biology students' critical thinking skills (Yaki, 2022).

Some combine the STEM approach with competency-oriented learning. As a result of competency-oriented learning practices, performance-based learning activities should be coordinated with targeted learning objectives. Performance tasks and assessment techniques should be complementary and aligned with the set objectives (Ernst et al., 2016). Another finding is that the learning environment affects STEM-based learning (Kranzfelder et al., 2019). In addition, the culture of students also affects STEM-based learning (Tran & Selcen Guzey, 2023).

The significance test results show that the improvement in students' critical thinking skills through PBL-STEM learning is greater than PBL learning (Hasanah et al., 2021). The integrated STEM approach is characterized by driving questions that will equip students to think critically, for example, what do you understand about the problem? This question will stimulate thinking skills. This approach provides opportunities for students to generate their ideas, seek solutions to open-ended problems, and engage in hands-on activities (Yaki, 2022). With this, we can expect that the STEM approach to learning can improve the HOTS ability of students, whether at the high school or college level.

In this study, it was found that the use of the right learning model was proven to help increase students' HOTS. Learning with the STEM approach provides opportunities for students to explore data in the form of numbers and can also stimulate students' thinking skills. Teachers can utilize online learning media such as the Arduino application that can be accessed publicly, or by innovating to develop their own learning modules and media. The development of learning media can be integrated with various cases that occur daily in the students' environment and require problem solving skills in order to train HOTS through the STEM approach. In addition, the learning model with the STEM approach integrated with 21st century skills are also an opportunity for other researchers who want to discuss it further. These skills can be used as one of the solutions in facing the era of the industrial revolution 4.0 (Hujjatusnaini et al., 2022).

Selected biology topic of study

Biology is a science with a wide range of topics and has a direct influence on human life. Because of the breadth of topics in biology and the variety of approaches to biology with other sciences, there are materials in biology that are considered difficult. Therefore, it requires higher skills from students in solving it. HOTS development can be done in the learning process, including biology

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learning (Hujjatusnaini et al., 2022). In the article analysis, we can summarize what biology topics are discussed as described in Table 2.

Table 2. Percentage of biological topics covered in 16 articles

Topic	Number of articles	Percentage
Forensic biology	1	6%
Plant biology	1	6%
General biology	2	13%
Ecosystem	2	13%
Genetics	2	13%
Immunity	1	6%
Environmental pollution	2	13%
Environmental knowledge	2	13%
Environmental changes	1	6%
Human movement system	1	6%
Human Breathing System	1	6%

Based on Table 2, the topics chosen by researchers in their articles are very diverse for both high school and university education levels. We see that the selection of topics by researchers is almost the same in number but there are topics that are chosen the same, namely topics on general biology, ecosystems, genetics, environmental pollution and environmental knowledge. Arch-related material was chosen because this material or topic is directly related to the real world (Hasanah et al., 2021).

In addition to the above topics, researchers also discuss other topics that are linked to STEM. With the broadening of biology topics discussed, it means that research related to STEM in biology learning is starting to receive attention. This refutes the assumption that biology is just memorization. Biology also involves data analysis, both in the form of numbers, graphs, tables, diagrams, and so on. The results of the article analysis show that other researchers have the potential to find solutions to help students acquire HOTS skills through the STEM approach for other biology topics. Biology topics that are still rarely discussed can be studied in more depth in future research. It seems that there is still a lot of room for research development in the field of Biology because there are still many biological topics that have not been maximally used in research.

Potential for HOTS Improvement Through STEM Approach

The STEM approach is an integrated teaching and learning process approach that integrates content and skills in science, technology, engineering, and mathematics (Hasanah et al., 2021). Students' thinking skills are also influenced by the teacher's role in designing and using learning strategies or models that are in accordance with the characteristics of the material (Hujjatusnaini et al., 2022). Therefore, a teacher or lecturer needs to have knowledge and skills in using learning models that function as weapons or capital in carrying out their learning activities. By knowing many learning models, educators can flexibly use them for certain situations or face different learning materials or topics so that they can utilize them effectively. For example, such as during a pandemic situation that has occurred. When this situation occurs, teachers can adjust their learning in this pandemic situation so that learning can still be done well. STEM-based learning is also very suitable to be combined with the use of online application technology (Brunelli & Macirella, 2021).

When faced with a life problem, the generation raised in the 21st century is expected to solve the problem strategically and think analytically. To solve everyday life problems, students must first know the source of the problem, interpret it, and establish causal relationships.

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Therefore, equipping students with the ability to establish cause-effect relationships is an issue that teachers should add to their agenda (Görgülü Arı & Meço, 2021). STEM-based learning is known to improve students' HOTS skills (Yaki, 2022).

CONCLUSION

In this study, articles highlighting efforts to improve HOTS through learning with a STEM approach published in 16 articles were reviewed. It was found that there is an increasing trend of research variations in various methods to discuss this matter. The quasi-experiment method is most widely used by researchers through the application of various learning models. Meanwhile, the most widely used biology material in STEM research is Environmental Pollution, both at the high school and university levels. The results of the research that has been conducted show that STEM-based learning for various learning models is known to improve students' HOTS abilities. Teachers need knowledge and skills in mastering various learning models and learning media to be more flexible in conducting teaching and learning activities. In addition, more diverse biology topics can be used in future research by utilizing diverse learning media.

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Authors' Note

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