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Study of Ecology and Biodiversity Learning Based on Project Based Learning-Science Technology Engineering Mathematics (PjBL-STEM) in Empowering Students' Critical Thinking

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Abstract: The Project-Based Learning-Science Technology, Engineering Mathematics (PjBL-STEM) model is needed to empower students' critical thinking abilities and independence. PjBL-STEM implementation has been carried out in various fields of study and at various levels. A comprehensive study is needed to map the potential opportunities and limitations of implementing PjBL-STEM, including its influence on students' thinking skills. Therefore, this research aims to conduct a comprehensive literature review regarding implementing PjBL-STEM to improve students' critical thinking skills. In particular, this study is correlated with the potential implementation of PjBL-STEM in Ecology and biodiversity material. The literature review method was used in this research. The scientific articles selected in this study are those indexed on Google Scholar and published in 2010-2022. The keywords "PjBL-STEM and Critical Thinking" were used as the initial basis for selecting articles. After applying the criteria and article limitations, 90 articles were obtained for analysis. The results of this study show that the implementation of PjBL-STEM in empowering critical thinking is carried out at the elementary school to tertiary level. Apart from that, implementing PjBL-STEM is also done in general research, such as developing teacher competencies. The strengths, weaknesses, challenges, and obstacles that may occur when applying the PjBL-STEM model to ecology and biodiversity material in empowering students' critical thinking are discussed in this article.

Keywords: Critical Thinking; Learning of Ecology and Biodiversity; PjBL-STEM

Introduction

Problems within the scope of the ecosystem are urgent problems that must be resolved immediately. In particular, the decline in biodiversity in recent decades has caused many species to become endangered (Díaz et al., 2020). Based on a report from the International Union for Conservation of Nature (IUCN), in the last two decades, 1% of species on earth have a high risk of extinction (Mora et al., 2011). Human activities in meeting their needs through natural exploitation are the main factors causing the loss of ecosystem balance. Even though the balance of the ecosystem is needed for the survival of all organisms on earth. In addition, global biodiversity loss reduces ecosystem function and nature's contribution to human life (Isbell et al., 2022).

Education changes mindsets and behavior by instilling the character values of caring for a sustainable life (Kemdikbudristek, 2022). Continuing education has the goal of helping students develop their knowledge, attitudes, and skills in making decisions for their present and future interests based on valid information (Ramadoss, 2010). In the independent curriculum, the teacher is free to design learning according to the needs of students by taking into account the conditions of the school. Inserting learning about ecology and biodiversity in the education curriculum is an effort to raise awareness about the importance of biodiversity in

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ecosystems (Navarro-Perez & Tidball, 2012). Teachers can design learning that integrates sustainable living by providing problems in ecosystems for students to solve. When looking for solutions to problems, students indirectly try to instill values and behaviors that care about the environment.

Every human being has a responsibility to protect the biodiversity on earth. For this reason, experts invite students to play a role in solving environmental problems. Through critical arguments to propose conservation solutions that can be implemented (Rounsevell et al., 2020). Previous studies revealed that the current focus of learning is identifying land use change and natural exploitation as the main factors in biodiversity loss. For this reason, teachers can shift their focus to marine exploitation, which can drive global biodiversity loss (Maxwell et al., 2016). With various learning focuses, students can critically compare the best efforts that can be made as damage recovery efforts. So, in the end, students can propose comprehensive biodiversity conservation that can prevent further extinction (Haddad et al., 2015).

The ability to think critically is a provision for students to survive in the era of advances in information technology in the 21st century (Elisanti et al., 2018). Learning must shift from memorizing concepts to solving problems through critical thinking processes. Teachers can empower students to think critically to solve problems, for example, using the topic of ecosystems, mainly related to the decline in biodiversity on earth. Critical thinking skills are needed to generate ideas for solutions relevant to problems. However, in reality, the critical thinking skills of Indonesian students based on the International Trends in International Mathematics and Science Study (TIMSS) study show that they are ranked lower. Of course, this needs to be addressed immediately with critical thinking exercises in learning activities (Syafitri et al., 2021).

The low ability to think critically can be caused by various things, for example, conventional learning, where students are used to learning that contains activities to memorize concepts. Usually, students memorize concepts and do not apply them in everyday life (Priyadi et al., 2018). Trigger factors are textbooks that only present general material and do not provide innovative student learning activities. The learning process must be evaluated and improved to empower critical thinking skills.

The teacher can choose Project Based Learning (PjBL), integrated with Science, Technology, Engineering, and Mathematics (STEM) to empower students' critical thinking skills. The PjBL model emphasizes contextual learning through student activities exploring concepts, planning learning activities and ties, and carrying out projects by collaborating with groups to produce products (Priantari et al., 2020). Project-based learning helps students develop critical thinking skills in solving problems by integrating various fields of knowledge. The existence of STEM in project-based learning helps students understand the core of the problem with a more interesting learning experience when producing products that are applied to everyday life (Berry et al., 2012). The PjBL-STEM model shifts conventional teacher-centered habits into student-centered learning (Nadrotun et al., 2022). Project-based learning integrated with STEM is believed to develop students' abilities in identifying, applying, and associating concepts in the STEM area to understand complex problems and innovate in developing problem solutions (Smith et al., 2022). Students can investigate topics based on real problems that exist in everyday life through various sources of information. With this, students critically filter the truth of the information to integrate various concepts when making products (Fiteriani et al., 2021).

Interdisciplinary collaborative learning is how the curriculum prepares students to adapt to the fast-changing times while remaining responsive to the industrial world (Murray et al., 2020). Through PjBL-STEM learning, students are trained to think critically and communicate in project development, design, and implementation activities. In addition, interdisciplinary project-based learning provides a conducive environment for students to develop their creativity. Indirectly, this can encourage students to think outside their comfort zone and express ideas in their groups (Pennington, 2008).

The Project-Based Learning-Science Technology, Engineering Mathematics (PjBL-STEM) model is needed to empower students' critical thinking abilities and independence. PjBL-STEM implementation has been carried out in various fields of study and at various levels. A comprehensive study is needed to map the potential opportunities and limitations of implementing PjBL-STEM, including its influence on students' thinking skills. Therefore, this research aims to conduct a comprehensive literature review regarding implementing PjBL-STEM to improve students' critical thinking skills. In particular, this study is correlated with the potential implementation of PjBL-STEM in Ecology and biodiversity material.

Method

The research uses bibliometric qualitative methods with literature review techniques from research journals that have been published. Data is processed systematically through the stages in Figure 1.

Figure 1. Processing data

Determining keywords

Research reviewed 90 articles on the internet with the help of keywords in the form of PjBL-STEM and critical thinking. In this paper, researchers use inclusion data that is directly related to PJBL-STEM. To strengthen the argument, researchers include exclusion data that is not directly related. Researchers looked for exclusion data with the keywords pjbl and stem.

Literature search

The search was done using Google Scholar and then tracked using https://sinta.ristekbrin.go.id/ and https://www.scimagojr.com/.

Data selection

Journal data were analyzed descriptively to determine trends using PjBL-STEM in learning that empowers critical thinking. The original articles used as data were published in 2010-2022, containing abstracts, introductions, methods, and research results.

Final data analysis

The data is aggregated as a whole and then grouped based on index categories, level of implementation of the pjbl-stem. Based on the data obtained, researchers can create trends in the use of the PjBL-STEM model. After analyzing a number of journals, researchers were able to summarize the advantages, disadvantages and weaknesses of PjBL-STEM based learning. Apart from that, researchers also developed a SWOT for using the PjBL-STEM model in learning ecology and biodiversity to empower critical thinking.

Result and Discussion

Trends in using the PjBL-STEM model.

Human actions exploiting natural resources to meet economic needs have disrupted the balance of ecosystems. Issues within the ecosystem, particularly biodiversity loss, represent an urgent crisis that requires immediate attention. Therefore, addressing this problem is now included in the education curriculum. To propose meaningful solutions to complex problems, critical thinking is essential. We propose integrating STEM-based project learning to nurture students' critical thinking habits regarding ecology and biodiversity.

Project-based learning teaches students to understand concepts through complex problem-solving activities with projects that produce a product. Previously, students critically reviewed the literature to obtain problem-solving solutions and developed products. With STEM-integrated learning, students are taught to think comprehensively through problem-solving patterns with aspects of science, technology, engineering, and mathematics. This aims to train students to think critically with techniques or problem-solving designs in the real world based on science and mathematics (Priantari et al., 2020). PjBL-STEM-based learning is done through reflection, research, discovery, application, and communication syntax (Rush, 2010). In these activities, students are trained to learn to think critically through indicators of giving simple explanations, building basic skills, drawing conclusions, providing further explanations, and setting strategies for solving problems (Ennis, 1996).

Teachers can use the PjBL-STEM model in science learning, especially in ecology and biodiversity material. This is reinforced by problems involving biodiversity that students can find daily. For example, problems regarding ecosystem damage caused by human activities provide space for students to design products related to conservation efforts. Real problems raised by the teacher can present contextual learning.

Based on data analysis, it was found that research that had been carried out using the PjBL-STEM model was published by Sinta and Scopus-indexed national and international journals. The research data obtained based on the journal index can be seen in Table 1.

Tabel 1. Trends in the PjBL-STEM journal index

Journal index	Number of journals
Sinta 1	2
Sinta 2	7
Sinta 3	7
Sinta 4	4
Sinta 5	2
Sinta 6	0
Q1	22
Q2	11
Q3	7
Q4	4
Proceeding	3
Not known	21

Journals on PjBL-STEM were most commonly found indexed in Scopus Quartile 1. Research on PjBL-STEM was found at least in indexed journals Sinta 1 and Sinta 5. However, it turned out that research on implementing STEM-based project learning was not found in journals indexed by Sinta 6. The research was also conducted in the form of international proceedings. In addition, there are still 21 journals that discuss STEM-based project learning that are not indexed.

The data used is from journals published from 2010-2022. Trends in journals that examine PjBL-STEM in empowering critical thinking can be seen in Figure 2.

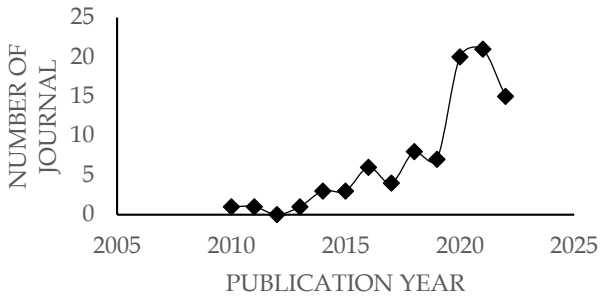

Figure 2. PjBL-STEM research trends by year

The application of STEM-based project learning has been around for a long time. However, based on the analysis results, the project-based learning model is most widely applied in 2021. This dismisses the opinion that project learning cannot be carried out during a pandemic.

Based on the PjBL-STEM model, learning is carried out from elementary schools to tertiary institutions (Farcis et al., 2022). In addition, PjBL-STEM was also used to assist the public interest. The implementation of learning using the PjBL-STEM model based on the level can be seen in Table 2.

Tabel 2. Number of PjBL-STEM applications by level

Level	Amount
Primary School	10
Junior High School	22
Senior High School	32
College	11
General	15

Critical thinking is an ability that must be honed in various ways, one of which is learning. The use of PjBL-STEM in learning at the elementary school level is reported to stimulate student creativity (Lu et al., 2022). Creative thinking and critical thinking are interrelated abilities and are much needed to adapt to changing times (Fitriyah & Ramadani, 2021). At the elementary school level, teachers have difficulty integrating concepts from various subjects to provide contextual learning for students (Kartimi et al., 2021). At the lower secondary school level, the PjBL-STEM model helps develop critical thinking through challenging activities that generate curiosity (Lou et al., 2017). Learning materials have led to abstract concepts at the senior high school level. So, the PjBL-STEM model is needed to help understand abstract concepts by thinking critically (Arisa & Sitinjak, 2022). In several studies, PjBL-STEM learning is carried out with the help of media, for example, by applying 3D printing technology (Lin et al., 2018). At the university level, PjBL-STEM learning is presented to provide not too theoretical learning so that students can develop their critical thinking skills through direct problem-solving experience (Esmaeili, 2014). Apart from being applied to classroom learning, it turns out that PjBL-STEM is also being applied to general activities, for example, teacher capacity-building activities in designing and implementing learning (Smith et al., 2022).

The advantages and disadvantages of PjBL-STEM-based learning

In principle, PjBL-STEM is implemented by exposing students to real problems. Students are asked to be involved in finding solutions from various perspectives based on scientific knowledge learned and relevant practical knowledge. Implementing PjBL-STEM in learning is faced with various situations, so an outline of the advantages and disadvantages can be drawn. The advantages of using PjBL-STEM-based learning include:

1) Practicing 4C skills, especially critical thinking. PjBL-STEM guides students to think critically to produce products as solutions to complex problems. Student activities seeking information from various sources also empower critical thinking activities about the correctness of the information. The syntax in PjBL-STEM allows students to produce out-of-the-box solutions and products. Putri (2020) reported that PjBL-STEM is better at improving critical thinking skills than just using PjBL alone (Putri et al., 2020).
2) The problems raised in class are real complex problems. This helps students connect classroom understanding with real-life phenomena (Billiark et al., 2014).
3) The interaction between students and the learning environment provides a meaningful learning experience. When problems are presented, students assimilate and accommodate their knowledge schemes to new situations (Tseng et al., 2013). So that students can produce solutions in the form of products that are different from their groups. Learning with a group system allows students with a low learning speed to be helped by friends with a high learning speed (Saidaturrahmi et al., 2021). In its implementation, PjBL-STEM allows students to study independently through various learning sources. So that students construct their initial knowledge with newly acquired knowledge. Then share the knowledge and learning experience gained with their friends (Siew & Ambo, 2018).
4) PjBL-STEM is an interdisciplinary learning model combining various aspects of studies such as science, technology, engineering, and mathematics in integrated learning. Students learn to connect material concepts learned in class with real problems that exist in everyday life. The issues raised in PjBL-STEM have complex and authentic characteristics. The complexity of the problems raised requires students to combine a cross-

disciplinary understanding of STEM in developing solutions (English et al., 2017).

5) Providing opportunities for students to feel like a scientist who acts in solving problems in the world (Williams, 2011). Students can contribute critical ideas in overcoming environmental problems.

6) PjBL-STEM provides a positive competitive atmosphere in the classroom. Even though the actual goal of PjBL-STEM is not to focus on creating competition, the whole group will try to produce the best design. The teacher will appreciate the group with the best creative design. This will arouse the activity of all group members (Siew & Ambo, 2018).

7) Train students' communication skills. During the presentation, all students will share their opinions regarding the content being presented. Presenters try to answer critical questions from respondents. In addition, activities in PjBL-STEM also maintain communication and cooperation in groups. So, in the end, students are confident to share ideas and help each other produce quality products.

8) Assist teachers in presenting student-centered learning. With this, students have flexibility about what to learn (Loi, 2017). The autonomy given by the teacher to students in preparing projects aims to present a learning based on student's interests and abilities. Full responsibility is given by the teacher to students to learn independently through a collaborative approach (Saidaturrahmi et al., 2021).

9) Train teachers' professional abilities by designing PjBL-STEM learning that considers the relationship between learning objectives, learning processes, and assessment.

10) The PjBL-STEM model can be implemented in face-to-face or online classes. If implemented online, it can use the help of cloud computing, which teachers and students access. PjBL-STEM learning that is carried out online can improve students' planning, collaboration, and communication skills (Çakiroğlu & Erdemir, 2019).

In addition to its various advantages, PjBL-STEM-based learning also has the following weaknesses:

11) Requires an extended learning time to produce a product. Each group must organize tasks, materials, and time in carrying out the project. Limited direct learning time also influences teachers' willingness to implement STEM learning (Shidiq et al., 2020).

12) For Some students with a low learning speed, the teacher must facilitate understanding and solving problems (Siew & Ambo, 2018).

13) Disproportionate division of labor makes students uncomfortable with their groups. The division of tasks for each group dramatically affects group performance. The role of one member that is not optimal will affect the work of other group members. To overcome these problems, teachers need to remember the duties and roles of each group member (Koh et al., 2007).

14) Lack of cooperation in groups causes not optimal projects carried out by students. Feelings of dissatisfaction arise due to each group member's lack of communication and self-awareness. So, some group members feel dissatisfied with the group's work products (Beier et al., 2019).

15) Lack of understanding of learning content and students' interest in being active in class causes PjBL-STEM-based learning to be unsuccessful. Passive students usually try to avoid when learning takes place. However, they were still bound by the task given by the group. If the time given by the teacher is too long to compile the product, passive students will feel bored and unhappy when learning occurs.

16) Lack of confidence causes product presentations to be less than optimal. Confidence can be caused by the product being presented as less than optimal. For this reason, teachers must motivate students to experiment with different content and materials to produce the best products to increase student confidence.

SWOT analysis using the PjBL-STEM model in learning ecology and biodiversity in empowering critical thinking

Based on the literature review conducted, the strengths, weaknesses, challenges, and obstacles that might occur if PjBL-STEM is used in teaching ecology and biodiversity are obtained to empower students' critical thinking. The advantage that supports the implementation of PjBL-STEM in empowering students' critical thinking is inviting students to be active when learning occurs. The syntax in the PjBL-STEM model assists teachers in analyzing indicators of critical thinking being carried out by students. At the reflection stage, the teacher can empower students to think critically through activities to determine the subject matter. When continuing at the research and discovery stage, the teacher can empower students' critical thinking by uncovering facts, selecting arguments, and detecting bias. The teacher's application stage can empower students' critical thinking by selecting arguments, detecting bias, and drawing conclusions. At the communication stage, students are trained in developing argumentation skills by providing further explanations and drawing conclusions. So, every syntax in the PjBL-STEM model implemented in learning ecology and biodiversity can empower every indicator of critical thinking (Muzana et al., 2021). The PjBL-STEM model facilitates teachers in presenting differentiation learning in learning products while empowering students' critical thinking.

The weakness of implementing the PjBL-STEM model on ecology and biodiversity in developing critical thinking is that the syntax requires a long time. The

material on studying ecology and biodiversity is very dense. So, implementing the PjBL-STEM model may require more time for students to make projects. In addition, students who tend to be passive in class do not get meaningful learning. This is because the activities in PjBL-STEM learning require real student action in making products.

The long time in PjBL-STEM implementation is a challenge for teachers in managing time when the learning process occurs. In addition, the slow learning speed of students requires special attention. Usually, students associate making products (to solve problems) with the material concepts of ecology and biodiversity. On the other hand, content management in learning is also a challenge for teachers. This is done to bridge students with a high learning speed with students with a slow learning speed. Teachers can use this gap to empower critical-thinking students with slow learning speeds by providing various motivations.

Obstacles may occur when the PjBL-STEM model is implemented in classes with low learning motivation. Because PjBL-STEM requires student activity so that they gain knowledge independently through a critical thinking process. Various factors can optimally support PJBL-STEM, such as adequate teacher resources, characteristics of students classified as active, supporting facilities, and infrastructure (Shafiul Amri et al., 2020).

Conclusion

STEM-based project learning is needed to empower students' critical thinking on ecology and biodiversity material. This is evidenced by the many studies conducted on the effectiveness of the PjBL-STEM model in training critical thinking skills. The data comes from 90 journal data that discuss STEM-based project learning published in 2010-2022. All journals are indexed by Google Scholar. Based on the analysis, the STEM PjBL model has been implemented at the elementary school level up to tertiary institutions. Some general studies even apply STEM-based project learning in teacher capacity-building activities. They all have strengths, weaknesses, challenges, and obstacles that may occur when implementing the PjBL-STEM model on ecology and biodiversity in empowering students' critical thinking.

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The authors declare no conflict of interest.

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