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Improving Students' Critical Thinking through Science, Technology, Engineering, and Mixed Mathematics Learning on Ecosystem Materials

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A B S T R A C T

Critical thinking skills are an important competency in the 21st century that still needs to be improved in biology learning, especially in ecosystem materials. This study aims to analyze the influence of *the* STEM-based *Blended Learning* model on the critical thinking skills of high school students on ecosystem materials. The study used a pre-experimental method with *a one-group pretest-posttest design*. The subjects of the study were 36 students of class X of SMA Negeri 1 Bangilan. The BL-STEM model is applied through offline and online learning with *a STEM* approach, including *Science* in the form of understanding ecosystem concepts, *Technology* using Virtual Lab digital simulations (*ecology lab learner*), *Engineering* challenges engineering ecosystem balance, and *Mathematics* through data collection, graph analysis, and population change tables. The results showed an increase in the average critical thinking skill of 15.75 points, from 74.78 in the *pretest* to 90.53 in the *posttest*, and the increase was statistically significant and the N-Gain was 0.66 in the medium category. This increase was supported by the implementation of BL-STEM learning which reached 99.5% according to the LKPD and a very positive student response of 94.4%. Critical thinking skills are measured based on six indicators, namely interpretation, analysis, inference, explanation, evaluation, and self-regulation. These indicators are measured through students' ability to interpret and analyze data from simulations, identify cause-and-effect relationships between ecosystem components, draw conclusions about population change, evaluate ecological factors, and reflect on the thought process in solving ecosystem problems. Thus, BL-STEM learning is effective in improving students' critical thinking skills in high school ecosystem materials.

Keywords: *Blended Learning, STEM, Critical Thinking Skills, Ecosystem.*

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INTRODUCTION

Facing the challenges of the contemporary era, individuals are required to have the ability to balance economic development with solving complex problems through the use of various innovations that develop within the framework of the industrial revolution, including internet technology. This condition requires the world of education to direct the curriculum to strengthen competencies *hard skill* and *soft skill* which are relevant to the needs of the 21st century, such as the ability to think critically, creatively, innovatively, effective communication, global insights, and readiness to face the dynamics of the industrial revolution. Therefore, curriculum development needs to be focused on strengthening the field *Science, Technology, Engineering, and Mathematics* (*VOTE*) as a learning foundation that is adaptive to the development of the times (Mukhlasin, 2019).

Quality learning requires the application of appropriate and contextual strategies. Teachers have a central role in designing and managing the learning process so that educational goals can be achieved optimally. The effectiveness of learning is not only determined by the achievement of learning outcomes, but also by its ability to meet the needs of students and adapt to the demands of global development (Purnasari & Sadewo, 2020).

Along with the development of information technology, learning methods in the world of education have undergone significant transformation, especially through the use of digital technology in the teaching and learning process (Umami, 2022).

In the context of 21st century global competence, critical thinking skills are one of the essential skills that must be developed. Critical thinking skills play an important role in helping students adjust to the rapid development of science and technology. This ability is defined as a problem-solving process that involves integrating knowledge and logical reasoning to produce rational decisions (Cahyono, 2017). Students who have critical thinking skills tend to be able to analyze information in depth, formulate logical arguments, and make decisions based on valid evidence. Conceptually, Ennis (2011) stated that critical thinking skills include several main aspects, including basic elaboration, development of core competencies, drawing conclusions, further elaboration, and prediction and integration of information (Rahmawati et al., 2016).

The results of the *Programme for International Student Assessment* (PISA) evaluation show that the science literacy and critical reasoning skills of Indonesian students are still relatively low. PISA data in 2019 places Indonesia in 71st place with an average science score of 396 points (Tohir, 2019). In addition, the 2018 PISA results showed a reading literacy score of 371, mathematics 379, and science 389, all of which are below the OECD country average. These findings indicate that the critical thinking and problem-solving skills of Indonesian students have not been developed optimally. This is reinforced by the research of Susilawati et al., (2020) which reported that most students were in the low category in critical thinking skills. Various factors also affect these conditions, including the application of less varied learning models, low literacy culture, monotonous teaching strategies, and limited learning time in the classroomm(Nuranafi & Rusnilawati, 2022).

One of the learning models that is considered relevant to answer these challenges is *blended learning* that is integrated with *STEM approaches*. *Blended learning* is a combination of face-to-face learning and online learning that utilizes digital technology in a structured manner (Sari, 2021). This model includes four learning spaces, namely direct synchronous, virtual synchronous, self-synchronous, and collaborative asynchronous (Chaeruman & Maudiarti, 2018). A number of studies show that the application of *blended learning* has a positive effect on improving critical thinking skills, learning independence, and student learning outcomes (Pratiwi et al., 2022). The integration of *STEM* approaches in learning has been proven to be able to develop high-level thinking skills, including critical thinking and problem-solving through contextual problem-based learning (Wahono *et al*., 2020). However, the results of previous studies show that most studies still examine *blended learning* and *STEM* separately. Research that systematically integrates *STEM-based blended learning* is still limited, especially in biology learning at the high school level. In addition, most BL-STEM research still focuses on physics and chemistry subjects, while studies that specifically examine the application of BL-STEM to ecosystem materials and its impact on the critical thinking skills of high school students are still very limited (Utami *et al*., 2022).

Ecosystem material at the high school level is one of the topics that requires critical thinking skills because it involves analyzing the relationship between biotic and abiotic components, population dynamics, and ecosystem balance. Research shows that students still have difficulty in understanding the complex relationships between ecosystem components and in formulating data-based scientific arguments (Wawan & Setiawan, 2021). However, there have not been many studies that have examined the application of *STEM-based blended learning* supported by virtual simulations in ecosystem learning to improve the critical thinking skills of high school students. Therefore, this study aims to determine the improvement of students' critical thinking through *blended STEM ecosystem* materials in high school, as an effort to fill the research gap related to the integration of BL-STEM in biology learning and to make an empirical contribution to the development of learning models that are in line with the demands of the Independent Curriculum and 21st century learning. (Setiawan & Iasha, 2020).

In line with the Independent Curriculum, the learning outcomes of Biology phase E (class X of high school) emphasize students' ability to understand and analyze biological phenomena and their relationship with science, technology, the environment, and society. Critical thinking skills are one of the main prerequisites in achieving these goals because they are closely related to scientific processes, such as analyzing data, evaluating evidence, and drawing logical conclusions (Wahono *et al.*, 2023).

METHOD

This study uses a quantitative approach with a pre-experimental *design* of *the One Group Pretest–Posttest Design* type (Sugiyono, 2019). The design aims to compare the level of students' critical thinking skills before and after the implementation of learning using a *STEM-based blended learning* approach. *The pretest* is given as the first step to collect data on students' basic abilities before the learning process begins, then learning is carried out using *a* STEM-based *blended learning* model supported by lkpd on ecosystem materials. After learning, *a Posttest* is given at the end of the learning to measure the improvement of students' critical thinking skills. The design of the study follows the pattern shown in Table 1.

Table 1. Research Design *One Group Pre-Test Post-Test Design*

Stages	Treatment	Instruments
Pre-test	-	Critical thinking skills test
Treatment	BL-VOTE	LKPD & learning activities
Post-test	-	Critical thinking skills test

The research was carried out at SMAN 1 Bangilan, Tuban Regency, East Java, in August 2025. The research subjects consisted of 36 students in class X-E2 who were selected using *purposive sampling techniques* based on the recommendations of biology teachers, with the consideration that the class had not received learning on ecosystem materials and was considered representative for the application of BL-STEM learning. The independent variable in this study is *the* STEM-based *Blended Learning* (BL-STEM*) learning model*, while the bound variable is the students' critical thinking skills. Critical thinking skills are measured based on six indicators according to Facione (2015), namely interpretation, analysis, inference, explanation, evaluation, and self-regulation.

The research instruments included critical thinking skills tests, observation sheets on learning implementation, and student response questionnaires. The critical thinking skills test is in the form of 12 multiple-choice questions given during *the pretest* and *posttest*. The test instrument has been validated by material experts and learning evaluation experts through expert judgment. The observation sheet was used to assess the implementation of BL-STEM learning based on *the stages of Science*, Technology, *Engineering*, and *Mathematics* in the *Discovery Learning syntax*. The student response questionnaire was used to find out students' responses to the application of BL-STEM learning. The research procedure includes three stages, namely:

Table 2. Research Procedure

Preparation Stage	Includes the preparation and validation of learning tools as well as research instruments and *pretests* at the beginning.
Implementation stage	It is carried out by applying *the Discovery Learning* model in BL-STEM learning through offline and online activities, which integrates the exploration of ecosystem concepts (*Science*), the use of *Virtual Lab Ecology* (*Technology*) simulations, the design of ecosystem balance strategies (*Engineering*), and the collection and analysis of population change data (*Mathematics*).
Final stage	Including the provision of *posttests*, filling out student response questionnaires, and collecting and processing data.

Data analysis was carried out descriptively and inferentially. Descriptive analysis was used to describe *pretest* and *posttest* scores, learning implementation, and student responses. The normality test was carried out using *the Shapiro–Wilk* test. Furthermore, the difference in *pretest* and *posttest* scores was analyzed using *the Paired Sample t-Test* at a significance level of 0.05. The improvement of students' critical thinking skills is calculated using the N-Gain value with the following categories:

Table 3. *N-Gain Category*

N-Gain *Value*	**Category**
≥ 0.70	Height
0,30–0,69	Medium
< 0.30	Low

FINDINGS AND DISCUSSION

This study aims to analyze the effect of the application of *STEM-based blended learning* model (BL-STEM) on improving the critical thinking skills of high school students in class X on ecosystem materials. The presentation of research results includes the implementation of BL-STEM learning, the achievement of students' critical thinking skills based on *the results of the pretest* and *posttest*, the results of inferential statistical tests, and the students' responses to applied learning.

The implementation of BL-STEM learning is observed using observation sheets to ensure that all stages of learning are carried out in accordance with the plan that has been prepared. Observations are carried out during the learning process by paying attention to the implementation of *Science*, *Technology*, *Engineering*, and *Mathematics* aspects in ecosystem learning. The recapitulation of the results of observations on the implementation of BL-STEM learning is presented in Table 4.

Table 4. Implementation of *STEM-Based Blended Learning*

Learning Aspects	**Percentage (%)**	**Category**
Understanding predator-prey interaction and problem identification (*Science* & *Technology*)	100	Highly Implemented
Exploration of digital simulations and ecosystem balance engineering challenges (*Technology* & *Engineering*)	98,8	Highly Implemented
Data Collection, Data Analysis, and Reflection (*Technology* & *Mathematics*)	100	Highly Implemented
Average	**99,5**	**Highly Implemented**

Based on Table 4, all aspects of BL-STEM learning are carried out in the category of very implemented. The average implementation of 99.5% shows that learning runs according to the designed syntax and reflects the integration between offline and online STEM-based activities. The implementation of this high learning is an important prerequisite for the achievement of improving students' critical thinking skills.

Students' critical thinking skills were measured using *pretest* and *posttest tests* given to 36 students. A summary of the average score of students' critical thinking skills is presented in Table 5.

Table 5. Average Scores of *Pretest* and *Posttest* Critical Thinking Skills

Tests	**N**	**Average score**
Pretest	36	74,78
Posttest	36	90,53

Table 5 shows an increase in the average score of students' critical thinking skills by 15.75 points after the implementation of BL-STEM learning. This increase indicates that learning that integrates *STEM approaches in* blended learning *schemes* is able to have a positive impact on students' critical thinking skills. Next, *the Paired Sample t-Test* is carried out to find out the difference between *pretest* and *posttest* scores. The results of the t-test are presented in Table 6.

Tabel 6. Uji *Paired Sample t-Test*

Variabel	***Mean Difference***	***t***	***Sig. (2-tailed)***
Pretest post-test	-15,75	-19,100	0,000

The results of *the paired sample t-test* showed a significant difference between *the pretest* and *posttest scores* ($t = -19.100$; $p < 0.001$). These results indicate that the application of BL-STEM learning has a significant effect on improving students' critical thinking skills.

To meet the analysis of learning improvement and effectiveness, *pretest* and *posttest* data were further analyzed using *N-Gain* scores. A summary of the results *of N-Gain* students' critical thinking skills is presented in Table 7.

Table 7. Summary of *N-Gain Results*

Parameter	Value
Number of Students (N)	36
Rata-rata *pretest*	74,78
Posttest *rate-rate*	90,53
Average *N-Gain*	0,66
Category: *N-Gain*	Medium
Minimum value *of N-Gain*	0,38
Maximum Value *of N-Gain*	1,00

Based on Table 7, an average N-Gain value of 0.66 was obtained which is included in the medium category, so it can be concluded that the application *of the* STEM-based *blended learning* model is effective in improving students' critical thinking skills.

Furthermore, student responses to the implementation of BL-STEM learning were analyzed using student response questionnaires. A recapitulation of student responses is presented in Table 8.

Table 8. Student Response Recapitulation

Statement	Percentage of Positive Response (%)
The material is in accordance with *STEM concepts* and is easy to understand	94,4
Offline activities help understanding the concept of ecosystems	100
BL-STEM learning provides an opportunity for reflection and reasoning	94,4
The BL-STEM learning model trains data-driven decision-making	100
BL-STEM learning model stimulates creativity and innovation	100
The BL-STEM learning model helps with a thorough understanding of concepts	100

The results of the questionnaire showed that student responses were in the very positive category, which indicates that BL-STEM learning can be well received and felt to be beneficial in supporting ecosystem learning.

The results of this study show that the application of *the* STEM-based *blended learning* model has a positive and significant influence on improving students' critical thinking skills in ecosystem materials. The increase is reflected in the difference in the average score of pretest and posttest of 15.75 points, which is strengthened by the results *of the paired samples t-test* with a significance value of 0.000. These findings indicate that learning that combines face-to-face interaction and online learning with *a STEM approach* is able to create a learning environment that encourages students to think critically in a more in-depth and systematic manner. The success of improving critical thinking skills is inseparable from the very high implementation of BL-STEM learning. All stages of learning, starting from understanding ecosystem concepts, exploring digital simulations, ecosystem balance engineering challenges, to data collection and analysis, were carried out optimally. The high implementation of learning ensures that students are actively involved in every learning process, thus providing ample opportunities to practice high-level thinking skills. This is in line with the view of Kusumawardani (2024) who states that consistent learning implementation is the main prerequisite for the successful implementation of innovative learning models.

STEM in *blended learning* makes a real contribution to the development of students' critical thinking skills. In the *Science aspect*, students are trained to understand the concept of ecosystem and the interaction between biotic components through contextual problems. The *Technology aspect* is realized through the use of virtual lab digital simulations (*Ecology Lab Learner*) which allows students to observe dynamic population changes. Furthermore, *the Engineering aspect* is trained through the activity of designing solutions to maintain the balance of the ecosystem, while *the Mathematics* aspect is developed through data collection, graph analysis, and interpretation of population change tables. The integration of these four aspects encourages students to process data-based information, draw logical conclusions, and critically evaluate the resulting solutions. The improvement of critical thinking skills is also supported by student-centered learning characteristics through the application of *Discovery Learning syntax*. Students not only receive information, but are actively involved in the process of discovering concepts, analyzing data, and reflecting on learning outcomes. This condition

strengthens the development of critical thinking skills, especially in the aspects of analysis, inference, and evaluation, which require the ability to process information and solve evidence-based problems. These findings are in line with Supriyadi *et al.* (2023) which states that *STEM* learning is effective in developing higher-level thinking skills because it actively engages students in analytical and contextual activities.

In addition to being reviewed from the test results, the effectiveness of BL-STEM learning was also strengthened by a very positive student response. Most students stated that learning helped them understand the concept of ecosystems holistically, provided opportunities for reflection, and supported data-driven decision-making. This positive response shows that students not only experience improved cognitive abilities, but also feel comfortable and motivated in following learning. This supports the findings of Luciana *et al*. (2024) and Kamilah (2024) who stated that *STEM-based blended learning* is able to increase student learning engagement and have a positive impact on critical thinking skills.

Overall, the optimal implementation of BL-STEM learning, the integration of *STEM* in learning activities, and excellent student acceptance show that *the* STEM-based *blended learning model* is effective in improving students' critical thinking skills on ecosystem materials. The improvement of critical thinking skills can also be seen from the achievements of each indicator. Interpretation indicators are trained through activities on the LKPD that direct students to observe and interpret the graph of changes in the population of organisms in the *Ecology Lab Learner simulation*, specifically in the activity of observing predator-prey interactions between rabbits and wolves up to a specific day (e.g. the 30th and 100th days). At this stage, students are asked to read population graphs, record changes in the number of organisms, and explain the trend of increasing or decreasing populations based on the simulation results. The achievement of interpretation indicators showed relatively stable results in the *pretest* and *posttest*, which indicated that the students' initial ability to interpret ecological data and graphs was good enough before the treatment was given.

In contrast, the indicators of analysis, inference, and evaluation experienced the most significant increase after the implementation of learning. The analysis indicators developed through LKPD activities at the data collection and analysis stage, when students compared several ecosystem scenarios, such as differences in the types of plants consumed by herbivores, the addition of omnivores, and changes in food configuration. Through these activities, students are trained to identify cause-and-effect relationships between ecosystem components based on numerical data and graphs of simulated results. Inference indicators are trained through conclusion drawing activities in LKPD, especially when students are asked to conclude the impact of the addition or decrease of organisms on the balance of the ecosystem, as well as predict the condition of the population in the future based on the observed patterns. Meanwhile, evaluation indicators developed through *ecosystem engineering challenge activities*, where students were asked to assess the success or failure of the ecosystem configuration they designed, as well as provide logical and data-driven reasons regarding the accuracy of the relationships between ecological factors that affect ecosystem stability. These findings confirm that learning that combines direct interaction, digital technology, and *STEM approaches* is able to create meaningful learning experiences and are oriented towards the development of higher-level thinking skills.

CONCLUSIONS

The application *of the* STEM-based *blended learning* model (BL-STEM) has been proven to have a significant effect on improving students' critical thinking skills on ecosystem materials. The average score increased from 74.78 to 90.53 with a statistically significant difference (*Sig*. = 0.000 < 0.05) and an *N-Gain* value of 0.66 (medium category). These findings show that the integration of face-to-face learning, digital technology, and *STEM approaches* is effective in training students' critical thinking skills. Practically, biology teachers are advised to implement BL-STEM by utilizing simulation and data analysis as strategies to develop

critical thinking skills. Further research is recommended to apply this model to other biological materials as well as to use a more robust experimental design with a control group to strengthen the validity of the findings.

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REFERENCES

Chaeruman, U. A., & Maudiarti, S. (2018). Quadrant of Blended Learning: a Proposed Conceptual Model for Designing Effective Blended Learning. *Jurnal Pembelajaran Inovatif*, *1*(1). https://doi.org/10.21009/jpi.011.01

Ennis, R. H. (2011). *Sifat Berpikir Kritis: Sebuah Garis Besar Disposisi Berpikir Kritis*.

Kusumawardani, W. (2024). PBL in blended learning design to increase critical thinking and problem-solving skills among senior high school students. *JPPIPA*.

Mukhlasin, A. (2019). Kepemimpinan Pendidikan Di Era Revolusi Industri 4.0. *Jurnal Tawadhu*.

Nuranafi, D. A., & Rusnilawati, R. (2022). Efektivitas Discovery Learning Menggunakan Media Pop-up Book untuk Meningkatkan Hasil Belajar dan Keterampilan Berpikir Kritis. *Kwangsan: Jurnal Teknologi Pendidikan*, *10*(2). https://doi.org/10.31800/jtp.kw.v10n2.p239--260

Pratiwi, A., Fauzi, A., & Sumatra, N. (2022). Development of HOTS-Based Student Activity Sheet with an Open Ended Approach to Improve Mathematical Metacognition Ability and Self Confidence of Students of 20 Medan Junior High School. *Journal of Education and Practice*, *13*(16), 53–62. https://doi.org/10.7176/jep/13-16-06

Purnasari, P. D., & Sadewo, Y. D. (2020). Pemanfaatan Teknologi Dalam Pembelajaran Sebagai Upaya Peningkatan Kompetesnsi Pedagogik. *Jurnal Publikasi Pendidikan*.

Rahmawati, I., Rahayu, S., & Hidayat, A. (2016). Analisis Keterampilan Berpikir Kritis Siswa SMP Pada Materi Gaya dan Penerapannya. *Pros. Semnas Pend. IPA Pascasarjana UM*, *1*.

Sari, D. R. (2021). *Rural EFL Teachers ' Emotion s and Agency in Online Language Teaching : I Will Survive*. *10*(1), 1–14. https://doi.org/10.21580/vjv10i17727

Sugiyono. (2019). Quantitative, qualitative, and R&D research methods. In *Student Library*.

Susilawati, E., Agustinasari, A., Samsudin, A., & Siahaan, P. (2020). Analisis Tingkat Keterampilan Berpikir Kritis Siswa SMA. *Jurnal Pendidikan Fisika Dan Teknologi*, *6*(1). https://doi.org/10.29303/jpft.v6i1.1453

Tohir, M. (2019). keterampilan berpikir kreatif siswa dalam menyelesaikan soal olimpiade matematika berdasarkan level metakognisi. *Alifmatika: Jurnal Pendidikan Dan Pembelajaran Matematika*, *1*(1), 1–14. https://doi.org/10.35316/alifmatika.2019.v1i1.1-14

Umami, R. (2022). Efektifitas Model Pembelajaran Blended Learning Dengan Pendekatan STEM Terhadap Kemampuan Berfikir Kritis Siswa Di SMA IT TGH UMAR Kelayu Tahun 2021/2022. *Jurnal Pengabdian Magister Pendidikan IPA*, *5*(2). https://doi.org/10.29303/jpmpi.v5i2.1601

Wawan, & Setiawan, A. (2021). *Efektifitas Pembelajaran Kolaboratif Berbasis Online Terintegrasi E-Akademik Terhadap Kemampuan Berpikir Kritis dan Sikap Terhadap Matematika*.