Biology learning model to improve critical thinking skills of ten grade students: A meta-analysis

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ABSTRACT

Critical thinking skill is one of the higher-order thinking skills which has to be mastered by students. However, many studies showed that students' critical thinking skills are still relatively low. So, it is necessary to carry out learning activities that can increase critical thinking skills, one of that is through the application of learning models. The purpose of this study was to find out the types of biology learning model that can improve the critical thinking skills of class X students. The type of research used quantitative research with the research method used in the form of meta-analysis. The results of the study revealed that there were 17 types of learning models that were proven to be able to improve the biological critical thinking skills of class X students. The guided discovery learning model based on e-learning was proven to have the highest effect size value of 1,07. The learning model which was recommended to improve the critical thinking skills based on material includes: problem-based learning for biodiversity material, think pair share (TPS) cooperative type model for environmental pollution material, problem-based learning combined with student facilitator and explaining for fungi, and guided discovery and e-learning based learning for ecosystem materials.

INTRODUCTION

One of the learning targets is the achievement of graduate competency standards (SKL), one part of which is being able to think critically (Mahfud, 2019). Critical thinking is a process of intellectual skills in building concepts, applying, evaluating, synthesizing, and analyzing that is required in learning biology (Fitriani et al., 2020). This is important, because biology is a subject which not only discusses concrete natural phenomenons, but also discusses abstract objects such as metabolic processes, hormonal systems, coordination systems, and reproductive systems. Critical thinking skills can support students to reach a deep understanding because students who have developed these skills will have the ability to identify problems, consider questions to solve problems, and discover information needed to solve problems (Cahyono, 2017). Students lacking proficient critical thinking abilities will struggle to methodically examine issues, find it challenging to address various problems in a structured fashion, and may not possess a strong competitive edge. (Benyamin et al., 2014). For this reason, critical thinking skills are essential skills that students must acquire.

The results of research conducted by Khasani et al. (2019) show that students' critical thinking skills are still relatively low with an average score of 49. In parallel with the research of Khasani et al. (2019), which stated that students' critical thinking skills were still relatively low with an average score of 49.26. If the score is interpreted into the critical thinking skills criteria table, it will be included in the less critical category (Basri & As'ari, 2019).

The low level of students' critical thinking skills occurs because these skills are not developed during the learning process. Learning in the classroom generally emphasizes the use of low-level thinking skills and tends to be dominated by the teacher, thus causing students to only act as objects of learning (Veramuthu & Shah, 2020). Students are required to passively absorb information and then recall it when taking tests. The learning process that only encourages students to passively absorb information prevents students from developing critical thinking skills. In fact, this skill is indispensable in facing the challenges of life. One alternative way to developing students' critical thinking skills is through the application of appropriate and varied learning models (Setiana & Purwoko, 2021). According to Juniati (2017), choosing the right learning model can create a conducive classroom condition and situation so that learning can take place according to the desired goals.

There have been many studies that discuss the application of learning models to develop students' critical thinking skills. Learning models that are proven to develop critical thinking skills include: group-investigation type cooperative model, guided-inquiry type cooperative, guided inquiry, problem-based learning, student facilitator and explaining (Miarsyah et al., 2021), think pair share (Murniati et al., 2020), and guided-discovery learning. Since there are so many models that can be used to develop critical thinking, it is necessary to conduct a meta-analysis research related to the improvement of students' critical thinking skills through the application of learning models.

Meta-analysis is a method of research that engages the use of previous studies that have been used by other researchers. This approach is conducted with quantitative and systematic methods to reach accurate conclusions. This type of research will evaluate previous studies so that researchers will not have to conduct investigations in the real field. Another advantage of meta-analysis is the ability to overcome differences in results between the results of studies because it can describe the connection between studies well (Lee, 2019).

Previous studies that have conducted meta-analysis on learning models including the research of Duda et al. (2019) which studied the use of PBL model to improve science process skills; Pramana et al. (2020) which examined the PBL model in biology learning; and Miarsyah et al. (2021) who studied the cooperative model in biology learning. Based on the literature review, there is no research that discusses the learning model used to improve the critical thinking skills of grade X students. This study aims to determine the types of biology learning models that have

the potential to improve the critical thinking skills of grade X students. The most recommended biology learning model to improve critical thinking skills of grade X students in each learning material is identified by considering the results of the effect size value.

METHODS

The research method used here is quantitative research with a research method in the form of meta-analysis. This type of research is used to summarize various studies related to learning models that can develop students' critical thinking skills. The implementation time of this research started from January-June 2021. The population in this study were Biology Education articles that had been published in national journals in the range of 2011-2020. The samples in this study were some articles with these following criteria.

a. The research focuses on the use of learning models to improve students' critical thinking skills in biology subjects.
b. The research was conducted at the X grade high school education level.
c. Article published in a Sinta accredited journal.
d. The content of the article fulfills the data needed in calculating the effect size, namely the mean value of the experimental group, the mean of the control group, the standard deviation, the t-count, the free degree, and the sum of the squares.

The research instrument used in this study was a coding category form. Meta-analysis research uses analysis with effect size techniques. As in the research of Juandi et al. (2020) specifically for data with testing based on mean and standard deviation. The formula is as follow.

$$\eta^2 = \frac{\bar{x}\ experiment - \bar{x}\ control}{SD\ control}$$

Description:

η2 = effect size amount
$\bar{x}\ experiment$ = experimental group-mean
$\bar{x}\ control$ = control group mean

Experimental research that only involves two groups, namely the experimental group and the control group, using comparative analysis (t-test), then uses the effect size formula as follows.

$$\eta^2 = \frac{to^2}{to^2 + db}$$

Description:

η^2 = effect size amount
t_0 = t count
db = degrees of freedom

Experimental research involving more than two groups and using comparative analysis with the One-Way Anova analysis technique, the formula is as follows.

$$\eta^2 = \frac{JK\ between}{JK\ total}$$

Description:

η^2 = effect size amount
JK = sum of squares

If the experimental research involves more than two groups and their interactions, and uses group analysis with the Two-Way Anova analysis technique, the formula used is as follows.

$$\eta^2 = \frac{JK\ (A)}{JK\ (A) + JK\ (D)}$$

Description:

η^2 = effect size amount
JK (A) = sum of squares of factor A
JK (D) = sum of within squares

Research using group analysis with covariance analysis techniques, the formula used is as follows.

$$\eta_A^2 = \frac{JK\ (A)}{JK\ (A) + JK\ (D)}$$
$$\eta_x^2 = \frac{JK\ (X)}{JK\ (X) + JK\ (D)}$$

 Description:

η^2 = effect size amount

JK (A)   = sum of squares of factor A

JK (X)   = sum of squares of covariates X

JK (D)   = sum of within squares

The criteria used to determine the interpretation of the effect size results use the following standard.

Minor effect   = 0.01 < η2≤ 0.09

Moderate effect   = 0.09 <η2 ≤0.25

Major effect   = η2 > 0.25

RESULTS AND DISCUSSION

A biology learning model with potential to improve critical thinking skills of grade X students

Based on the analysis of 20 articles sampled, 17 biology learning models were found that potentially improved critical thinking skills of grade X students. Of the 17 learning models, problem-based learning has the highest frequency, as many as three articles that used this model to improve critical thinking skills of grade X biology students. The guided inquiry model is the second most used to improve critical thinking skills of grade X biology students, with two articles. The list of biology lessons that have the potential to improve critical thinking skills of grade X students is shown in (Table 1).

Table 1. Biology learning model to improve critical thinking skills of grade X students

No.	Article Code	Learning Model
1.	S.4	
	S.17	Problem-based learning
	S.20	
2.	S.1	Guided inquiry
	S.5	
3.	S.7	Problem-based learning based on socio-scientific issues
4.	S.2	Problem-based learning paired with student facilitators and explanations
5.	S.3	Project-based
6.	S.8	Reciprocal teaching with picture riddles
7.	S.6	Jigsaw cooperative type
8.	S.13	Think pair share (TPS) cooperative type
9.	S.9	Learning cycle 5E
10.	S.10	Problem solving
11.	S.11	Blended learning supported by digital comics
12.	S.12	Team assisted individualization with audiovisual media
13.	S.14	Problem-based teaching
14.	S.15	Concept-attainment model
15.	S.16	Group investigation (GI)
16.	S.18	E-learning based on guided discovery learning
17.	S.19	Science technology society

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Problem-based learning and guided inquiry models are part of the suggested learning models. According to Alvionita & Supardi (2020), the problem-based learning model can help students to learn the roles of adults and independent learners, and develop critical thinking skills. This is due to the fact that the application of the problem-based learning model through its syntax can develop critical thinking indicators, especially in the syntax of introducing problems students will be developed to answer questions and ask questions, and in the syntax of assisting student study group investigations in identifying assumptions, inducing, and observing. In addition, in the analysis and evaluation syntax, students will learn to choose an action and analyze the action so that students' critical thinking skills increase (Anazifa & Djukri, 2017). This is supported by Saiful et al. (2020) research which states that the application of problem-based learning models can develop critical thinking skills, especially on problem identification indicators. The guided inquiry learning model is also proven to improve critical thinking skills (Ade & Sarwanto, 2020) and student learning outcomes (Sejati et al., 2021). This learning model involves maximum student skills to study and search for existing phenomena logically and systematically so that students can formulate their own discoveries. (Antika & Mukarromah, 2021; Sumarli et al., 2017).

Other learning models besides problem-based learning and guided inquiry were only used in one sample article. Most of these learning models are learning models that place learners as the subject of learning, which means students are encouraged to be actively involved in learning. According to research by Reynders et al. (2020), to develop critical thinking skills, students need to be actively involved in the learning process, have skills in identifying, analyzing, and solving problems, have the ability to develop understanding independently, and be able to communicate explanations and formulate conclusions from their understanding. Learning models that position students as the main role of learning, develop students to find, analyze, and solve problems, encourage students to build and seek their own understanding, and facilitate students to be able to provide explanations and conclude their understanding are very suitable to be used to improve students' critical thinking skills

The most recommended biology learning model to improve critical thinking skills of grade X students based on effect size value

Overall, the average effect size value of the application of learning models in improving critical thinking skills is around 0.35. This indicates that the use of learning models in general has a significant impact in improving students' critical thinking skills. The e-learning-based guided discovery learning model has the highest effect size value, which is 1.07, indicating that the model has the greatest influence in helping to improve critical thinking skills of grade X biology students. The problem-based learning model combined with student facilitator and explaining with a value of 0.79 ranks second as the most effective learning model to improve critical thinking skills of grade X students in biology material, followed by think pair share (TPS) cooperative type model with an effect size value of 0.62. In addition to those three learning models, the science technology society learning model, group investigation (GI), problem solving, blended learning supported by digital comics, and project-based learning models also have relatively large effect size values in improving critical thinking skills of grade X biology students. The list of recommended biology learning models to improve critical thinking skills of grade X students based on the effect size value can be seen in (Table 2).

Learning activities are often teacher centered (Muganga & Ssenkusu, 2019). As a result, students are more passive because the teacher dominates which makes it difficult to engage them in active learning in situations that require critical thinking skills (Howell, 2021). Biology learning is basically a process of discovery through direct learning experiences by developing thinking skills, one of which is critical thinking (Suryawati & Osman, 2017). The solution that can be carried out by

teachers so that the quality of the learning process becomes higher is to apply the right learning model (Murniati et al., 2020).

Table 2. Effect size in terms of the type of learning model used

Learning Model	f	Mean effect size	Description
Team assisted individualization with audiovisual media	1	0,01	
Guided inquiry	2	0,09	Minor effect
Learning cycle 5E	1	0,09	
Problem based teaching	1	0,09	
Concept attainment model	1	0,14	
Jigsaw cooperative type	1	0,19	
Problem-based learning based on socio-scientific issues	1	0,2	Moderate Effect
Problem based learning	3	0,2	
Reciprocal teaching with picture riddles	1	0,24	
Project-based	1	0,34	
Blended learning supported by digital comics	1	0,36	
Problem solving	1	0,39	
Group investigation (GI)	1	0,51	
Science technology society	1	0,61	Major Effect
Think pair share cooperative type (TPS)	1	0,62	
Problem-based learning combined with student facilitation and exploration	1	0,79	
Guided discovery learning berbasis e-learning	1	1,07	

The guided-discovery learning model is a learning model that makes students learn to identify assumptions, analyze arguments, and identify reasons presented so that the learning model can facilitate students in improving critical thinking skills. The guided-discovery learning model will be more optimal to improve critical thinking skills if it is integrated with e-learning-based learning. A study proved that e-learning contributes to observational learning and constructivism aspects that enable students to expand their knowledge and improve critical thinking skills outside the classroom by conducting independent investigations and experiments (Evendi et al., 2022).

The combination of problem-based learning and student facilitator and explaining models encourages students to be brave in finding solutions to existing problems so that students gain experience to be more active in discussion and critical thinking (Alrahlah, 2016). The think pair share (TPS) cooperative type model creates an opportunity for interaction among students so that students have more responsibility and confidence to solve problems given by the teacher. Therefore, based on the results of research by Aufa et al. (2021), this learning model significantly influences the improvement of students' social attitudes, critical thinking skills, and cognitive skills.

The science technology society learning model, group investigation (GI), problem solving, blended learning with the support of digital comics, and project-based learning models also have relatively large effect size values in improving critical thinking skills of grade X biology students. These learning models are learning models that encourage students to be able to formulate a conclusion based on deductive reasoning, synthesize both arguments, statements, and evidences, and make decisions independently or in groups (Ju & Choi, 2018). Such learning conditions are learning that can help develop students' critical thinking skills (Rusmansyah et al., 2019; Tan, 2017).

Although it does not have a large effect size value, other learning models that have medium-small effect size values are also still relevant to be used to improve critical thinking skills of grade X biology students because they have been proven to be able to improve students' critical thinking skills even though the effect is small. This small effect size value is due to the fact that in addition to having advantages, the application of the learning model also has disadvantages, including:

student activities carried out outside of school are difficult for teachers to monitor, not many teachers can lead students to learning goals, and the application of learning models often requires a lot of media and a long time (Hapsari & Hanif, 2019). In addition, teachers find it difficult to change their usual learning style and struggle to conduct objective assessments (Ferreira et al., 2020). However, the use of learning models has an impact on students' knowledge and critical thinking skills. The weaknesses and advantages of the application of the learning model show that it is necessary to choose a learning model that is relevant to student conditions (Soboleva et al., 2022), material concepts, time allocations, and costs in order to achieve learning goals (Hytönen et al., 2021).

The most recommended biology learning model for improving students' critical thinking skills on each content of grade x material based on effect size value model

Data on the most recommended biology learning model to improve students' critical thinking skills on each grade X material content based on the effect size value can be seen in (Table 3).

Table 3. Effect size in terms of the material used as learning content

Learning Material	Type of Learning Model	Effect size	Keterangan
Biodiversity	Guided inquiry	0,10	Moderate effect
	Problem-based learning based on social-scientific issues	0,20	
	Reciprocal teaching with picture riddles	0,24	Major effect
	Problem based learning	0,51	
Environmental pollution	Problem based learning	0,00	Minor effect
	Guided inquiry	0,09	
	Concept attainment model	0,14	Moderate effect
	Jigsaw cooperative type	0,19	
	Problem solving	0,39	Major effect
	Think pair share cooperative type (TPS)	0,62	
Fungus	Problem based learning	0,09	Minor effect
	Problem-based learning combined with student facilitation and exploration	0,79	Major effect
Ecosystems	Team assisted individualization with audiovisual media	0,01	Moderate effect
	E-learning based on guided discovery learning	1,07	Major effect
Bryophyta	Learning cycle 5E	0,09	Minor effect
Pteridophyta			
Classification of living things	Guided inquiry	0,10	Moderate effect
Virus	Project based	0,34	Major effect
Bacteria			
Animalia	Blended learning supported by digital comics	0,36	Major effect

There are ten learning materials used as research subjects. The data showed that there were four learning models that were proven to improve students' critical thinking skills in biodiversity. The problem-based learning model proved to have the greatest effect. There are seven learning models that are proven to improve students' critical thinking skills on environmental pollution material, but the largest effect size is the think pair share cooperative type model (TPS). Furthermore, the problem-based learning model combined with student facilitator and explaining

has the greatest effect in improving students' critical thinking skills on fungi material and the e-learning-based guided-discovery learning model has the greatest effect in improving students' critical thinking skills on ecosystem material.

The problem-based learning model is proven to have the greatest effect in improving students' critical thinking skills on biodiversity material. This is because in the syntax of the PBL learning model, students not only get the material provided by the teacher, but they also take a direct role in the learning process (Dewi & Primayana, 2019). In addition, they also try independently to find information to solve problems given by the teacher such as making observations outside the classroom and looking for appropriate information from various sources so that students' critical thinking skills are more developed (Wulandari et al., 2020).

There are seven learning models that are proven to improve students' critical thinking skills on environmental pollution material. The think pair share (TPS) cooperative type model is proven to have the largest effect size value in improving students' critical thinking skills on environmental pollution material. This learning model is a model that provides many opportunities for students to think, answer, and help each other so that it has a significant effect on improving students' critical thinking skills (Murniati et al., 2020). The high domain of global awareness can be a reference for teachers to be able to create contextualized biology learning, which links the material with various current issues both at domestic and international level so that it is expected that students can be more interested and active in learning biology.

There are two learning models that are proven to improve students' critical thinking skills on fungi material, namely problem-based learning and problem-based learning combined with student facilitator which has the largest effect size value. The problem-based learning model combined with student facilitator facilitates students to learn how to find solutions to real-world problems, and to have the courage to argue and express the material taught to other students so that students' thinking skills are trained and fungal material that is complicated by scientific terms can be more easily learned. In addition, this learning model also emphasizes providing hands-on learning experiences so that students' critical thinking skills are more developed (Miarsyah et al., 2021).

The team assisted individualization learning model with audiovisual media and e-learning-based guided-discovery learning are proven to improve students' critical thinking skills on ecosystem material. The guided-discovery learning model combined with e-learning gets the largest effect size value. This learning model can train students' critical thinking skills through discovery activities so that students are able to build their own knowledge, find concepts from the subject matter, and have a longer memory (Al Mamun et al., 2022).

There is only one learning model that is proven to improve students' critical thinking skills on Bryophyta and Pteridhophyta material, namely the 5E learning cycle learning model. Learning cycle 5E (engagement, exploration, explanation, elaboration, and evaluation) is a cyclical learning with five phases that are student centered. Each phase in this learning can train and develop students' critical thinking skills. The engagement phase requires students to express their predictions of the concepts to be presented and the exploration phase encourages students to answer their predictions either through experimental activities or literature studies. These phases indirectly train students' critical thinking skills, especially for the last three phases students are encouraged to present the results of their experiments (explanation phase), apply the knowledge and skills they have gained to new things (elaboration phase), then end with an evaluation phase that encourages students to assess the results and learning process. This concept development will encourage students to think more critically (Mustofa, 2018). This is in line with Prayogi & Asy'ari's (2021) research which proves that the learning cycle learning model can significantly improve students' critical thinking skills.

The guided inquiry model is the only model proven to improve students' critical thinking skills in the classification of living things as written in Table 3. The guided inquiry model can encourage students to actively build their own knowledge so that students can become

independent, active, and skilled individuals in solving problems based on the information and knowledge obtained. This guided inquiry learning model can improve critical thinking skills and student learning outcomes (Sejati et al., 2021).

The project-based learning model has been proven to improve students' critical thinking skills in virus and bacteria material. Abstract material will be easily understood with fun learning and the experience of building information independently so that students become eager to learn it (Ciampa, 2014). Based on Table 3, it can be seen that the project-based learning model is proven to improve students' critical thinking skills. Project-based learning is carried out by providing a theme from the learning material, then students look for problems in the environment in accordance with the theme. Furthermore, students are taught to analyze problems, formulate hypotheses, manipulate variables, design and carry out investigations, make predictions, and interpret experimental data so that there are critical thoughts on a problem that exists around them (Ciampa, 2014). This is in line with Sari & Prasetyo (2021) statement, which states that in project-based learning, students will go through a long process of research, respond to questions from complex problems, and train collaboration, communication, and critical thinking skills.

The blended learning model with the support of digital comics has been proven to improve students' critical thinking skills on animalia material. According to Widana et al. (2018), this offline and online learning experience can increase students' interest in learning, independence, and critical thinking skills. During learning with the support of digital comics, students are trained to be able to express conclusions at each meeting.

CONCLUSION

Based on the findings and analysis of the research results, 17 biology learning models were identified that have the potential to improve critical thinking skills of grade X students. The most recommended type of biology learning model in improving critical thinking skills in class X is the e-learning-based guided discovery learning model assisted by concept maps with an effect size value of 1.07. Learning models that are proven to improve students' critical thinking skills based on the material include: problem-based learning for biodiversity material, think pair share (TPS) cooperative type model for environmental pollution material, problem-based learning combined with student facilitator and explaining for fungi material, guided-discovery learning based on e-learning for ecosystem material, learning cycle 5E for bryophyta and pteridophyta material, guided inquiry for classification of living things material, project-based learning for virus and bacteria material, and blended learning supported by digital comics for animalia material.

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Authors' Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

How to Cite this Article

Fuadiyah, M., Norra, B. I., & Astutik, F. (2022). Biology learning model to improve critical thinking skills of ten grade students: a meta-analysis. *Assimilation: Indonesian Journal of Biology Education*, *5*(2), 101-112.