



POGIL, Guided, and Free Inquiry: Which Model Best Enhances Students' Critical Thinking in Biology Learning?

Wiwik¹, Adnan^{2,*}, & Alimuddin Ali²

¹Biology Education Study Program, Universitas Negeri Makassar, Indonesia

²Biology Study Program, Universitas Negeri Makassar, Indonesia

Abstract: This study aims to determine the effect of inquiry-based learning models (POGIL, guided inquiry, and free inquiry) on improving students' critical thinking skills in biology. Biology learning requires high-level thinking skills, one of which is critical thinking, which must be developed through effective learning strategies. This study uses a quantitative approach with a quasi-experimental design. The study population consists of all eleventh-grade students at State High School 9, Makassar. The sample comprises 130 students, distributed across four classes: three experimental classes that implement inquiry-based learning models and one control class using the STAD learning model. The topic used in this study is the respiratory system. The instrument used was a critical thinking skills test administered before and after the treatment (pretest and posttest). Data analysis was conducted using Analysis of Covariance (ANCOVA) to determine the effect of the treatment, followed by the Least Significant Difference (LSD) test to identify significant differences between groups. The results of the study showed that there were significant differences in the improvement of critical thinking skills between the four models based on the ANCOVA test with a significance value of less than 0.05. The LSD test results showed that POGIL was superior to guided inquiry, free inquiry, and STAD. Meanwhile, guided inquiry and free inquiry did not show any differences, and STAD, as the control class, showed the lowest effect. In biology education, teachers should consider implementing the POGIL learning model as an alternative learning strategy to develop students' critical thinking skills. Teachers can also vary the use of inquiry models according to student characteristics and lesson content, and optimize the role of collaborative learning to enhance learning outcomes.

Keywords: POGIL, guided inquiry, free inquiry, critical thinking skills, STAD.

INTRODUCTION

The skills required for education today have been labeled as 21st-century skills (van Laar et al., 2020). Every individual needs to master 21st-century skills to adapt to the various challenges, problems, and demands of life in this era. The assessment and teaching of 21st-century skills organize skills, knowledge, attitudes, values, and ethics into four main categories. The skills commonly labeled as 21st-century skills are categorized into four main areas: communication, technological proficiency, creativity, adaptability, and critical thinking (Saavedra & Opfer, 2012). However, students and educational systems are still not fully capable of meeting these demands (Kain et al., 2024). In modern education, critical thinking skills have become a crucial topic. Every student needs to be equipped with critical thinking skills to an optimal level through the active role of educational institutions. 21st-century skills are essential competencies required to address future developments and challenges within a society that continues to undergo significant changes (Stukalo & Simakhova, 2020).

Critical thinking is a combination of mental processes, strategies, and methods that individuals use to solve problems. It includes attitudes and skills in assessing and evaluating the consistency and validity of a problem based on various criteria (Özelçi &

Çalışkan, 2019). This skill serves as the primary foundation for students to think creatively, as creative thinking emerges after one first develops critical thinking skills (Adnan et al., 2021). Therefore, critical thinking ability is consistently regarded as a key component in various lists of essential skills to prepare individuals for higher education and the professional world (Changwong et al., 2018).

In the learning process, critical thinking is evident when learners systematically review their beliefs and opinions, then use them to solve problems and formulate appropriate solutions (Adnan et al., 2019; Fernandes et al., 2024). In line with this, Ennis (1985) provides a framework for critical thinking skills, including basic classification, basic support, inference, advanced clarification, strategy, and tactics. Basic classification includes focusing on questions, analyzing arguments, and asking clarifying questions. Basic support includes assessing the credibility of sources and evaluating observational reports. Inference includes deduction and evaluating deductions, induction and evaluating induction, and making and evaluating statements. Advanced clarification involves defining terms, evaluating definitions, and identifying underlying assumptions. Strategy and tactics include defining actions and interactions.

Ennis' critical thinking framework is suitable for use in biology learning because it includes skills that are in line with scientific activities, such as observing, classifying, drawing conclusions, explaining concepts, and designing solutions to biological problems. The five areas in this framework (basic classification, basic support, inference, advanced clarification, and strategy and tactics) represent the important thinking processes involved in understanding, analyzing, and solving biological problems logically and based on evidence.

According to data released by the Programme for International Student Assessment (PISA), which tests students' ability to solve complex problems, think critically, and communicate effectively, the average skills in mathematics, reading, and science declined compared to 2018. In this case, students in Indonesia scored below the OECD average in mathematics, reading, and science. In science education, particularly in biology, critical thinking skills are crucial, but many teachers still struggle to create a learning environment that fosters critical thinking, leading to low interest and motivation in biology (Melati et al., 2022). Biology learning activities are typically filled with memorization of facts, numbers, and processes, which are indeed important components of biology. However, learning through memorization alone is insufficient to foster the development of critical thinking skills (Wilson, 2017).

Therefore, the development of critical thinking skills needs to be one of the main focuses in education, especially in biology learning. To improve critical thinking skills, a learning model that emphasizes student activity, motivation, and enthusiasm for learning can be used. One learning model that is appropriate and emphasizes student activity is the inquiry learning model. The inquiry-based learning model emphasizes the active integration of knowledge and mimics the scientific discovery process, enabling students to explore and participate in various components of scientific research, which can help them improve their discovery skills (de Jong et al., 2024; Dah et al., 2024).

Inquiry-based learning models generally consist of three types: Process-Oriented Guided Inquiry Learning (POGIL), guided inquiry, and free inquiry. POGIL is a collaborative student-centered learning method that involves small groups of four to six people (Mamombe et al., 2021). Learning with POGIL emphasizes inquiry in discovering

concepts during the learning process, making it a student-centered approach (Simonson & Shadle, 2013). Next is guided inquiry, a teaching strategy that actively involves students in the learning process through scientific investigation by presenting problems that must be solved by them (Vlassi & Karaliota, 2013). Meanwhile, free inquiry is a large-scale investigative strategy that occurs in the classroom without explicit direction or supervision from the teacher (Wang et al., 2022).

Several studies have demonstrated the effectiveness of POGIL in learning, for example, in Mamombe et al. (2021), which states that POGIL improves student participation, motivation, enjoyment, focus, and active engagement. According to Idul & Caro (2022), POGIL can be used as an effective learning intervention to improve academic achievement. Similarly, guided inquiry, as described by Koksall & Berberoglu (2014), is an effective model that is both teacher-centered and student-centered. The role of teachers as moderators in guiding question-based activities appears to be effective in improving students' achievement, questioning skills, and positive attitudes. Free inquiry, according to Dah et al. (2024), influences conceptual understanding and increases student motivation, providing opportunities for students to develop scientific skills and thinking as they engage in the questioning process itself.

However, these studies generally analyze one type of inquiry-based learning model separately, and most focus on aspects of engagement, motivation, and academic achievement in general. Some studies have compared two inquiry-based learning models, such as Owolade et al. (2022), who investigated the effectiveness of guided inquiry and free inquiry in improving students' biology achievement. Some have compared them to critical thinking variables, such as those presented by Andani (2019), between POGIL and guided inquiry in terms of critical thinking skills. Others have compared them to other active learning models, such as Eberlein et al. (2008), who compared POGIL with Problem-Based Learning (PBL) and Peer-Led Team Learning (PLTL).

The focus of these studies is limited to general academic performance and does not explicitly discuss critical thinking skills by comparing the three inquiry-based learning models. To date, no comprehensive study has been found that compares the three types of inquiry-based learning models in the context of developing critical thinking skills. Therefore, this study aims to fill this gap by systematically analyzing the influence of each type of inquiry-based learning model on students' critical thinking skills. POGIL, guided inquiry, and free inquiry are all based on the inquiry approach but differ in the level of independence and the role of the teacher. These differences have the potential to influence the development of critical thinking skills, making a comparison of the three important for determining the most effective inquiry model in biology education.

The main objective of this study was to determine the comparative effects of three types of inquiry-based learning models in the experimental class and the STAD model in the control class on critical thinking skills. STAD was used as a control because it is a common model that is frequently used in schools. Additionally, STAD is also group-based like POGIL and other inquiry models, so differences in outcomes can be more closely linked to differences in thinking processes. To address this question, the proposed hypothesis is that there is a statistically significant difference at the 0.05 level in critical thinking skills due to the use of POGIL, guided inquiry, free inquiry, and STAD.

▪ METHOD

Participants

The population in this study included all 216 students in grade XI at SMA Negeri 9 Makassar. The research sample consisted of four classes, namely XI.3, XI.4, XI.5, and XI.6, with a total of 136 students. Sampling in this study used purposive sampling. Purposive sampling was used based on the homogeneity of each sample class. State Senior High School 9 Makassar is one of the well-known public schools and is a leading school.

Research Design and Procedure

The research design used is a pretest-posttest control group design. This design was chosen because it is capable of showing the differences in the effects of various types of inquiry learning models as independent variables on critical thinking skills as dependent variables. Before receiving treatment, both groups first took a pretest to assess their initial conditions, followed by a posttest to measure the changes that occurred after treatment. The research design is presented in Table 1.

Table 1. Pretest posttest control group design

Group	Pretest	Treatment	Posttest
Experiment 1	O ₁	POGIL	O ₂
Experiment 2	O ₃	Guided Inquiry	O ₄
Experiment 3	O ₅	Free Inquiry	O ₆
Control	O ₇	STAD	O ₈

O₁, O₃, O₅, and O₇ are pre-tests given to the experimental and control groups, while O₂, O₄, and O₆ are post-tests given to the experimental group after learning with different inquiry models. O₈ is a post-test given to the control group after learning with the STAD model.

The research procedure included a review of literature related to inquiry-based learning models, the development and validation of instruments, and field research. The field research procedure began with a pretest administered to all experimental and control classes prior to the commencement of learning activities. The purpose of this pretest was to measure students' initial critical thinking skills and to ensure that all groups had relatively homogeneous ability levels. Next, the learning process is conducted in the classroom, covering material on the respiratory organs, their functions, and disorders of the respiratory system. Each experimental class is taught using a different inquiry-based learning model, whereas the control class is taught using the STAD model. The syntax of the learning models is presented in Table 2.

Table 2. Syntax of each learning model

POGIL	Guided Inquiry	Free Inquiry	STAD
Orientation – The teacher conditions and motivates students.	Formulating problems – Students are guided to create questions related to the material.	Formulating problems – Students independently formulate questions related to the material.	The teacher conveys the learning objectives and motivates students.

Exploration – The teacher forms groups and distributes worksheets to them.	Testing hypotheses – Students in groups are guided to develop temporary answers.	Formulating hypotheses – Students independently develop tentative answers.	The teacher presents the main material to the entire class.
Concept discovery – The teacher guides the discussion and identifies problems in the worksheets.	Collecting data – Students are guided to find data from various sources.	Collecting data – Students independently search for data from various sources.	Students work in heterogeneous groups to study the material.
Application – Students apply concepts to new contexts.	Testing hypotheses – Proving hypotheses with example problems.	Testing hypotheses – Proving hypotheses with example questions.	Students discuss in groups to solve problems.
Closing – Groups present their results & the teacher confirms.	Formulating conclusions – Students are guided to summarize the learning outcomes.	Drawing conclusions – Students independently summarize the learning outcomes.	Group presentations and clarification from the teacher.

The four classes were taught by the researcher himself to ensure that the learning model was implemented according to the syntax. The material was delivered over four meetings and two tests (pretest and posttest) within 30 days. After learning, the posttest was administered to students in both the experimental and control classes at the final meeting to assess changes in learning outcomes.

Instrument

Data collection in this study was conducted by administering critical thinking skills test instruments. Before the tests were given to the experimental and control groups, the questions were first validated by expert validators. There are three aspects assessed by validators, namely content or material, construction, and language. The results of the validators' assessment show that the content/material aspect received a score of 4.72 in the highly valid category, the construction aspect received a score of 4.70 in the highly valid category, and the language aspect received a score of 4.50 in the highly valid category. Overall, the average assessment score was 4.64, which falls into the highly valid category.

Validator input is typically found in the content and construction of questions, making them more logical and accurate in accordance with Ennis' critical thinking indicators. The validated essay test consists of six questions that assess six critical thinking skill indicators according to Ennis. Ennis' critical thinking skill indicators are detailed in Table 3.

Table 3. Indicators for each question in the research instrument

Aspect	Explanation of Aspect	Competency	Question Number
Focus	Focusing attention on the main question or problem	Identifying the organs and functions of the respiratory system	1

Reason	Determining the reasons that support or refute a statement	Explaining the process of air entering and exiting the human body	2
Inference	Drawing conclusions based on evidence	Summarizing the effects of disorders on the respiratory system	3
Situation	Considering the context and situation in decision-making	Analyzing environmental factors that affect respiratory system health	4
Clarity	Explaining ideas clearly and in detail	Interpreting experimental data on lung capacity	5
Overview	Reflecting on and evaluating the entire thought process	Evaluating various efforts to maintain respiratory system health	6

Data Analysis

First, descriptive analysis using N-Gain was used to examine the improvement in students' critical thinking skills as a form of stimulation from the use of the inquiry-based learning model, based on pretest and posttest scores. The N-Gain scoring criteria according to Hake (1999) can be seen in Table 4 below.

Table 4. N-Gain Criteria

N-Gain Value	Category
$g > 0.7$	High
$0.3 \leq g \leq 0.7$	Medium
$g < 0.3$	Low

The data obtained from the pretest and posttest were then analyzed statistically using a one-way ANCOVA test. Before conducting the ANCOVA test, the data obtained were first tested for normality to ensure that the data were normally distributed. If the significance value of the normality test was greater than 0.05, the data were then tested for homogeneity. The homogeneity test was then conducted to ensure that the data variance was homogeneous. If the significance value of the homogeneity test was greater than 0.05, the ANCOVA test was continued. The ANCOVA test was conducted to assess the effect of the inquiry and STAD learning models. If the significance value of the ANCOVA test was less than 0.05, it was concluded that there was a difference in effect between the four models. Additionally, the LSD test is conducted to compare the effects of each type of inquiry-based learning model and STAD in pairs and identify significant differences between the models.

▪ RESULT AND DISCUSSION

Analysis of Critical Thinking Skills Indicators in Pretests and Posttests

The following are the results of the N-Gain analysis obtained from the pretest and posttest scores for all models and indicators. The N-Gain analysis results show that all learning models are capable of improving students' critical thinking skills in the moderate category. The POGIL model proved to be the most effective with an average N-Gain of 0.7, followed by guided inquiry (0.6), free inquiry (0.5), and STAD, which was the lowest (0.4). In terms of indicators, the greatest improvement occurred in focus, situations, and

Table 5. N-Gain value of all models and indicators

Model /Indicator	Focus	Reason	Inference	Situations	Clarity	Overview	Average Model	Category
N-Gain								
POGIL	0.8	0.6	0.6	0.6	0.7	0.7	0.7	Medium
Guided Inquiry	0.5	0.6	0.5	0.5	0.6	0.7	0.6	Medium
Free inquiry	0.6	0.5	0.4	0.6	0.5	0.6	0.5	Medium
STAD	0.6	0.3	0.6	0.5	0.4	-0.1	0.4	Medium
Average Indicators	0.6	0.5	0.5	0.6	0.6	0.5	0.5	
Category	Medium	Medium	Medium	Medium	Medium	Medium	Medium	

clarity (0.6), indicating that students were increasingly able to focus their attention on problems, adapt their reasoning to the context, and express their ideas clearly. Conversely, reason, inference, and overview were only at an average of 0.5, indicating that the ability to provide logical reasons, draw conclusions, and review answers was still limited. N-Gain analysis shows that POGIL is superior to other models in developing students' critical thinking skills, particularly in terms of focus, situations, and clarity of answers, although the overall improvement remains in the moderate category. Based on the N-Gain analysis, it is evident that the POGIL model produces higher improvements in critical thinking skills compared to guided inquiry, free inquiry, and STAD. However, these differences are still descriptive and cannot yet be confirmed as statistically significant. Therefore, further analysis using ANCOVA is needed to test the significance of differences in critical thinking skill improvements between learning models by controlling for pretest scores as covariates.

Data Normality Test

Based on the Kolmogorov-Smirnov (K-S) normality test, the pretest data for the POGIL class ($p = 0.067$), Guided Inquiry ($p = 0.070$), Free Inquiry ($p = 0.099$), and STAD ($p = 0.070$) classes showed p -values > 0.05 , indicating that all pretest data were normally distributed. Similarly, the results of the posttest normality tests for the POGIL class ($p = 0.077$), Guided Inquiry ($p = 0.200$), Free Inquiry ($p = 0.192$), and STAD ($p = 0.095$) also yielded p -values greater than 0.05, indicating that the posttest data were normally distributed.

Data Homogeneity Test

Based on the homogeneity test using Levene's statistic, the pretest data showed a p -value of 0.973 ($p > 0.05$), indicating homogeneity. Similarly, the posttest data obtained a p -value of 0.098 ($p > 0.05$), also indicating that the posttest data were homogeneous.

Hypothesis Testing

The following are the results of testing the hypothesis of the effect of the inquiry learning model on critical thinking skills using the ANCOVA test.

Table 6. ANCOVA test of the effect of inquiry learning model

Source	Df	F	p
Pretest	1	0.093	0.761

Model (Posttest)	3	18.309	0.000
------------------	---	--------	-------

Table 6 shows the results of the ANCOVA test, indicating that the inquiry-based learning model has a significant effect on students' critical thinking skills. This is indicated by the F value of 18.309 with a significance level of $p = 0.000$ ($p < 0.05$) for the model variable. Meanwhile, the pretest score did not significantly affect the posttest results ($F = 0.093$; $p = 0.761$), meaning that the difference in critical thinking skills scores on the posttest was more due to differences in the learning model treatment than to students' initial abilities. Thus, it can be concluded that the difference in the inquiry-based learning model used had a significant impact on improving critical thinking skills. Simsek and Kabapinar (2010) state that inquiry-based learning generally encourages students to be actively involved in the learning process. The combination of it with guidance and support from teachers allows students to gain a better understanding of scientific concepts. Antonio and Prudente (2024) state that the potential of inquiry-based learning in developing students' thinking skills is linked to the constructivist approach. This constructivist approach, which is student-centered, encourages exploration, data interpretation, and problem-solving. Through scientific processes such as investigation, evidence collection, evaluation of explanations, and communication of results, students are trained to use higher-order thinking skills to complete tasks effectively.

Since the use of inquiry-based learning models was found to influence critical thinking skills, the analysis was continued using the LSD (Least Significant Difference) test to determine the most significant learning model. The results of the LSD test are shown in Table 7. To determine the most significant inquiry learning model in improving critical thinking skills, see the corrected mean values in Table 8 below.

Table 7. LSD post-hoc test ANCOVA test of the effect of inquiry learning model

Variable	Class	Mean Difference	p	Description
Critical Thinking Skills	POGIL and Guided Inquiry	5.805	0.002	Significant
	POGIL and Free Inquiry	8.612	0.002	Significant
	Guided Inquiry and Free Inquiry	2.356	0.232	Not significant
	POGIL and STAD	13.305	0.000	Significant
	Guided Inquiry and STAD	7.500	0.000	Significant
	Free Inquiry and STAD	5.144	0.010	Significant

Table 8. Corrected mean values

Model	Average
POGIL	83.441 ^a
Guided Inquiry	77.636 ^b
Free Inquiry	75.280 ^b
STAD	70.136 ^c

The difference in influence can be seen in the LSD test results. The LSD test results in Table 7 show that all inquiry-based learning models have significant differences compared to STAD. In addition, POGIL is also significantly different from free inquiry and guided inquiry, while free inquiry and guided inquiry do not show significant differences or have similar influences. Table 8 shows the corrected mean values, indicating that POGIL has a more optimal effect on critical thinking skills, followed by guided inquiry and free inquiry, which have similar effects, and finally STAD.

POGIL has the most optimal effect on students' critical thinking skills. POGIL is a learning approach in which the learning process is entirely focused on students and, in its implementation, they discuss in small groups with the teacher acting as a facilitator, unlike free inquiry, which tends to be loose and confusing for untrained students. According to Vincent-Ruz et al. (2020), POGIL is process-oriented with explicit attention to student-centered approaches and teamwork that prioritizes critical thinking and idea building among students. Students actively investigate and discover concepts independently, while Artus and Roble (2021) emphasize that the problem-solving nature of POGIL encourages the development of process skills that are part of critical thinking. By being allowed to explore various methods, including alternative ones, students are encouraged to analyze problems from multiple perspectives, thereby deepening their conceptual understanding while honing essential analytical skills for critical thinking. The significant improvement in critical thinking skills in POGIL can be partly attributed to the presence of a strategy analyst in each group during the exploration syntax. Students with this role observe group dynamics, regularly report to the group and class on performance and areas for improvement, ensure the use of effective strategies, and ensure that written responses reflect group consensus (Rumain & Geliebter, 2020; de Gale & Biosselle, 2015). Soraya et al. (2024) also state that strategy analysts are responsible for reflecting on or evaluating understanding within the group. In POGIL learning, in the syntax of concept discovery, teachers act as facilitators of the thinking process, not as providers of information, similar to the guided inquiry learning model, but with a more systematic and consistent approach. POGIL combines problem-based learning, where every activity in POGIL begins with a challenging problem for students to solve. In both POGIL and problem-based learning, teachers act as facilitators rather than solution providers, and students work in small collaborative groups (Rumain & Geliebter, 2020). Umamah and Sholehah (2022) emphasize that through the POGIL learning syntax, students become accustomed to thinking critically to solve problems with steps that include (1) Identifying the need to learn; (2) Connecting with prior understanding; (3) Exploring; (4) Discovery, recognition, and concept formation; (5) Practicing the application of knowledge; (6) Applying knowledge in new contexts; and (7) Reflecting on the process.

POGIL consistently outperforms other learning models, as evidenced by studies conducted in Western countries. As found by Al Neyadi (2024), POGIL improves problem-solving and collaboration skills. Further findings from Bailey et al. (2012), although conducted at the university level, still apply to biology classes. POGIL provides students with opportunities to develop skills such as problem-solving, teamwork, critical thinking, communication, and time management. Mata (2022) also noted that POGIL effectively enhances students' cognitive abilities compared to those taught using non-POGIL methods.

Guided inquiry and free inquiry have relatively the same effect. Both guided inquiry and free inquiry require high-level thinking activities, such as formulating problems, developing hypotheses, and concluding data, so that both naturally encourage the development of critical thinking skills, albeit through different approaches. This aligns with Susparini et al. (2016), who noted that the syntactic similarities between the two learning models resulted in values of significance that were not significantly different. According to Ramdhayani et al. (2023), inquiry-based learning models generally use an approach that optimally activates all students' potential to explore and investigate an event or phenomenon in a structured, critical, and logical manner, enabling them to discover concepts independently. Direct involvement in the process of finding answers and applying them deepens students' understanding of the concepts. The syntactic similarities between guided inquiry and free inquiry, particularly during the data processing stage, enable students to develop their critical and analytical thinking skills, allowing them to think inductively when analyzing the consistency between observational results and theoretical studies to prove preliminary hypotheses and answer problem statements (Susparini et al., 2016).

The similar effects of guided inquiry and free inquiry are also influenced by the strengths and weaknesses of each model. Guided inquiry is often considered a traditional approach and the lowest form of inquiry because it is teacher-centered, making students passive recipients of information (Blanchard et al., 2010). However, guided inquiry is based on constructivism, which emphasizes student-centered learning through social interaction and cognitive challenges. This method fosters critical, creative, and problem-solving skills relevant to the real world and has the potential to increase interest in chemistry. However, its success depends on the teacher's ability (Igboanugo, 2023). In free inquiry learning, Blanchard et al. (2010) state that students possess prior knowledge, skills, and experience in scientific investigation. This learning environment tends to impose a higher cognitive load compared to minimal guidance learning, leading critics to argue that unguided inquiry is most detrimental to the learning process. However, this can be balanced by students who have more opportunities to construct their own knowledge. When students have control over their inquiry, they can give personal meaning during the knowledge-building process (Abaniel, 2021). In Tanchuk's (2020) study, it is stated that inquiry-based learning affects students' cognitive load, even for beginners, despite a framework that recognizes the crucial role of teacher guidance and content mastery.

STAD focuses on group discussions to solve exercises given by teachers, without an explicit mechanism to encourage reflective questions or open-ended problem-solving, so that groups tend to emphasize finding the correct answer rather than exploring alternative thinking processes. This is in line with the findings of Sapitri and Hartono (2015) that STAD is not particularly superior in developing students' critical thinking skills. This study shows that the discussion structure in STAD learning tends to be limited to solving practice questions given by the teacher, without encouraging deep exploration of ideas. STAD remains a cooperative learning model that focuses on supportive group activities, such as quizzes and exercises, helping students understand and achieve their learning objectives better (Takko et al., 2020). Thus, STAD still has a higher N-Gain value on the focus (focusing attention on questions) and inference (drawing conclusions) indicators. However, STAD does not emphasize the application of scientific methods (as

in the inquiry model), which have been proven effective in training higher-order thinking skills (Prayitno et al., 2018).

If teachers are unable to implement POGIL fully, they can still adapt its core principles to ensure that learning objectives are achieved. For example, teachers can maintain the use of problem-based learning and small group work to encourage student engagement, even if not all stages of POGIL are implemented. In addition, teachers can provide structured worksheets that guide students' thinking processes, allowing critical thinking skills to continue developing even if POGIL is not fully implemented. The role of teachers as facilitators also remains important to maintain, by providing appropriate guidance and prompting questions, even when time and resources are limited.

This study has several limitations, including that it was conducted at only one level of education and in a single school, and focused on a single topic: the human circulatory system. In addition, this study only compared inquiry-based learning models with similar models, and the duration of the intervention was only four sessions.

▪ CONCLUSION

POGIL showed the highest influence on critical thinking skills. Guided inquiry and free inquiry showed relatively similar results, as both involved higher-order thinking processes despite using different approaches. Meanwhile, STAD had the lowest influence because it focused on problem-solving exercises without encouraging deep exploration of ideas. Overall, structured and interactive learning models such as POGIL are superior in developing critical thinking skills when compared to guided inquiry, free inquiry, and STAD in biology learning among high school students. Therefore, further research is recommended to be conducted at various levels of education and in multiple schools with different characteristics to enhance the generalizability of the findings. Additionally, learning topics should be more varied to test the model's effectiveness across different materials. Future research should also compare inquiry-based learning models with other learning models, such as project-based learning or problem-based learning, to gain a more comprehensive understanding of the relative advantages of each model. Furthermore, it is recommended that the intervention duration be extended to allow for the observation of more optimal and sustainable learning outcomes. Furthermore, it is recommended that the intervention duration be extended to allow for observation of more optimal and sustainable learning outcomes. Students who participated in inquiry-based learning showed greater improvement than those who participated in conventional learning. These findings reinforce that inquiry-based learning is an effective strategy for enhancing students' critical thinking skills and is relevant for application in biology education, supporting the achievement of 21st-century skills.

▪ REFERENCES

- Abaniel, A. (2021). Enhanced conceptual understanding, 21st-century skills, and learning attitudes through an open inquiry learning model in physics. *Journal of Technology and Science Education*, 11(1), 30-43. <https://doi.org/10.3926/jotse.1004>
- Adnan, Mulbar, U., Sugiarti, & Bahri, A. (2019). Biology science literacy of junior high school students in south sulawesi, Indonesia. *Journal of Physics: Conference Series*. 1-8. <https://doi.org/10.1088/1742-6596/1752/1/012084>

- Adnan, Mulbar, U., Sugiarti, & Bahri, A. (2021). Scientific literacy skills of students: problem of biology teaching in junior high school in south sulawesi, Indonesia. *International Journal of Instruction*, 14(3), <https://doi.org/10.29333/iji.2021.14349a>
- Al Neyadi, S. (2024). Assessing the effects of POGIL-Based instruction versus lecture-based instruction on grade 12 self-efficacy and performance in circular motion unit. *Journal of Ecohumanism*, 3(3), 1219–1238. <https://doi.org/10.62754/joe.v3i3.3625>
- Andani, C. (2019). *Perbandingan model pembelajaran process guided inquiry learning (POGIL dan guided inquiry (GI) terhadap keterampilan berfikir kritis siswa* [comparison of process guided inquiry learning (POGIL) and guided inquiry (GI) learning models on students' critical thinking skills]. *Prosiding Seminar Nasional Biologi dan Pembelajarannya*, 234-240. <https://ojs.unm.ac.id/semnasbio/article/view/10540>
- Antonio, R.P. & Prudente, M.S. (2024). Effects of inquiry-based approaches on students' higher-order thinking skills in science: A meta-analysis. *International Journal of Education in Mathematics, Science, and Technology (IJEMST)*, 12(1), 251-281. <https://doi.org/10.46328/ijemst.3216>
- Artuz, J.K.A., & B. Roble, D. (2021). Developing students' critical thinking skills in mathematics using online-process oriented guided inquiry learning (O-POGIL). *American Journal of Educational Research*, 9(7), 404–409. <https://doi.org/10.12691/education-9-7-2>
- Bailey, C. P., Minderhout, V., & Loertscher, J. (2012). Learning transferable skills in large lecture halls: Implementing a POGIL approach in biochemistry. *Biochemistry and Molecular Biology Education*, 40(1), 1–7. <https://doi.org/10.1002/bmb.20556>
- Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability?: A Quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education*, 94(4), 577–616. <https://doi.org/10.1002/sce.20390>
- Changwong, K., Sukkamart, A., & Sisan, B. (2018). Critical thinking skill development: Analysis of a new learning management model for Thai high schools. *Journal of International Studies*, 11(2), 37-48. <https://doi.org/10.14254/2071-8330.2018/11-2/3>
- Dah, E. M., Noor, M. S. A. M., Kamaruddin, M. Z., & Aziz, S. S. S. A. (2024). The impacts of open inquiry on students' learning in science: A systematic literature review. *Educational Research Review*, 43, 1-15. <https://doi.org/10.1016/j.edurev.2024.100601>
- de Gale, S., & Biosselle, L. N. (2015). The effect of POGIL on academic performance and academic confidence. *Science Education International*, 26(1), 56–79. <https://eric.ed.gov/?id=EJ1056455>
- de Jong, T., Lazonder, A. W., Chinn, C. A., Fischer, F., Gobert, J., Hmelo-Silver, C. E., Koedinger, K. R., Krajcik, J. S., Kyza, E. A., Linn, M. C., Pedaste, M., Scheiter, K., & Zacharia, Z. C. (2024). Beyond inquiry or direct instruction: Pressing issues for designing impactful science learning opportunities. In *Educational Research Review*, 44, 1-8. <https://doi.org/10.1016/j.edurev.2024.100623>

- Eberlein, T., Kampmeier, J., Minderhout, V., Moog, R. S., Platt, T., Varma-Nelson, P., & White, H. B. (2008). Pedagogies of engagement in science: A comparison of PBL, POGIL, and PLTL. In *Biochemistry and Molecular Biology Education*, 36(4), 262–273. <https://doi.org/10.1002/bmb.20204>
- Ennis, R. H. (1985). Critical thinking and the curriculum. *National Forum: Phi Kappa Phi Journal*, 65(1), 28-31.
- Fernandes, R., Willison, J., & Boyle, J. (2024). Characteristics of facilitated critical thinking when students listen to and speak english as an additional language in Indonesia. *Thinking Skills and Creativity*, 52, 1-17. <https://doi.org/10.1016/j.tsc.2024.101513>
- Hake, R. R. (1999). *Analyzing Change/Gain Scores*. AREA-D American Education Research Association's Division, Measurement and Research Methodology.
- Idul, J. J. A., & Caro, V. B. (2022). Does process-oriented guided inquiry learning (POGIL) improve students' science academic performance and process skills? *International Journal of Science Education*, 44(12), 1994–2014. <https://doi.org/10.1080/09500693.2022.2108553>
- Igboanugo, B. I. (2023). Interactive effects of guided inquiry and teachers' experience on chemistry students' interest. *Journal of Chemistry*, 2023, 1-8. <https://doi.org/10.1155/2023/9970946>
- Kain, C., Koschmeider, C., Matischek-Jau, M., & Bergner, S. (2024). Mapping the landscape: a scoping review of 21st century skills literature in secondary education. *Teaching and Teacher Education*, 151, 1-27. <https://doi.org/10.1016/j.tate.2024.104739>
- Koksal, E.A., & Berberoglu, G. (2014). The effect of guided-inquiry instruction on 6th grade turkish students' achievement, science process skills, and attitudes toward science, *International Journal of Science Education*, 36(1), 66-78, <http://dx.doi.org/10.1080/09500693.2012.721942>
- Mamombe, C., Mathabathe, K. C., & Gaigher, E. (2021). Teachers' and learners' perceptions of stoichiometry using pogil: a case study in South Africa. *EURASIA Journal of Mathematics, Science and Technology Education*, 17(9), 1-11. <https://doi.org/10.29333/ejmste/11140>
- Mata, L. E. (2022). The effectiveness of POGIL on high school student chemistry end-of-course examinations. *Science Education International*, 33(2), 171–180. <https://doi.org/10.33828/sei.v33.i2.5>
- Melati, S., Alberida, H., Arsih, F., Anggriyani, R., & Zuryana, Y. (2022). *Pengaruh model pembelajaran discovery learning terhadap kemampuan berpikir kritis peserta didik pada materi jaringan tumbuhan kelas XI SMAN 1 Sutera* [The effect of discovery learning model on students' critical thinking skills in plant tissue culture subject in grade XI at SMAN 1 Sutera]. *Jurnal Pendidikan Rokania*, 7(3), 286-291. <https://doi.org/10.37728/jpr.v7i3.587>
- Owolade, A. O., Oladipupo, P. O., Kareem, A. O., & Salami, M. O. (2022). Effectiveness of guided and open inquiry instructional strategies on science process skills and self-efficacy of biology students in osun state, Nigeria. *African Journal of Teacher Education*, 11(1), 56–74. <https://doi.org/10.21083/ajote.v11i1.7014>

- Özelçi, S. Y., & Çalışkan, G. (2019). What is critical thinking? A longitudinal study with teacher candidates. *International Journal of Evaluation and Research in Education*, 8(3), 495–509. <https://doi.org/10.11591/ijere.v8i3.20254>
- Prayitno, B. A., Suciati, & Titikusumawati, E. (2018). Enhancing students' higher-order thinking skills in science through the instad strategy. *Journal of Baltic Science Education*, 17(6), 1046–1055. <https://doi.org/10.33225/jbse/18.17.1046>
- Ramdhayani, E., Syafruddin, S., & Dekayanti, L. (2023). *Pengaruh model pembelajaran inkuiri terhadap berpikir kritis siswa pada materi pertumbuhan* [The effect of inquiry learning models on students' critical thinking in growth]. *Jurnal Ilmiah Wahana Pendidikan*, 9(6), 93-99. <https://doi.org/10.5281/zenodo.7774851>
- Rumain, B., & Geliebter, A. (2020). A process-oriented guided-inquiry learning (pogil)-based curriculum for the experimental psychology laboratory. *Psychology Learning and Teaching*, 19(2), 194–206. <https://doi.org/10.1177/1475725720905973>
- Saavedra, A., & Opfer, V. (2012). *Teaching and Learning 21st Century Skills: Lessons from the Learning Sciences*. A Global Cities Education Network Report.
- Sapitri, S., & Hartono, H. (2015). Keefektifan cooperative learning STAD dan GI ditinjau dari kemampuan berpikir kritis dan komunikasi matematis [The effectiveness of STAD and GI cooperative learning in terms of critical thinking and mathematical communication skills]. *Jurnal Riset Pendidikan Matematika*, 2(2), 273–283. <https://doi.org/10.21831/jrpm.v2i2.7346>
- Simonson, S. R., & Shadle, S. E. (2013). Implementing process-oriented guided inquiry learning (POGIL) in undergraduate biomechanics: Lessons learned by a novice. *Journal of STEM Education: Innovations and Research*, 14(1), 56-63. <https://search.proquest.com/docview/1349167967?accountid=169438>
- Şimşek, P., & Kabapınar, F. (2010). The effects of inquiry-based learning on elementary students' conceptual understanding of matter, scientific process skills, and science attitudes. *Procedia - Social and Behavioral Sciences*, 2(2), 1190–1194. <https://doi.org/10.1016/j.sbspro.2010.03.170>
- Soraya, R., Mashari, A., & Oktaviana, A. (2024). Efektivitas model pogil ditinjau dari kemampuan berpikir kritis matematis siswa [The effectiveness of the pogil model in terms of students' mathematical critical thinking skills]. *AKSARA: Jurnal Ilmu Pendidikan Nonformal*, 10(1), 267-276 <http://dx.doi.org/10.37905/aksara.10.1.267-276.2024>
- Stukalo, N., & Simakhova, A. (2020). COVID-19 Impact on ukrainian higher education. *Universal Journal of Educational Research*, 8(8), 3673 - 3678. <https://doi.org/10.13189/ujer.2020.080846>
- Susparini, N. T., Rahayu, S., & Saputra, A. (2016). *Pengaruh model pembelajaran inkuiri terbimbing dan inkuiri bebas termodifikasi pada materi termokimia terhadap keterampilan berpikir tingkat tinggi dan hasil belajar siswa kelas XI SMA Negeri 1 Sukoharjo tahun pelajaran 2015/2016* [The effect of guided inquiry and modified free inquiry learning models on thermochemistry material on higher-order thinking skills and learning outcomes of 11th grade students at SMA Negeri 1 Sukoharjo in the 2015/2016 academic year]. *Jurnal Pendidikan Kimia Universitas Sebelas Maret*, 5(2), 44–51. <https://www.neliti.com/publications/124901/pengaruh-model-pembelajaran-inkuiri-terbimbing-dan-inkuiri-bebas-termodifikasi-p>

- Takko, M., Jamaluddin, R., Kadir, S. A., Ismail, N., Abdullah, A., & Khamis, A. (2020). Enhancing higher-order thinking skills among home science students: The effect of cooperative learning Student Teams-Achievement Divisions (STAD) module. *International Journal of Learning, Teaching and Educational Research*, 19(7), 204–224. <https://doi.org/10.26803/IJLTER.19.7.12>
- Tanchuk, N. (2020). Is inquiry learning unjust? cognitive load theory and the democratic ends of education. In *Journal of Philosophy of Education*, 54(5), 1167-1185. <https://doi.org/10.1111/1467-9752.12435>
- Umamah, N., & Sholehah, H. (2022). The POGIL learning model and students' critical thinking improvement in the history subject. *Pancaran Pendidikan*, 11(3), 11–22. <https://doi.org/10.25037/pancaran.v11i3.420>
- van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2020). Determinants of 21st-century skills and 21st-century digital skills for workers: a systematic literature review. *SAGE Open*, 10(1), 1-14. <https://doi.org/10.1177/2158244019900176>
- Vincent-Ruz, P., Meyer, T., Roe, S. G., & Schunn, C. D. (2020). Short-Term and Long-Term effects of POGIL in a large-enrollment general chemistry course. *Journal of Chemical Education*, 97(5), 1228–1238. <https://doi.org/10.1021/acs.jchemed.9b01052>
- Vlassi, M., & Karaliota, A. (2013). The comparison between guided inquiry and the traditional teaching method. A case study for the teaching of the structure of matter to 8th-grade Greek students. *Procedia - Social and Behavioral Sciences*, 93, 494-497. <https://doi.org/10.1016/j.sbspro.2013.09.226>
- Wang, H. H., Hong, Z. R., She, H. C., Smith, T. J., Fielding, J., & Lin, H. Shyang. (2022). The role of structured inquiry, open inquiry, and epistemological beliefs in developing secondary students' scientific and mathematical literacies. *International Journal of STEM Education*, 9(1), 1-17. <https://doi.org/10.1186/s40594-022-00329-z>
- Wilson, J. S. (2017). Promoting critical thinking in general biology courses: the case of the white widow spider. *Journal on Empowering Teaching Excellence*, 1(2), 53-61. <https://doi.org/10.26077/jmb7-zh62>