USING AN E-MODULE BASED ON PROBLEM-BASED LEARNING COMBINED WITH SOCRATIC DIALOGUE TO DEVELOP STUDENTS' CRITICAL THINKING SKILLS: A QUALITATIVE STUDY

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ABSTRACT

Critical thinking skills are needed to face the challenges of living in the 21st century. Education must be able to foster students' critical thinking and enable them to think independently. This study aims to investigate the development of students' critical thinking skills during the learning process using an e-module based on problem-based learning combined with Socratic dialogue. This qualitative research study measured students' critical thinking skills during the learning process using Socratic dialogue questions on a learning activity sheet. The students' answers on their learning activity sheets were analyzed qualitatively using a coding process. The results show that the application of an e-module based on problem-based learning combined with Socratic dialogue can improve students' critical thinking skills. During the learning process, all aspects of critical thinking skills (i.e., interpretation, analysis, evaluation, inference, explanation, and self-regulation) improved over the duration of the study.

Keywords: *critical thinking skills, e-module, problem-based learning, Socratic dialogue*

INTRODUCTION

Critical thinking skills are cognitive abilities that are important for students to learn so they can face the challenges of the 21st century. One of the goals of education is to encourage students' critical thinking and teach them to think independently. Kek and Huijser (2011) stated that critical thinking skills are important in education to prepare students to face the complex and rapidly changing conditions of the modern world. Learning should train students to be able to access accurate and reliable information and to think critically about that information (Kabataş Memiş & Çakan Akkaş, 2020). Additionally, Dwyer et al. (2014) and Thomas and Hayes (2021) stated that critical thinking skills are needed in the decision-making and problem-solving processes. Critical thinkers make wise decisions and sound judgments when they face complex problems (Butler et al., 2012).

The preliminary investigation conducted by the researchers indicated that students' critical thinking skills are still low. A test of critical thinking skills in the biology subject was conducted to assess students' initial abilities. The results showed that the average score earned by students was 48.84. These results are supported by survey results on an international scale (Organisation for Economic Cooperation and Development, 2014; 2016; 2019) and in previous research (Elisanti et al., 2018; Widodo et al., 2019). Trends in the results of the Program for International Student Assessment (PISA) show that the scientific literacy of Indonesian students is still below average, ranking 64th out of 65 countries (2012), 64th out of 72 countries (2015), and 74th out of 79 countries (2018) (see Organisation for Economic Cooperation and Development, 2014; 2016; 2019). Critical thinking skills are needed to solve PISA questions, so the low PISA results indicate that students' critical thinking skills are still low (Organisation for Economic Cooperation and Development, 2020). The results of research by Elisanti et al. (2018) and Widodo et al. (2019) also show that the average score for Indonesian students' critical thinking skills in biology is still below 50.

The results of interviews with high school biology teachers in Indonesiashow that the learning process in class is still dominated by the teacher. Students are not actively involved in constructing their knowledge. The learning process does not yet encourage students to search for, process, and assess various information sources critically to construct their knowledge. This is in line with research by Saputri et al. (2018) and Suyamto et al. (2018), which state that learning in the classroom is still teacher-centered and does not train critical thinking skills. Widodo et al. (2019) added that teachers require students to listen and memorize more during the learning process, so students tend to be passive and not used to thinking critically when participating in the learning process.

Critical thinking skills can be fostered by implementing the correct learning model. One learning model that can empower critical thinking skills is the Problem-Based Learning (PBL) model (Asyari et al., 2016; Miterianifa et al., 2019; Sebatana & Dudu, 2022). In PBL, students are trained to produce various solutions to problems that are often encountered in everyday life (Aslan, 2021; Suwono et al., 2023; Tarhan & Ayyildiz, 2015). This learning model facilitates decision-making and problem-solving activities, both of which encourage students to think critically (Asyari et al., 2016; Bezanilla et al., 2019). When solving problems, students must make choices, and this can help students learn how to be critical about their choices.

The transition from traditional learning to PBL can be difficult for many students. Kim et al. (2018) stated that students who are new to PBL can experience difficulties due to varied levels of background knowledge, learning skills, and motivation. Students have difficulty changing study habits from initially being told what to study to taking responsibility for deciding what needs to be studied (Hung, 2011). Questions are one form of assistance provided by teachers in PBL to overcome these difficulties. Moallem and Igoe (2020) stated that teacher questions can help students analyze problems and identify what needs to be learned about the problem.

Socratic dialogue is a teacher questioning technique that can be applied in PBL to guide students while also training their critical thinking skills. Socratic questions are closely related to PBL because students query their knowledge when facing new problems (Rogal & Snider, 2008). Socratic dialogue develops students' critical thinking abilities through exchanging ideas and points of view, giving new meaning to concepts, exploring the application of concepts to problems, and providing implications for real-life situations (Maiorana, 1991; Yang et al., 2005).

The PBL learning model combined with Socratic dialogue can be integrated into an e-module to increase learning effectiveness. An e-module is a form of technology that can make the learning process more interesting and interactive, can be done anytime and anywhere, and can improve the quality of learning (Handayani et al., 2021). Damayanti et al. (2021) stated that the use of e-modules provide more planned learning activities and increase learning efficiency and effectiveness. Apart from that, the use of e-modules is in line with 21st-century learning trends that encourage unlimited learning (i.e., anytime and anywhere) (Scott, 2015).

THEORETICAL FOUNDATION

Vygotsky's Sociocultural Theory

Vygotsky's (1978) sociocultural theory underlies this research. Vygotsky believed that intelligence develops as individuals encounter new experiences and as they strive to resolve discrepancies posed by these experiences. In the quest for understanding, individuals link new knowledge to prior knowledge and construct new meaning. Vygotsky's theory emphasizes the interaction of interpersonal (social), cultural-historical, and individual factors as the key to human development. Social factors receive the most attention of the three factors. Vygotsky believed that social interaction with others spurs the construction of new ideas and enhances students' intellectual development.

Learning occurs through social interactions with teachers and peers. With the appropriate challenges and help from teachers or more capable peers, students can move forward into the zone of proximal development where new learning occurs.

Critical Thinking Skills

There are many definitions of critical thinking skills according to the experts. Paul (1995) defines critical thinking as the ability to analyze, criticize, advocate ideas, reason inductively and deductively, and reach conclusions based on reasonable inferences. Critical thinking according to Ennis (1985) is a form of rational and reflective thinking with a focus on deciding what to believe or do. Facione (1990) states that critical thinking is a metacognitive process that focuses on judgment that aims to produce interpretation, analysis, evaluation, and inference, as well as an explanation of the evidentiary, conceptual, methodological, criteriological, or contextual considerations that form the basis of the assessment. Polat and Aydın (2020) state that critical thinking skills enable students to examine their own opinions, demonstrate consistency, and make generalizations by evaluating different evidence and rationally interpreting the experiences they encounter.

Facione (1992/2023) divides critical thinking skills into six aspects: (1) interpretation, (2) analysis, (3) evaluation, (4) inference, (5) explanation, and (6) self-regulation. Interpretation is the ability to understand and express the meaning or significance of various types of situations, data, or events. Analysis is the ability to identify inferential relationships between data, statements, or concepts. Evaluation is the ability to assess statements' quality and the logical strength of inferential relationships between statements. Inference is the ability to identify and obtain the elements needed to draw reasonable conclusions and form a conjecture or hypothesis. Explanation is the ability to state and justify reasoning based on reasonable evidence, concepts, methodologies, criteria, and considerations. Self-regulation is the ability to apply analysis and evaluation to inferential judgments.

Problem-Based Learning

PBL is a student-centered learning model where students in a collaborative environment produce various solutions to problems that are often encountered in real life using prior knowledge and new information obtained from various resources (Aslan, 2021; Suwono et al., 2023; Tarhan & Ayyildiz, 2015). The PBL model uses ill-structured problems that allow students to explore several reasonable solutions and determine the most appropriate solution to solve the problem (Hung, 2015).

The PBL model according to Arends (2012) is divided into five learning stages: (1) orienting students to the problem, (2) organizing students for study, (3) assisting independent and group investigation, (4) developing and presenting artifacts and exhibits, and (5) analyzing and evaluating the problem-solving process. The third stage of PBL is the core of the PBL model where students carry out investigative activities to make explanations and determine solutions (Arends, 2012). During this stage, students learn to critically and independently evaluate required knowledge and make critical judgments about the application and appropriateness of certain knowledge (Kek & Huijser, 2011).

Socratic Dialogue

Socratic dialogue is a learning technique in which the teacher uses a series of questions to encourage and guide students' thinking rather than giving students a lot of information through direct instruction (Chin, 2007). Instead of providing direct answers, the questioning technique of Socratic dialogue encourages students' thinking processes to continuously investigate a topic using thought-provoking questions (Lee et al., 2014; Yang et al., 2005).

The categories of questions in the Socratic dialogue, according to Paul (Lee et al., 2014), are questions of clarification, questions that probe assumptions, questions that probe reasons and evidence, questions about viewpoints or perspectives, questions that probe implications and consequences, and questions about the question. Questions of clarification are questions to ask for verification or additional information on one main point or idea. Questions that probe assumptions are questions to ask for an explanation or reliability of an assumption. Questions that probe reasons and evidence are questions to ask for additional examples, reasons for making statements, or processes that lead students to their beliefs. Questions about viewpoints or perspectives are questions to find out whether there are other alternatives from a certain point of view or for comparisons between points of view. Questions that probe implications and consequences are questions to help students describe the implications of what is being done or the causes and effects of an action. Questions about the question are questions to find out whether students understand the question itself.

Socratic Dialogue as a Questioning Technique in Problem-Based Learning

In PBL, teachers act as facilitators; they do not directly transmit or teach knowledge content to students (Moallem & Igoe, 2020). Conversely, teachers support students' learning processes by observing students, encouraging students to think deeply by asking probing questions, encouraging students to articulate their thinking, and encouraging collaboration among group members (Hmelo-Silver et al., 2007; Sockalingam et al., 2011).

The PBL model places learning in complex tasks so students can experience difficulty solving the problems presented to them (Hmelo-Silver et al., 2007). Difficulties that students can face include (1) understanding problems and making hypotheses, (2) engaging in problem investigation activities, and (3) analyzing and drawing conclusions (Fidan & Tuncel, 2019; Hung, 2011).

Students need help to overcome the difficulties they face. Scaffolding is a form of temporary assistance that is provided by someone more experienced (such as a parent, teacher, or peer) to an individual learner to help them move forward (Belland, 2017; Puntambekar & Hubscher, 2005). The scaffolding provided can help students manage the investigation and problem-solving process, and it can encourage students to articulate thoughts and reflect on learning (Hmelo-Silver et al., 2007). The question is a form of scaffolding that is suitable to be applied to the PBL model. Hmelo-Silver (2004) stated that in the PBL model, teachers guide students mainly through questions. Questions can help students focus their attention and monitor their learning (Ge & Land, 2003).

Socratic dialogue is a questioning technique that can be applied to the PBL model to guide students and train their critical thinking skills (Katsara & De Witte, 2019). Socratic questions are closely related to PBL because students question their knowledge when facing new problems (Rogal & Snider, 2008). Banning (2005) argued that in Socratic dialogue the teacher obtains responses from students through questions that aim to probe the layers where knowledge is built.

E-module

Enke et al. (2015) define modules as teaching materials that are arranged systematically (including material, methods, and evaluation) and are independent to achieve certain expected competencies. An e-module is a form of presenting independent learning material that is systematically arranged into the smallest learning units to achieve certain learning objectives presented in an electronic format (Handayani et al., 2021). The advantage of using e-modules is that they make the learning process more interesting and interactive, they can be done anytime and anywhere, and they improve the quality of learning (Handayani et al., 2021). Electronic modules can attract students' learning interest and illustrate abstract material. E-modules can also be accessed easily by students using computers and various types of devices anywhere and at any time, thus allowing students to get direct feedback and understand the lesson material completely (Saraswati et al., 2019).

RESEARCH QUESTION

This study aims to investigate the development of students' critical thinking skills during the learning process using an e-module based on problem-based learning combined with Socratic dialogue. In particular, we address the following question: How does the level of students' critical thinking skills change during the learning process using an e-module based on problem-based learning combined with Socratic dialogue?

METHODOLOGY

Research Design

This study was a qualitative research study that aims to analyze students' critical thinking skills during the learning process. Ary et al. (2010) stated that a qualitative study seeks to understand and interpret human and social behavior as it is lived by participants in a particular social setting. This type of research acknowledges the subjective perceptions and biases of both participants and researchers.

The method used in this study was a basic qualitative study. Ary et al. (2010) stated that a basic qualitative study provides rich descriptive accounts targeted to understanding a phenomenon, process, or particular point of view from the perspective of those involved. This study provides an overview of students' thinking processes during the course of learning and was conducted to find out whether the e-module applied during learning activities can encourage students' critical thinking.

Participants

This study was conducted at a high school in Karanganyar, Central Java, Indonesia. The subjects of this research were ten high school students in grade 10 between the ages of 15 and 16 years old.

Data Collection Tools

The participants' critical thinking skills during the learning process were measured using Socratic dialogue questions on a learning activity sheet. The e-module was equipped with a learning activity sheet that functions as a guide for students to carry out learning activities according to the PBL steps. On the learning activity sheet, there were Socratic dialogue questions that students had to answer. According to Facione (1992/2023), Socratic dialogue questions measure aspects of critical thinking skills, namely interpretation, analysis, evaluation, inference, explanation, and self-regulation. Details of the Socratic dialogue questions are presented in Table 1.

The questionnaire was used to obtain additional data regarding student responses to the implementation of the e-module based on PBL combined with Socratic dialogue. The questionnaire consisted of 16 statements about the presentation of the material, learning activities, Socratic dialogue questions, and the use of the e-module. Statements in the questionnaire were measured using a Likert scale with the criteria of *strongly agree* (score 4), *agree* (score 3), *disagree* (score 2), and *strongly disagree* (score 1).

Characteristics of the E-module Based on Problem-Based Learning Combined with Socratic Dialogue

The e-module used in this study was developed by us using development procedures according to Borg and Gall (1983). The e-module consisted of the following components: (1) cover page, (2) credits page, (3) table of contents, (4) e-module description, (5) e-module usage guide, (6) competencies that must be achieved, (7) concept map, (8) learning activity sheet, (9) glossary, and (10) bibliography. The e-module was developed in flipbook form. Flipbook was chosen because it is interactive and can contain images, videos, audio, and links, and it is easy to access and can be opened via computer and various types of devices anywhere at any time.

The e-module was structured based on the PBL steps according to Arends (2012), namely: (1) orienting students to the problem, (2) organizing students for study, (3) assisting independent and group investigation, (4) developing and presenting artifacts and exhibits, and (5) analyzing and evaluating the problem-solving process. Socratic dialogue questions were given at the first, second, and third stages of PBL. Socratic dialogue was presented as a series of questions that aimed to guide students in carrying out investigative activities. These questions encouraged students to re-examine the decisions they make, thereby promoting students' critical thinking.

The e-module was designed so students can learn independently without full guidance from the teacher. Aslan (2021) and Savery and Duffy (1995) stated that several factors make PBL difficult for teachers to implement, including controlling more than one group simultaneously and organizing the information students gather for problem situations. The e-module we developed can help teachers overcome these difficulties. Having a disproportionate number of students and teachers can make it impossible for teachers to provide the same guidance to each student throughout the learning process. Using e-modules ensures that every student gets the guidance they need throughout the learning process.

Procedure

The learning process was carried out by following the steps of the PBL model using an e-module based on problem-based learning combined with Socratic dialogue. Students met for 90 minutes three times in a row for three weeks. Students were presented with ill-structured problems that became a stimulus for the learning process. They then carried out scientific investigations to understand the problem and find the most appropriate solution to solve the problem. Learning activities were carried out in groups. During the learning, the students worked on the learning activity sheet contained in the e-module. Data on students' critical thinking skills were obtained from students' answers on the

Table 1.
Details of the Socratic Dialogue Questions on the Learning Activity Sheet

Learning Stages of PBL	Category of Socratic Dialogue Question	Aspects of Critical Thinking Skills	Question Indicator	Question Number
Orient students to the problem	Question of clarification	Interpretation	Students can assess the suitability of the experimental question they ask with the objectives of the experiment and explain the reasons.	1
	Question of clarification	Interpretation	Students can assess the suitability of the hypothesis they propose with the experimental question and explain the reasons.	2
	Question that probes reasons	Self-regulation	Students can defend the hypothesis they propose by explaining the reasons for proposing the hypothesis.	3
	Question that probes consequences	Explanation	Students can explain how to prove the scientific truth of the hypothesis they propose.	4
	Question about the question	Explanation	Students can detail how to carry out experimental activities to prove the hypothesis they propose.	5
Organize students for study	Question of clarification	Interpretation	Students can assess the suitability of the experimental equipment they choose with the objectives of the experiment and explain the reasons.	6
	Question of clarification	Interpretation	Students can assess the suitability of the experimental equipment they choose with the data table of observation results and explain the reasons.	7
	Question that probes assumptions	Analysis	Students can overcome bias in experimental results by explaining the criteria for selecting experimental objects.	8
	Question about viewpoints or perspectives	Self-regulation	Students can defend the experimental steps they have created.	9
	Question that probes consequences	Evaluation	Students can assess whether the experimental steps they created can be put into practice in experimental activities.	10
Assist independent and group investigation	Question of clarification	Interpretation	Students can explain the meaning of the experimental data they obtained.	11
	Question of clarification	Analysis	Students can explain the inferential relationship between experimental data and the concept of environmental pollution.	12
	Question of clarification	Explanation	Students can explain the efforts they can take to prevent pollution problems.	13
	Question of clarification	Inference	Students can conclude the experimental activities that have been carried out.	14
	Question of clarification	Interpretation	Students can assess the suitability of the conclusions they make with the objectives of the experiment and explain the reasons.	15
	Question about viewpoints or perspectives	Explanation	Students can explain the negative impact of waste on living things.	16

learning activity sheet that they worked on during the learning process.

Data Analysis

We analyzed the data on students' critical thinking skills qualitatively. The data consisted of the answers on the learning activity sheet from ten students who had attended three meetings. According to Arends (2012), qualitative data analysis is divided into three stages: (1) familiarizing and organizing, (2) coding and reducing, and (3) interpreting and representing. In the first stage, familiarizing and organizing, we read and reread all the students' answers to become familiar with the data. The students' answers were then organized by meetings (i.e., the first, second, and third meeting). For each meeting, there were 16 questions on the learning activity sheet (see Table 1).

In the second stage (coding and reducing), coding was carried out on the students' answers. Students are given the codes S1 through S10 to identify them. The questions were coded according to the question number, namely I1, I2, I3, ..., I16. The students' answers were categorized into three codes based on their level of critical thinking skills, namely C− (not critical), C+ (moderate), and C++ (high). Even though there were only three codes used in this study, we created a coding guide for each question because each question has different content. The coding guide was also adjusted to aspects of the critical thinking skills measured in the question. Each question measured a specific aspect of critical thinking skills. In this study, critical thinking skills were divided into six aspects (Facione, 1992/2023): interpretation, analysis, evaluation, inference, explanation, and self-regulation. The preliminary coding scheme was then tested on a small subset of the data, which allowed us to identify problems that arose in the coding process and ensured the accuracy and practicality of the coding scheme. After testing, the final coding scheme was obtained and the coding process was carried out by a collaborative team. The coding results are presented in Table 2. Student answers that had been coded were then grouped based on aspects of critical thinking skills. After that, the total number and percentage of C−, C+, and C++ codes for each aspect of critical thinking skills were calculated. The calculation results are presented in Table 3. Data analysis was carried out with the help of Microsoft Excel.

The third stage was interpreting and representing. Interpretation is defined as bringing out the meaning, providing an explanation, and developing plausible explanations (Ary et al., 2010). The codes were converted into percentages for each aspect, which were used to determine the level of students' critical thinking skills using the e-module during the learning process. Changes in the level of students' critical thinking skills throughout the learning process could be determined by comparing the percentages from one meeting to the next.

RESULTS

The coding results of students' answers on the learning activity sheet are presented in Table 2.

The coding results for each aspect of critical thinking skills were then calculated in percentages to determine the level of students' critical thinking skills. The results are presented in Table 3.

DISCUSSION

The analysis results show that students' critical thinking skills emerged during the learning process using the e-module based on PBL combined with Socratic dialogue. In general, there is an increase in students' critical thinking skills over time. By the third meeting, students showed a higher level of critical thinking skills compared to the second meeting. Likewise, the level of students' critical thinking skills at the second meeting was higher compared to the first meeting.

At the high level (C++), the Interpretation aspect showed the largest percentage increase during the learning process, going from 20% at the first meeting to 69% at the third meeting. Meanwhile, the aspect that experienced the smallest percentage increase was Evaluation, from 0% at the first meeting to 10% at the third meeting. Overall, at the third meeting, the skills that received the highest percentage at the high level (C++) was Explanation at 85% and Evaluation received the lowest percentage, which was 10%.

At the high level (C++), the Interpretation at the first meeting was 20% and increased to 40% at the second meeting and 69% at the third meeting. Interpretation is the ability to understand and express the meaning or significance of various types of situations, data, or events (Facione, 1992/2023). Based on the results of the analysis, students could understand and determine whether the experimental questions and experimental

Table 2.
Coding Results of Students' Answers on the Learning Activity Sheet

Question Items	Students' Critical Thinking Skills								
	1st Meeting			2nd Meeting			3rd Meeting		
	C–	C+	C++	C–	C+	C++	C–	C+	C++
I1	S2, S4, S5, S7	S6, S9, S10	S1, S3, S8	S2, S4, S6, S9, S10	S5, S7	S1, S3, S8	S2, S10	S9	S1, S3, S4, S5, S6, S7, S8
I2	S2, S3, S4, S5, S7, S8, S9, S10	S1, S6		S2, S4, S8, S9, S10	S5, S7	S1, S3, S6	S2, S4, S7, S8, S10		S1, S3, S5, S6, S9
I3	S1, S2, S3, S4, S5, S6, S7, S8, S9, S10			S2, S3, S4, S5, S6, S7, S8, S9		S1, S10	S2, S4, S7, S8, S9		S1, S3, S5, S6, S10
I4	S1, S4, S7, S9		S2, S3, S5, S6, S8, S10	S1, S4, S5, S7		S2, S3, S6, S8, S9, S10	S1, S7		S2, S3, S4, S5, S6, S8, S9, S10
I5	S2, S5, S9, S10	S1, S8	S3, S4, S6, S7	S9		S1, S2, S3, S4, S5, S6, S7, S8, S10	S2, S9		S1, S3, S4, S5, S6, S7, S8, S10
I6	S1, S2, S4, S6, S7, S9, S10	S3, S5	S8	S2, S3, S4, S6, S9, S10	S1, S5, S7	S8	S4	S5, S6	S1, S2, S3, S7, S8, S9, S10
I7	S1, S2, S3, S4, S5, S6, S7, S8, S9, S10			S2, S4, S6, S7, S9, S10	S1, S5	S3, S8	S4, S5, S7		S1, S2, S3, S6, S8, S9, S10
I8	S1, S4, S6, S7, S8, S10	S2, S3, S5, S9		S7	S2, S4, S8, S10	S1, S3, S5, S6, S9		S7	S1, S2, S3, S4, S5, S6, S8, S9, S10
I9	S1, S2, S3, S4, S5, S6, S7, S8, S9, S10			S1, S2, S3, S4, S5, S6, S7, S8, S9, S10			S1, S2, S4, S6, S7, S8, S9, S10		S3, S5
I10	S1, S2, S3, S4, S5, S6, S7, S8, S10	S9		S1, S2, S4, S5, S7, S8, S9, S10	S3, S6		S1, S2, S4, S7, S8, S9, S10	S5, S6	S3
I11	S2	S1, S5, S8, S10	S3, S4, S6, S7, S9		S3	S1, S2, S4, S5, S6, S7, S8, S9, S10		S2, S7	S1, S3, S4, S5, S6, S8, S9, S10
I12		S3, S5	S1, S2, S4, S6, S7, S8, S9, S10		S8, S10	S1, S2, S3, S4, S5, S6, S7, S9	S9	S1, S4, S10	S2, S3, S5, S6, S7, S8
I13	S5	S3	S1, S2, S4, S6, S7, S8, S9, S10		S3, S5	S1, S2, S4, S6, S7, S8, S9, S10		S5	S1, S2, S3, S4, S6, S7, S8, S9, S10
I14	S2, S7, S10	S1, S3, S5	S4, S6, S8, S9	S10	S2, S4, S7	S1, S3, S5, S6, S8, S9	S10	S4, S9	S1, S2, S3, S5, S6, S7, S8
I15	S2, S3, S5, S9	S1, S7, S10	S4, S6, S8	S5, S7, S10	S4	S1, S2, S3, S6, S8, S9	S7, S9, S10		S1, S2, S3, S4, S5, S6, S8
I16	S10	S9	S1, S2, S3, S4, S5, S6, S7, S8	S10	S3	S1, S2, S4, S5, S6, S7, S8, S9		S10	S1, S2, S3, S4, S5, S6, S7, S8, S9

Table 3.
Analysis Results of Students' Critical Thinking Skills Levels During the Learning Process

Aspects of Critical Thinking Skills	Question Items	Code	1st Meeting		2nd Meeting		3rd Meeting	
			Number of Codes	Percentage (%)	Number of Codes	Percentage (%)	Number of Codes	Percentage (%)
Interpretation	I1, I2, I6, I7, I11, I15	C−	34	57	25	42	14	23
		C+	14	23	11	18	5	8
		C++	12	20	24	40	41	69
Analysis	I8, I12	C−	6	30	1	5	1	5
		C+	6	30	6	30	4	20
		C++	8	40	13	65	15	75
Evaluation	I10	C−	9	90	8	80	7	70
		C+	1	10	2	20	2	20
		C++	10	0	0	0	1	10
Inference	I14	C−	3	30	1	10	1	10
		C+	3	30	3	30	2	20
		C++	4	40	6	60	7	70
Explanation	I4, I5, I13, I16	C−	6	25	2	15	2	10
		C+	4	10	3	7	2	5
		C++	20	65	25	78	26	85
Self-Regulation	I3, I9	C−	20	100	18	90	13	65
		C+	0	0	0	0	0	0
		C++	0	0	2	10	7	35

hypotheses they created are appropriate and in accordance with the objectives of the experiment. Students were able to interpret the experimental data obtained and understand and express the meaning of the data during experimental activities. Apart from that, students were also able to understand and determine whether the conclusions made are in accordance with the objectives of the experiment and answer the experimental questions.

At the high level (C++), Analysis at the first meeting was 40% and increased to 65% at the second meeting and 75% at the third meeting. Facione (1992/2023) states that analysis is the ability to identify inferential relationships between data, statements, or concepts. Objects used in experimental activities must meet certain criteria to avoid bias in the experimental results. The results of the analysis show that the majority of students were able to determine the criteria that must be met in selecting experimental objects to ensure the quality of the experiment. Most students were also able to analyze experimental data and explain the inferential relationship between data obtained from experimental activities and the concept of environmental pollution obtained from various information sources. Students could then build logical explanations regarding experimental results obtained with support from relevant theories.

At the high level (C++), Evaluation at the first meeting was 0% and stayed the same (0%) at the second meeting and increased to 10% at the third meeting. Evaluation is the ability to assess the quality of statements and the logical strength of inferential relationships between statements (Facione, 1992/2023). The results of the analysis show that the majority of students did not demonstrate evaluation skills during learning activities. At the last meeting, only 10% of the students were able to evaluate the experimental steps they had made. Socratic dialogue questions in the evaluation aspect aim to train students to assess whether the experimental steps that students make can be put into practice in experimental activities, but in this study, only a few students could answer them correctly.

At the high level (C++), Inference at the first meeting was 40% and increased to 60% at the second meeting and 70% at the third meeting. Facione (1992/2023) states that inference is the ability to identify and obtain the elements needed to draw reasonable conclusions and form a conjecture or hypothesis. The results of the analysis show that the majority of students were able to conclude the experimental activities that have been carried out. Facione (1992/2023) states that inference abilities are empowered when students carry out scientific experimental activities to confirm or deny empirical hypotheses.

At the high level (C++), Explanation at the first meeting was 65% and increased to 78% at the second meeting and 85% at the third meeting. Explanation is the ability to state and justify reasoning based on reasonable evidence, concepts, methodologies, criteria, and considerations (Facione, 1992/2023). Facione (1992/2023) states that explanatory ability is the ability to present the results of reasoning convincingly and coherently. The results of the analysis show that the majority of students were able to explain reasonably how to prove the scientific truth of the hypothesis they made. Students were also able to detail how to carry out experimental activities to prove a hypothesis. Further, students were able to explain the negative impacts that can result from environmental pollution and the appropriate efforts to overcome this pollution problem. This explanation was prepared based on evidence obtained from experimental results and supported by concepts obtained from various reliable sources of information.

At the high level (C++), Self-regulation at the first meeting was 0% and increased to 10% at the second meeting and 35% at the third meeting. Self-regulation refers to a person's awareness to monitor their cognitive process, the elements used in the thinking process, and the results that are developed (Facione, 1992/2023). Self-regulation abilities assist students in understanding their learner's role, improving their class performance, and taking responsibility for the learning process (Akcaoğlu et al., 2023). The results of the analysis show that the majority of students did not demonstrate self-regulation abilities during learning activities. Facione (1992/2023) states that self-regulation is the ability to apply analysis and evaluation to inferential judgments. The results of the analysis show that students were not able to apply analytical and evaluation skills to assess the truth and accuracy of the experimental design they created.

The coding results are supported by the results of the student questionnaire. The results show that the e-module was easy for students to understand. Explanations of concepts equipped with pictures and examples of applications in everyday life helped students understand the topic better. Apart from concept explanations, the learning activities contained in the e-module also helped students understand the topic of environmental change better. Socratic dialogue questions help the students' learning process. Students said that Socratic dialogue questions can guide them during investigative activities and that the e-module can train critical thinking skills. Learning activities structured on PBL steps train critical thinking skills through problem-solving activities. Socratic dialogue questions also encourage students to think critically.

The PBL learning model uses ill-structured problems that allow students to explore several reasonable solutions and determine the most appropriate solution to solve the problem (Hung, 2015). Real-life problems are used as a learning context so that students can think critically and solve problems, as well as gain important knowledge and concepts (Asyari et al., 2016). Ill-structured problems provide students with the opportunity to engage in critical thinking processes such as looking for alternatives and considering other points of view (Kim et al., 2013).

Research conducted by Choi et al. (2014) shows that the use of the PBL model increases student involvement in learning activities, thus encouraging increased critical thinking skills, increased motivation to seek new information, and increased conflict resolution skills. The research results show that PBL improves students' critical thinking skills because it involves students in learning processes such as clarifying problems, assessing information needs, identifying relationships between concepts, producing possible hypotheses, debating situation-related issues, considering alternative solutions, investigating, searching for truth, deferring or revising judgments, and accepting different points of view (Gholami et al., 2016; Kong et al., 2014; Yuan et al., 2008).

Hmelo-Silver et al. (2007) states that because PBL places learning in complex tasks, assistance is needed to help students engage in understanding, manage investigations and problem-solving processes, and encourage students to articulate thinking and reflect on learning. Questions are one form of assistance provided by teachers in PBL learning. Hmelo-Silver (2004) states that in PBL learning, the teacher acts as a facilitator who guides students, especially through questions. Teacher questions can also train students' critical thinking skills (Bezanilla et al., 2019). Browne and Freeman (2000) state that a learning environment that empowers critical thinking is one where more questions are asked and where further discussion, unexpected results, and active learning take place. Asking and answering challenging, interesting, and thought-provoking questions can stimulate students' discussion and critical thinking (Golding, 2011; Scott, 2015). Questions encourage students to explore and redefine their understanding of key concepts (Scott, 2015).

One type of questioning technique that can be applied to the PBL model to guide students while empowering students' critical thinking skills is Socratic dialogue (Katsara & De Witte, 2019). Socratic questions are closely related to PBL because students question their knowledge when facing new problems (Rogal & Snider, 2008). Banning (2005) argues that in Socratic dialogue, teachers obtain responses from students through questions that aim to probe the layers where knowledge is built. Socratic dialogue can trigger students' critical thinking because the teacher's role is not to reveal information to students but to foster questions (Katsara & De Witte, 2019). During the questioning process, students are encouraged to utilize past knowledge and experiences to seek their answers (Oermann, 2003).

Socratic dialogue uses systematic exploratory questions to trigger critical thinking on complex concepts (Martin et al., 2021). Exploratory questions invite responses without predetermined answers (Teo, 2016), thereby allowing students to express themselves freely. Cui and Teo (2023) state that through exploratory questions, teachers not only explore what students know but also what and how they think. Teachers focus more on reasoning than knowledge to encourage students' critical thinking. In PBL-based learning, Socratic dialogue questions trigger students' curiosity, which makes students develop critical thinking about the problems they face and actively seek solutions (Lee et al., 2014; Yang et al., 2005).

The research results obtained in this study are in line with previous studies. Research conducted by Yang et al. (2005) shows that teaching and modeling Socratic questioning helps students achieve higher levels of critical thinking skills. Discussion forums using Socratic dialogue questions can encourage students to engage in in-depth analysis, composition, negotiation, and reflection as their discussion of an issue develops. Discussion forums also allow teachers to model, foster, and evaluate the critical thinking skills demonstrated during the discussion process. Research conducted by Lee et al. (2014) shows that the use of Socratic questions is effective in improving students' critical thinking abilities and encouraging students to conduct novel, justified, and critical discussions.

LIMITATIONS AND RECOMMENDATIONS

The limitation of this study is that it was conducted on a small scale. The number of participants involved in this study was ten students. Further research needs to be carried out on a larger scale. Further research on other tenth-grade students in Indonesia will provide a broader data set that can enrich our understanding of the influence of an e-module based on PBL combined with Socratic dialogue on students' critical thinking skills.

This study was conducted in a specific context, which was in biology (on the topic of environmental change) in grade 10 at a high school in Indonesia. The findings may not be applicable or transferable to other contexts, such as different subjects, grade levels, or countries. Arends (2012) states that qualitative research shows concern for context and meaning. This approach assumes that human behavior is bound to context—that human experience takes its meaning from and, therefore, is inseparable from social, historical, political, and cultural influences. Thus, inquiry is always bound by a particular context or setting. Further research needs to be carried out in different settings (i.e., different subjects, different grade levels, different countries) to determine more broadly the influence of an e-module based on PBL combined with Socratic dialogue on students' critical thinking skills.

This study measures critical thinking skills by analyzing students' answers on the learning activity sheets that they complete during the learning process. This research only focuses on critical thinking skills in writing. Further research can be carried out to analyze the course of student discussions during the learning process so that students' verbal critical thinking skills can also be identified.

In addition, this study focuses on measuring students' thinking skills. Effective critical thinking requires both ability and willingness (i.e., critical thinking dispositions) to implement higher-order cognitive processes (Facione, 2000; Halpern, 1999). Individuals who possess certain personality dispositions (e.g., open mindedness, intellectual curiosity, and skepticism) are more likely to implement critical thinking skills in everyday life (Thomas & Hayes, 2021). Further research can be conducted to investigate critical thinking dispositions during the learning process.

CONCLUSION

The analysis results show that the application of an e-module based on PBL combined with Socratic dialogue can improve students' critical thinking skills. During the learning process, all aspects of critical thinking skills (namely interpretation, analysis, evaluation, inference, explanation, and self-regulation) improve over time. Students' critical thinking skills in all aspects by the third meeting were higher when compared to the first meeting. The PBL model trains students' critical thinking skills through problem-solving and decision-making activities. Socratic dialogue questions applied to the PBL model encourage students to think critically about problems that become learning topics and actively seek solutions to these problems.

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