



Research Article

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Profile of Students' Physics Critical Thinking Skills and Prospect Analysis of Project-Oriented Problem-Based Learning Model

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Abstract

This research studies the profile of students' critical thinking skills in physics in general, indicators, aptitudes, gender, and analyzes the perspectives of the Project-Oriented Problem-Based Learning (POPBL) model in improving these skills. The method used in this study was descriptive quantitative with a sample of 154 students. Data collection methods using written tests, questionnaires and bibliometric extraction through the Scopus database with 25 received documents. The study showed that students in general have the ability to think critically in physics, since most of them have critical thinking skills according to low criteria. When viewed by indicators, the average score is the highest in the indicator "Evaluating", and the lowest average score is according to the indicator "Synthesis". There are some gifted students who demonstrate higher critical thinking. In addition, the value of women's critical thinking abilities is higher than that of men and there are significant differences. Research on the POPBL model, designed to improve critical thinking skills in the field of learning physics, is very potential, since it is characterized by great novelty and originality.

Keywords: critical thinking, physics, POPBL learning model

1. Introduction

Physics is a subject that studies natural phenomena and their various forms of symptoms. Therefore, in studying physics, it is not enough to understand the concept, but it is also necessary to apply that understanding in real life (Pečuliauskienė & Dagys, 2016). Therefore, students need to be directed to practice critical thinking skills. This cognitive ability allows individuals to evaluate the supporting

data, assumptions, and reasoning behind the ideas of others. In physics learning, thinking critically is essential in increasing understanding of concepts and applying them to real-world problems (Amanda et al., 2022).

Various rubrics and indicators have been developed by previous research to determine critical thinking skills. For instance, elementary clarification, basic support, inference, advanced clarification, and strategy and tactics are Ennis's five top indicators of critical thinking (Aminudin et al., 2019). In addition, Reynders et al. (2020) revealed that there are five categories of critical thinking skills in the subject of Science, Technology, Engineering, and Mathematics (STEM), namely evaluating, analyzing, synthesizing, and forming arguments (structure & validity). The use of this rubric can be adjusted to the learning criteria implemented. Because of the importance of critical thinking skills, especially in physics learning, students must develop this ability through a suitable learning model.

One of the most prospective learning models to train critical thinking skills is Project-Oriented Problem Based Learning (POPBL). POPBL is an innovative strategy for learning because it can train students' abilities and skills (Lehmann et al., 2008). POPBL learning models can significantly train 21st-century skills (Husin et al., 2016). In POPBL, students encounter a real-world problem before creating a project to address it. The project is open-ended and structured as a pure problem-based approach due to the nature of this process. Therefore, POPBL can be a learning model that can bridge between critical thinking skills and learning activities. The POPBL learning model can be applied in physics learning because physics emphasizes applying concepts in solving everyday life (Docktor et al., 2015).

Therefore, this study investigated the profile of students' physics critical thinking skills and analyzed the prospects of the POPBL learning model in improving those skills. The profiles analyzed include profiles in general, then reviewed based on each indicator, giftedness, and gender. This research can be a reference for future research related to efforts to improve student's critical thinking skills as 21st-century skills, as well as provide information regarding the prospects of the POPBL model in physics learning.

2. Literature Review

2.1 Critical Thinking Skills

Critical thinking is a mental process that involves thoroughly analyzing or evaluating information in order to form an opinion about the truth of the information obtained or the opinions conveyed (Bytautas & Daukilas, 2022; Indrašienė et al., 2021; Taghinezhad & Riasati, 2020). The active process denotes the desire or motivation to find answers and achieve comprehension. Critical thinking studies other people's thought processes to determine whether the processes used are correct (logical or not) (Hitchcock, 2017). When writing, solving problems, coming to decisions, or working on a project, implicit critical thinking assesses the thinking that is suggested by what one hears, reads, and investigates the thought processes themselves (Paul & Elder, 2013). Critical thinking skills can be improved through problem-based learning activities (Asyari et al., 2016).

2.2 Project-Oriented Problem-Based Learning

POPBL is a development model of problem-based learning initiated by Aalborg University Denmark so that it can produce three important frameworks that define it, namely: (1) problems, (2) projects, and (3) teamwork (Hussain & Rosenørn, 2008). POPBL is more student-centered than the subject-oriented learning process and problem-based projects (Yasin & Rahman, 2011). The problems used as the basis for implementing POPBL are authentic or realistic, constructive and integrated problems, suitable in complexity, stimulating critical thinking and metacognitive skills.

POPBL is frequently used in the teaching of science and engineering. Several previous studies have applied the POPBL model in engineering (Akor et al., 2020; Qureshi et al., 2014), programming

courses (Ibrahim & Halim, 2013), architecture (Sharif et al., 2012), and computer science (Pucher & Lehner, 2011). POPBL is different from conventional Problem-Based Learning (PBL), where Inquiry, application, and integration of knowledge—rather than the final product—are the main focuses of the learning process in problem-based learning (Ramadhani et al., 2019). The final products, like a group report on their research findings, are more summative and straightforward. Planning, production, and evaluation are driven by the targeted end product. The learning syntax of the POPBL model can be seen in Table 1.

Table 1. POPBL Learning Model Syntax and Its Learning Activities (Akor et al., 2020)

Syntax	Learning Activities
Problem orientation and analysis	Teachers orient students towards authentic problems and ensure they believe that their solutions are adequate to overcome these problems
Prior knowledge activation	By going over their prior knowledge, students determine how prepared they are to tackle the problem. Members of a group may benefit from prior knowledge activation as a basis for newly acquired knowledge.
Research and learning objectives design	Students conduct additional research to supplement their prior knowledge. The goal of the given problem is now defined to guide the acquisition of new skills and knowledge based on the initiated problem.
Project initiation and execution	Students work on projects according to plans and objectives. Initiation and execution of projects have different processes or stages because different projects come from different problems and have different goals that determine the steps to be taken
Assessment and evaluation	The teacher conducts assessments and evaluations to ensure that the learning goals and objectives are met, and formative evaluations are performed throughout the process. This is intended to provide students with an understanding of the concept so that they can retain it through experience.
Project Results Presentation	Students are doing project results in presentations to disseminate their efforts in overcoming real-life problems through the initiation and implementation of projects.

2.3 Related Research

Many previous studies are almost similar to this study, as in Table 2. This research focuses on the physics critical thinking skill of high school students. However, the creativity in this study is a type of POPBL model and an additional bibliometric method that has never been studied before. More explanation of the method is explained in the next section.

Table 2. Related Research

Author(s)	Ability Profile	Subject	Grade	Prospect Learning Model	Research Method
(Hunter et al., 2014)	Critical Thinking	Nursing	University	-	Cross-sectional descriptive
(Badriyah et al., 2021)	Critical Thinking	Physics	High School	PBLRQA	Quantitative descriptive and Literature Review
(Yuliska & Syafriani, 2019)	Critical Thinking	Physics	High School	Inquiry	Qualitative descriptive
(Sa'dijah et al., 2019)	Creative Thinking	Math	High School	Contextual Teaching	Qualitative descriptive
(Pahrudin et al., 2019)	Scientific Literacy	Physics	University	-	Qualitative descriptive
(Yusuf & Widyarningsih, 2019)	HOTS	Physics	University	STEM-based	Quasi-experiment
Current Research	Critical Thinking	Physics	High School	POPBL	Quantitative descriptive and bibliometric

Note: PBLRQA = Problem-Based Learning and Reading, Questioning & Answering; HOTS = Higher Order Thinking Skills; STEM = Science, Technology, Engineering, and Mathematics

3. Method

Because this study takes a quantitative descriptive approach, hypothesis testing is not necessary (Fraenkel et al., 2011; Ponce et al., 2022). The results of this study are further considerations for implementing the POPBL model to improve students' critical thinking skills. The total sample in this study was 154 students (69 male; 85 female) from six classes in three high schools in East Java, Indonesia (2 classes per school). Of the three schools, one is a public school, while the rest are private. This research was conducted in August-December 2022 (Even semester 2022/2023). The sampling technique uses purposive sampling with the consideration of adjusting to the content of the material taught. Furthermore, the stages of this study can be seen in Figure 1.

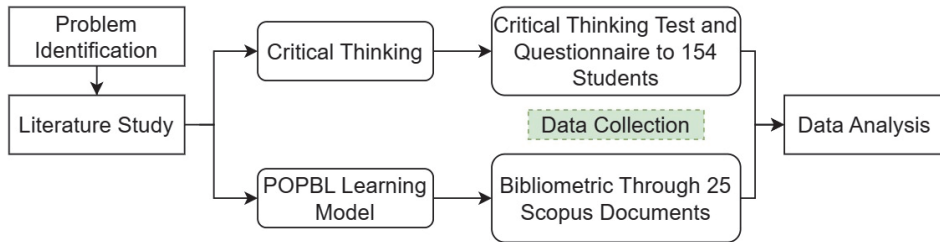


Figure 1: Research Stages

Based on the formulation of the problem, there are two conditions, namely (1) low physics critical thinking skills in students' and (2) the prospect of a POPBL learning model to overcome this. Therefore, there were two data collection processes in this study. Data was collected through tests and questionnaires on 154 students to determine the profile of physics critical thinking skills. The test instrument uses the rubric of critical thinking skills by Reynders et al. (2020), which consists of Evaluating, Analyzing, Synthesizing, and Forming Arguments (Structure & Validity). The number of questions tested on students is 3 points of description because it can provide more in-depth opportunities for students to answer questions. The questions given contain renewable energy material because this material supports students in thinking critically about the energy crisis. The questionnaire instrument consists of 5 questions regarding the description of physics learning so far by students using a Scale of 1-6 (1 = strongly disagree; 6 = strongly agree). This instrument has been validated in content and construct for two physics education experts and obtained valid results after revision. The results of instrument validation can be seen in Table 3, where the determination of validity criteria using rubrics (Rizki & Suprpto, 2024).

Table 3. Validity Assessment of Research Instruments

Instrument	Content Validation		Construct Validation	
	Score	Criteria	Score	Criteria
Critical Thinking Test	3.60	Very Valid	3.37	Very Valid
Student Questionnaire	3.87	Very Valid	3.66	Very Valid

To determine the prospects of the POPBL model in improving critical thinking skills, bibliometric analysis was carried out to map previous research trends (Donthu et al., 2021). Mapping research trends can reflect the research hotspots and development trends at a particular stage. This data collection was carried out on December 21, 2022, and began with a search with the keyword "Project-Oriented Problem-Based Learning" on the Scopus database. Scopus database selection is because the database is of the highest quality, reputable, and has a good index (Baas et al., 2020). The search

results found 25 documents regarding the POPBL learning model. The collected metadata is then extracted in .ris and .csv extensions. The process of mapping research trends using the VOSviewer application because this application can provide good visualization, open-access, and easy to understand (van Eck & Waltman, 2010). The data obtained are keyword trends regarding POPBL learning model research.

Data analysis of critical thinking tests and student questionnaires uses descriptive to determine the profile of students' critical thinking abilities and physics learning activities. The assessment results of the critical thinking test are adjusted according to the criteria: 0-1.66 (Low); 1.67-3.32 (Medium); 3.33-5.00 (High). Then, to find out a more in-depth profile based on gender, statistical tests of normality, homogeneity, and paired T were carried out. Finally, bibliometric data analysis based on node size and link strength based on the results of mapping visualization using VOSViewer. Node size and link strength are mapped based on the occurrence of keywords in each document analyzed.

4. Results

4.1 Profile of Physics Critical Thinking Skill in General

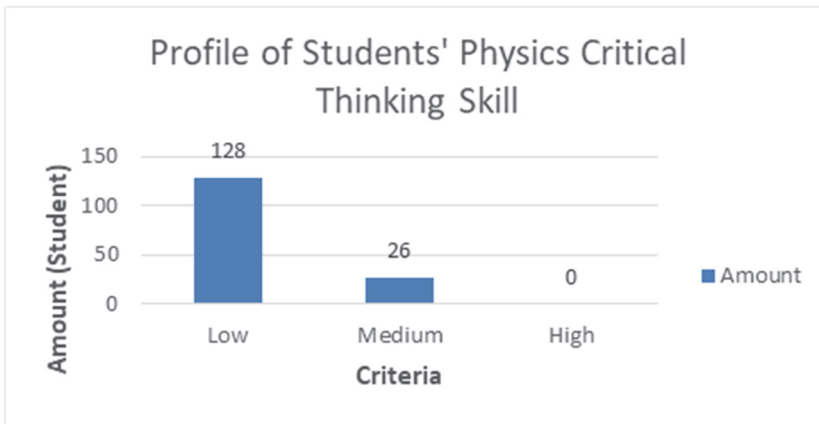


Figure 2: Graph of Students' Physics Critical Thinking Skill Profile Based on Criteria

The profile of critical thinking skills is obtained from the physics critical thinking test given to students. They are expected to evaluate the information given to the problem, then provide analysis and synthesis to provide arguments in a structured and valid manner. The profile data of students' critical thinking skills can be seen in Figure 2. It can be seen that 128 (83.1%) students have low criteria, 25 (16.23%) students have medium criteria, and no student has high criteria. Thus, the majority of students can think critically on low criteria.

4.2 Physics Critical Thinking Skill Profile By Indicator

Students' physics critical thinking skills per indicator are shown in Table 4. It can be seen that all indicators of critical thinking are at low criteria. The highest score is on the 'Evaluating' indicator, which is 1.36, while the lowest score is on the 'Synthesizing' indicator, which is 0.70. Thus, students can only evaluate the information in the questions that are used as a basis for solving the problem.

Table 4: Students' Physics Critical Thinking Proficiency Score Per Indicator

Indicators of Critical Thinking Skills									
E	c	A	c	S	c	F(S)	c	F(V)	c
1.33	Low	1.12	Low	0.70	Low	1.21	Low	1.12	Low

Note: E = Evaluating, A = Analyzing, S = Synthesizing, F(S) = Forming Argument (Structure), F(V) Forming Argument (Validity), c = Criteria

4.3 Profile of Physics Critical Thinking Skills by Gifted Students

Gifted students generally have an above-average level of intelligence, great creativity, have high curiosity, love challenges, and can analyze and solve problems well (Esra & Sukru, 2016). Therefore, to find out which students are gifted students can be seen from the outlier data as in Figure 3.

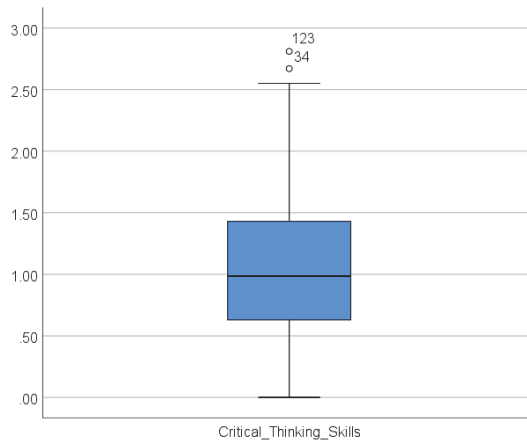


Figure 3: Boxplot Data on Students' Physics Critical Thinking Skill

4.4 Profile of Physics Critical Thinking Skills by Gender

Differences in the treatment of male and female at home and school greatly influence students' identity and academic development, including in thinking skills. Table 5 shows that the normality test results using the Kolmogorov-Smirnov test, and the data results are not normal. The data was then homogeneously distributed, according to a homogeneity test performed with Levene Statistics. To determine the significance of the difference in critical thinking skills between men and women, a type of non-parametric statistics was used (Mann-Whitney U Test). The average score of female's critical thinking skill (1.15) was higher than that of males (0.94). Statistically, the results of the mann-whitney U test showed significance values $p = 0.02 < 0.05$ so it can be concluded that there is a significant difference between male and female physics critical thinking skills.

Table 5: Mean, Normality, Homogeneity, and Mann-Whitney U Test by Gender

Gender	Normality		Homogeneity		Mean	Mann-Whitney U
	Sig.	Criteria	Sig.	Criteria		Sig.
Male	0.03	Not Normal	0.90	Homogeneous	0.94	0.02
Female	0.03				1.15	

4.5 Student Questionnaire Response

The student questionnaire response had five statements and then students were asked to choose between scale 1 (strongly disagree) to 6 (strongly agree). The results of student responses are presented in Table 6. It can be seen that more students agree that physics lessons are very difficult.

Table 6: Student Response Questionnaire Data

Statement	Student Responses (1 = Strongly Disagree; 6 = Strongly Agree)					
	1	2	3	4	5	6
I find physics lessons very difficult	4 (2.6%)	6 (3.9%)	24 (15.6%)	16 (10.4%)	11 (7.1%)	14 (9.1%)
The physics learning method used was less innovative so I felt bored	6 (3.9%)	19 (12.3%)	20 (13.0%)	14 (9.1%)	12 (7.8%)	4 (2.6%)
During physics lesson, I have never done project assignments	18 (11.7%)	10 (6.5%)	19 (12.3%)	4 (2.6%)	4 (2.6%)	20 (13.0%)
I agree with implementing a kind of mini-project in physics learning	11 (7.1%)	7 (4.5%)	20 (13.0%)	15 (9.7%)	13 (8.4%)	9 (5.8%)
I agree that the given mini-project can improve my critical thinking skills in physics learning	6 (3.9%)	5 (3.2%)	12 (7.8%)	22 (14.3%)	15 (9.7%)	15 (9.7%)

4.6 POPBL Prospect Analysis

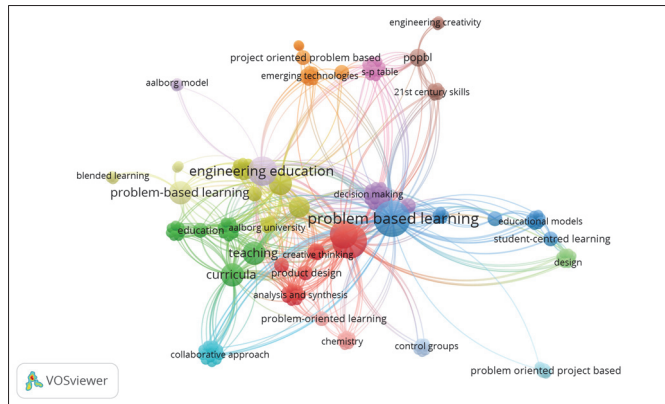


Figure 4: POPBL Keyword Mapping Visualization

Figure 4 shows the results of network visualization mapping of research trends in POPBL learning models. It can be seen that this learning model is still rarely studied as evidenced by the findings of 25 all-year documents. Then, it is clear that the POPBL model is a student-centered learning model that can provide them with a lot of learning experience. The majority of researchers apply this model in engineering education so that the application of this model in physics learning becomes novel because it has never been studied before. In addition, the term 'critical thinking' is also not found in keyword co-occurrence, but the term '21-st century skills' appears (Husin et al., 2016), where critical thinking skills are included in one of the skills of the 21st century. Therefore, research on the POPBL model to improve critical thinking skills in physics learning is very potential because it has high novelty and originality.

5. Discussion

In terms of profile of physics critical thinking skill in general shows that the majority of students' critical thinking skill merely on low criteria. This is because teachers do not teach the ability to think critically to their students by design. Teachers only focus on improving learning outcomes, so students' thinking skills become untrained (Fitriani et al., 2020; Suarniati et al., 2018). In addition, students are not used to managing thinking strategically and tactically in dealing with problems, as is because the strategies taught by teachers in every physics learning are the ability to think more mathematically, not deep reasoning. (Ogilvie, 2009). Moreover, the perception of students that physics lessons are difficult lessons and are not liked by them, resulting in students having the low motivation to learn physics and ending in low critical thinking skills. Several previous studies have proven that physics is one subject that students are not interested in (Jufrida et al., 2019; Lusiyana et al., 2019).

Based on the researchers' experience, the student's study habit is that they tend to have had enough of the teacher's explanation without questioning more deeply about what they learned (Doyle & Tagg, 2008; Etemadzadeh et al., 2013), thus causing students' critical thinking skills not to develop. Another factor that is predicted to cause students' physics critical thinking skills to be low is that students are poorly trained and are not familiar with the form of patterns that present physical phenomena (Docktor & Mestre, 2014; Stuckey et al., 2013). To train the critical thinking level, students can ask again about the natural events being studied. Teachers must also create learning that can contribute to students actively and communicatively in learning activities. This is important in order to create intensive interaction between students (Allen et al., 2013; de Kleijn, 2021), so it is expected to improve students' critical thinking skills.

Regarding the profile by indicator, when solving a problem, students should evaluate the relevance of the information they will eventually use to support a claim or conclusion (Miri et al., 2007). After evaluating the information, students cannot analyze the data and provide in-depth problem-solving. Moreover, synthesizing or linking pieces of valid information to make a conclusion or claim (Reynders et al., 2020). This can be because students do not have initial knowledge of a concept, making it difficult to relate concept knowledge to one another. When it comes to a class, students do not actually bring empty knowledge or empty minds. Yet, they have dismembered knowledge (Arends, 2011), so students have difficulty associating a concept with each other. Consequently, students cannot convey their ideas or thoughts, so the score on forming arguments, both structure and validity, is in a low category.

Figure 5 shows one of the student's answers that is considered complete (none of the indicators are empty) in answering any of the questions. In the question, an infographic is presented, and students are asked to answer the question "(a) By looking at the deficit in oil supply and Indonesia's potential, what is the picture of Indonesia's current oil condition?; (b) What is the impact of using non-renewable energy on the environment?". It can be seen that the student evaluated the information contained in the infographic is still incomplete, even though in the infographic provided, there are still quantitative data on the growth of the production of renewable energy sources. In the 'analyzing' rubric, students cannot provide arguments as to why petroleum conditions are declining and why non-renewable energy impacts society. Moreover, on this indicator, he answers about cooking oil that does not fit the context of the question. In the 'synthesizing' indicator, the student only refers to data based on the infographic. He should have written down these data pieces directly so they could corroborate claims about the current state of petroleum. Thus, the forming argument (structure) indicator still has an incomplete structure because arguments have not accompanied it. While in forming arguments (validity), it is said that it is still not fully valid because there is no complete data.

Mengevaluasi
Kenapa harus Energi terbarukan? Penggunaan sumber energi terbarukan seperti Angin, air, dan biomassa telah dikenal sejak berabad-abad yang lalu, jauh sebelum teknologi modern berkembang dan di gunakan secara luas. disini terdapat 5 mengapa energi terbarukan antara lain: Perubahan Iklim, Defisit pasokan minyak bumi, potensi Indonesia

Menganalisis *tren dunia, para 3T*
a.) kondisi perminyakan saat ini mengalami penurunan sedangkan kebutuhan terus meningkat, pada 2016 Indonesia hanya mampu memproduksi 820 ribu barel per hari dg kebutuhan 16 jt. per hari sehingga 51% kebutuhan minyak perlu di impor.

b.) dampaknya sangat dirasakan oleh masyarakat. karena masyarakat sangat membutuhkan terutama minyak bumi untuk kebutuhan sehari-hari goreng, bisa dilihat dan yang viral sekarang, berkurangnya pasokan minyak

Mensintesis
data diatas dibuat berdasarkan infografis yang minyak goreng tersedia di no. 1

Figure 5: One Example of a Student's Answer

Translation:

Evaluating

Why should renewable energy? The use of renewable energy sources such as wind, water and biomass has been known for centuries, long before modern technology was developed and widely used. Here there are 5 reasons for renewable energy, including: climate change, oil supply deficit, Indonesia's potential, world trends, remote areas.

Analyzing

- a) Current oil conditions continue to decline while the demand continues to increase. In 2006 Indonesia was only able to produce 820 thousand barrels per day with a requirement of 16 million per day, so that 51% of its needs needed to be imported.
- b) The impact is felt by the community, especially petroleum for daily needs which is currently viral. The reduced supply of cooking oil, we can see how confused people are about the lack of cooking oil.

Synthesizing

The data above is seen based on the infographic provided in question number 1.

What is more, if reviewed by giftedness, the formation of this outlier shows that the profiles of students in schools are, in reality not the same. Some students are gifted, so they have good concentration and focus (Chichekian & Shore, 2014). In addition, they also have high analytical and synthesis power so they can solve given problems easily. Figure 5 shows an answer given by one of the students that could be included in the gifted students' category. It can be seen that this student has higher critical thinking skills than non-gifted students in Figure 6. These gifted students can evaluate information properly and completely, provide argumentation and problem solving, and synthesize information sufficiently. This is because gifted students have different cognitive characteristics that positively relate to critical thinking skills (Dilekli, 2017).

However, research data shows that gifted students are included in the criteria for moderate critical thinking skill due to several factors, such as their lack of time to convey and writing down their ideas. In this case, the researcher cannot control the variable processing time because it is limited by school hours. In addition, another factor is that they do not fully understand the material provided by the teacher, thus reducing their level of critical thinking. According to Amanda et al., (2022); Halpern (2013), critical thinking skill is influenced by students' understanding of the material.

Mengevaluasi

a) Produksi minyak Indonesia mengalami penurunan minyak yang diproduksi sebanyak 820 ribu kebutuhan minyak sebesar 1.6 juta barrel hari, 51% kebutuhan minyak Indonesia perlu di impor.

b) 16x kebutuhan listrik Indonesia tahun 2014*, sumber energi tsb termasuk potensi energi air, angin, biomasa, matahari, panas bumi, gelombang laut.

Menganalisis

a) Dengan melihat data pada infografis, kekurangan minyak terjadi karena kebutuhan dan hasil produksi yang tidak seimbang, kekurangan itu bisa diatasi dengan mencari energi alternatif yang dapat menggantikan minyak tsb. menurut saya minyak bumi dapat digantikan dgn biodiesel.

b) banyak hal yang sudah ditemukan untuk mengganti energi listrik konvensional. Salah satunya yaitu memanfaatkan energi terbesar di bumi yaitu matahari, menggunakan energi alternatif ini dapat menjaga lingkungan karena energi tsb ramah lingkungan.

Mensintesis

a) minyak bumi ini biasa dipakai untuk bahan bakar seperti kendaraan, untuk mencegah kebakaran banyak ditemukan energi alternatif seperti hidrogen yang diubah menjadi listrik. solar cell untuk kendaraan listrik ada juga biodiesel. biodiesel ini terbuat dari minyak nabati

b) Sekarang banyak dijumpai energi alternatif untuk menghasilkan listrik contohnya seperti panel surya yang dapat mengubah cahaya matahari menjadi listrik dan turbin air, arus air dapat mendorong/memutar turbin air lalu disambungkan ke generator dan diubah menjadi energi listrik.

Mengevaluasi

Figure 6: One Example of Student Answers Categorized as Gifted

Translation:

Evaluating

- (a) Indonesia's oil production experienced a decline in oil produced by 820 thousand, oil needs of 1.6 million barrels per day, 51% of Indonesia's oil needs need to be imported
- (b) 16x Indonesia's electricity needs in 2014, these energy sources include the energy potential of water, wind, biomass, solar, geothermal, ocean waves

Analyzing

- (a) By looking at the data in the infographic, oil shortages occur due to unbalanced needs and production results. This shortage can be overcome by finding alternative energy that can replace the oil. In my opinion, petroleum can be replaced with biodiesel.
- (b) Many things have been found to replace conventional electrical energy. One of them is utilizing the earth's largest energy, namely the sun. Using this alternative energy can protect the environment because this energy is environmentally friendly.

Synthesizing

- (a) Petroleum is usually used for fuel such as vehicles. To prevent shortages, many alternative energy sources are found, such as hydrogen which is converted into electricity, suitable for electric vehicles, there is also biodiesel made from vegetable oil.
- (b) Now there are many alternative energies to generate electricity, for example solar panels that can convert sunlight into electricity and waterwheels, water currents can drive/turn the waterwheels and then connected to generators and converted into electrical energy.

Furthermore, in terms of gender, the results provide findings in this study that the critical thinking skill of female students' physics is greater than that of males. This is because females are also superior to males in making conclusions, which means that females are better able to identify the elements needed to draw conclusions, compile hypotheses, and consider relevant information (Caplan & Caplan, 2015). Females' brain areas related to language function work harder than males', resulting in higher female language skills (Wodak & Benke, 2017). Language is a tool for communicating ideas. The ability to use language with good grammar indicates a high level of thinking ability. Women have a greater ability to express themselves to others (Guiler et al., 2005).

These findings are in line with research by Tamam et al. (2021) that female students outperformed the male ones in critical thinking and there is a significant difference between the two. In addition, Perdana et al. (2019) research states that females' critical thinking skills are better than males, while males' creativity is superior to females. Other research by Mashami & Gunawan (2018)

also agrees that physics critical thinking skills in female students are better than in male students. However, this study is not in line with Mitrevski & Zajkov (2012) research, which shows no significant difference between males and females in physics critical thinking skill. Research by Marni et al. (2020) also proved that there was no significant difference in critical thinking skill reviewed by gender. These findings add more evidence to the debate over the use of gender as a predictor in critical thinking skills. As reflective practitioners, teachers should respond well to the expectations and biases teachers may have to give equal treatment to both genders. Although males and females have different characteristics, teachers should give students equal opportunities and encouragement in learning (Lueg & Vila, 2017).

Additionally, based on the students' questionnaire results, there is a perception that they have a difficulty in physics lesson. This perception can obviously make students have less motivation to learn physics. Even though learning motivation has a positive relationship with critical thinking skills (Nur'azizah et al., 2021). In addition, many students feel that the physics learning methods carried out by teachers are not innovative enough so they feel bored. This is in line with research by Bestiantono et al. (2020); Marušić & Sliško (2014); Saleh (2021) that the majority of teachers teach physics by the lecture/direct method so as to make students feel bored.

The next statement is about project-based learning. Many students feel that they have never done project-based assignments, even though the project-based learning model has very important and beneficial advantages for students. Through project-based learning, students are more active in collaborating and solving complex problems with tangible product results (Chen et al., 2019; Fernandes et al., 2021; Rizki & Suprpto, 2024). Therefore, many students agree that applying some kind of mini-project in physics learning. In addition, they also believe that the project can improve critical thinking skills in physics learning. One of the learning models that can improve students' critical thinking skills is POPBL which has real product-based outputs.

Based on the bibliometric prospect result, the article with the highest citation belongs to Lehmann et al. (2008) entitled "Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education". This study investigates the concept of sustainable development, considers the general skills of engineering education graduates, and looks at how non-technical topics are incorporated into various environmental engineering programs. Based on this discussion, it highlights how crucial it is to take a problem-oriented strategy as opposed to a subject-oriented one in order to find a balance between problem occurrence (or identification) and creative problem solving. Meanwhile, the latest article is owned by Chang et al. (2022) entitled "Enhancing student creativity through an interdisciplinary, project-oriented problem-based learning undergraduate curriculum". This research discusses the POPBL model-based undergraduate curriculum for student creativity. These experimental curricula were designed and implemented by four professors from the fields of future studies, architecture, engineering, and education. Participatory design, future thinking, and visual communication were three key concepts incorporated into the curriculum around creative design thinking. The findings of this study are that interdisciplinary creativity can be fostered through POPBL instruction combined with participatory design pedagogy.

Thus, it can be underlined that the profile of the physics critical thinking skill of the majority of students has low criteria. The prospect of a solution to overcome this is to apply the POPBL learning model which has novelty and has never been studied before. Through the POPBL model, students can apply their knowledge to solve project-based real-life problems. This is in line with Piaget's constructivism theory that learning is an active activity when students construct their own knowledge, find out what has been learned, and is the process of completing new concepts and ideas with their own framework.

This study gives implications to educators, curriculum developers, and policymakers:

1. **Educators:** The findings of this study offer valuable insights for educators in the field of physics education. By understanding the profile of students' critical thinking skills in physics, educators can tailor their teaching strategies to address areas of weakness and

reinforce strengths. Additionally, the prospect analysis of the POPBL model provides educators with a concrete framework for implementing innovative teaching approaches that promote critical thinking.

2. **Curriculum Developers:** Curriculum developers play a crucial role in shaping the educational landscape. This study's findings inform the development of physics curricula that prioritize the cultivation of critical thinking skills. Developers can design learning materials and assessments that effectively target key competencies by aligning curriculum objectives with the identified profile of students' critical thinking abilities.
3. **Policymakers:** Policymakers are responsible for guiding educational policies that support student learning and success. The insights gained from this study can inform policymaking efforts to improve physics education at both the institutional and systemic levels. Policymakers can use the findings to advocate for initiatives that promote integrating critical thinking development into educational standards and assessments.

The study's practical implications for educators, curriculum developers, and policymakers underscore the importance of fostering critical thinking skills in physics education. By leveraging the insights and recommendations provided, stakeholders can collaborate to implement effective teaching strategies and bridge the gap between research and practice, ultimately enhancing the relevance and applicability of physics education in today's dynamic world.

6. Conclusion

The profile of students' physics critical thinking skills, in general, is that the majority of them have critical thinking skills on low criteria. This is due to several factors, such as: teachers who do not teach by design critical thinking skills, students are not used to thinking strategically and tactically, students' perception that physics subjects are difficult, and students' study habits that feel that only enough with the teacher's explanation. When the profile of physics critical thinking skills is reviewed based on indicators, the highest average score obtained by students is on the 'Evaluating' indicator, while the lowest average score is on the 'Synthesizing' indicator. Based on giftedness, from the entire sample of students, there were several gifted students who showed that they had higher critical thinking so as to be able to complete all critical thinking indicators. When reviewed by gender, the value of females' critical thinking skills is higher than that of males. Supported by statistical tests that there is a significant difference between the both.

The results of the student response questionnaire showed that many students found physics lessons very difficult. In addition, many of them have never worked on project tasks in physics lessons. Students also if applying some kind of mini-project in physics learning. One of the project-based learning models that can improve students' critical thinking skills is POPBL. This learning model is very prospective to be applied in physics learning. The results of bibliometric analysis show that research on the POPBL model to improve critical thinking skills in physics learning is very potential because it has high novelty and originality.

Specifically, the implications of this study are 1) it can be a guide for teachers to be able to better teach critical thinking skills by design to students and respond well to differences in learning characteristics for gifted students, male students, and female students; 2) there is a need to improve students' physics critical thinking skills; 3) research needs to be carried out on the implementation of the POPBL learning model to improve students' physics critical thinking skills; 4) most relevant issues about POPBL learning model and the authors that had the most significant impact.

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