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The Effectiveness of STEM-Based Electrochemistry E-Modules in Enhancing Critical Thinking Skills

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Abstract: The Effectiveness of STEM-Based Electrochemistry E-Modules in Enhancing Critical Thinking Skills. Graduates of schools in the period of Industrial Revolution 4.0 must be proficient in 21st-century abilities such as critical thinking, creativity, invention, communication, and teamwork. By incorporating STEM into the electrochemistry e-module, it has the potential to improve critical thinking skills. This study evaluates the effectiveness of STEM-Based Electrochemistry E-Modules in enhancing critical thinking skills and examines student responses to their implementation. This research was conducted as part of the Capita Selecta Chemistry course in the PSPK 22C class. The study employed a one-group pretest-posttest design. Instruments included written essay tests to measure students' critical thinking skills and a questionnaire to assess their responses to the e-module. The N-Gain test results revealed an average score of 0.792 for critical thinking skills, indicating a high category. Additionally, the student response of the STEM-based electrochemistry e-module recorded an average score of 82.8, reflecting a very good classification.

Keywords: E-Module, STEM, Critical Thinking Skills, Response, Electrochemistry.

Abstrak: Efektifitas E-Modul Elektrokimia Berbasis STEM Untuk Meningkatkan Kemampuan Berpikir Kritis. *Setiap mahasiswa yang lulus dalam era revolusi industri 4.0 harus memiliki kemampuan abad 21 seperti berpikir kritis, kreatif, penemuan, komunikasi dan kerja sama tim. Dengan memasukkan STEM ke dalam e-modul elektrokimia berpotensi untuk meningkatkan kemampuan berpikir kritis. Penelitian ini mengkaji efektifitas E-Modul Elektrokimia Berbasis STEM dalam meningkatkan kemampuan berpikir kritis dan bagaimana respon mahasiswa terhadap penggunaannya. Penelitian ini dilaksanakan dalam mata kuliah Kapita Selekta Kimia pada kelas PSPK 22C. Desain penelitian yang digunakan adalah one-group pretest-posttest design. Instumen yang digunakan adalah kuesioner untuk mengukur respon mahasiswa terhadap e-modul dan soal essay untuk mengukur kemampuan berpikir kritis. Hasil uji N-Gain menunjukkan skor rata-rata 0,792 untuk kemampuan berpikir kritis, yang termasuk dalam kategori tinggi. Selain itu, respon mahasiswa terhadap e-modul elektrokimia berbasis STEM menunjukkan skor rata-rata 82,8, yang termasuk dalam klasifikasi sangat baik.*

Kata kunci: *E-Modul, STEM, Kemampuan berpikir Kritis, Respon, Elektrokimia*

- **INTRODUCTION**

In the period of Industrial Revolution 4.0, education places a strong emphasis on giving graduates the 21st-century abilities of critical thinking, creativity, invention, communication, and teamwork. This is further highlighted in Article 6 of Regulation No. 49 of 2014 on Higher Education Standards by the Indonesian Ministry of Education and Culture, which mandates that undergraduate graduates have general skills, such as the capacity to apply critical, logical, methodical, and creative thinking in the advancement or use of science and technology while upholding humanities values pertinent to their field of study (Santi et al., 2018).

Critical thinking involves careful reasoning and evaluation of opinions to solve problems, draw valid conclusions, and address challenges in dynamic contexts such as STEM education (Abdullah, 2013). It is an essential ability, especially when dealing with the difficulties of the fourth industrial revolution (Mardliyah, 2019). Critical thinking skills need to be trained with the aim of preparing students to be able to face various situations in life that are always faced with various problems and choices so that they are able to make decisions about what to believe (Munthe., et al, 2023). Among the scientific disciplines, chemistry offers opportunities to develop critical thinking skills. Chemistry, a branch of the natural sciences, focuses on the study of matter, including its composition, structure, properties, and the transformations it undergoes (McMurry & Fay, 2005:2). Everyday chemical phenomena provide insights into the interplay between chemical changes and energy, the various types of chemical reactions, and the mechanisms of chemical transformations (Kolomuc & Tekin, 2011). These phenomena encourage students to relate and explain concepts they have learned.

The Science, Technology, Engineering, and Mathematics (STEM) approach represents an effective strategy for fostering critical thinking in the Industrial Revolution 4.0 era. This approach integrates the four disciplines science, technology, engineering, and mathematics into a problem-solving-oriented learning framework. By employing STEM, students are encouraged to generate innovative ideas while developing essential skills such as critical thinking, problem-solving, and collaboration (Khairunnisa et al., 2023; Rahmadana et al., 2022).

Initial observations during the Capita Selected Chemistry course indicated a reliance on traditional learning resources, including textbooks, journals, and instructional videos. The teaching materials lacked STEM integration, providing only content and practice questions. Students struggled to understand the material, as evidenced by low critical thinking skills during learning activities, resulting in poor academic performance.

In chemistry education, teaching quality and learning outcomes are influenced by several factors, including instructional materials. Instructional materials help instructors and students facilitate the learning process. Among these materials, modules stand out as a resource that instructors can develop. Developing modules aligned with information and communication technology advancements is crucial. Nasution (2020) defines an E- Module as an innovation significantly contributing to transformative learning processes, where students engage in activities such as observing, experimenting, and demonstrating, rather than passively listening to lectures.

STEM-based e-modules are innovative digital learning resources designed for easy accessibility. Some research results show that STEM-integrated teaching materials are also effectively used in the learning process which can improve student learning outcomes (Dalimunthe, 2022). STEM-based learning supports critical thinking processes, including analysis, evaluation, problem-solving, investigation, and decision-making, according to research by Davidi et al. (2021). Additionally, studies by Khoiriyah et al. (2018), Izzati et al. (2019), and Fathoni et al. (2020) highlighted the effectiveness of STEM approaches in fostering students' critical thinking abilities.

Based on the results of previous research, it is necessary to integrate STEM in electronic chemistry teaching materials that can be accessed easily. Through the integration of STEM in e-modules, it is expected to have an impact on students to solve problems, design/create new things (innovation), understand themselves, think logically, and master technology. The STEM approach is focused on the real world and authentic problems so that students can learn to reflect on the problem-solving process (Cahyono, 2022). With the integration of STEM, students can have deep insight and be dynamic and creative so as to create a superior generation.

▪ METHOD

The research was conducted on the use of e-modules in the Kapita Selekta Chemistry course in the PSPK 22C class of 30 students. The type of research used in this study is experimental. According to Sugiyono (2013) experimental research methods can be interpreted as research methods used to seek the effect of certain treatments on others under controlled conditions. Based on this opinion, it can be understood that experimental research is always carried out by giving treatment to research subjects and then seeing the effect of the treatment (Fitrianingsih, R., et al, 2015). The research design used was Pre-Experimental Design with One-Group Pretest-Posttest Design model. This research design was chosen because it was only conducted in one class to test the effectiveness and response of the use of e-modules. Measurements were taken before treatment (pretest) and after treatment (postest) as shown in table 1. This design allows for more accurate analysis because the results of the scores can be compared between the conditions before and after treatment (Sugiyono, 2013).

Table 1. Research Design: One-Group Pretest-Posttest

Class	Pretest	Treatment	Posttest
Eksperiment	P1	X	P2

Where :
P1 : Initial test (Before the treatment)
P2 : Final test (After the treatment)
X : Learning using the STEM-Based Electrochemistry E-Module

A written exam with essay questions created especially to gauge students' critical thinking abilities served as the study's instrument. Ennis (2011), who outlined a number of indicators spanning five dimensions, served as the foundation for the critical thinking indicators. Out of the twelve indicators of critical thinking ability, this study examined five aspects with nine indicators: 1) Basic clarification: Formulating questions, analyzing arguments, and the processes of asking and answering questions, 2) The decision's foundation: Evaluating the reliability of information sources, 3) Inference: Making deductions and evaluating them, making inductions and evaluating them, and performing evaluations, 4) Advanced clarification: Identifying assumptions, 5) Supposition and integration: Making predictions.

Before implementation, the test consisting of 11 questions aligned with critical thinking indicators underwent a validation process. This included tests for validity, reliability, item discrimination analysis, and difficulty level analysis for each question. The N-Gain analysis method to assess the effectiveness of the STEM-based Electrochemistry E-Module, utilizing the following formula.

$$\langle g \rangle = \frac{Posttest\,Score - Pretest\,Score}{Total\,Score - pretest\,Score}$$

If the average N-Gain score is higher than 0 (g > 0), signifying an improvement in pretest and posttest scores, the STEM-based Electrochemistry E-Module is deemed effective. A checklist-style questionnaire with a Likert scale was used to gauge students' answers to the STEM-based E-Module. Using the formula, the evaluation results were descriptively examined as a percentage.

$$P = \frac{f}{N} x 100\%$$

Where:
P = Percentage of response
F = Number of scores obtained
N = Total score

▪ RESULT AND DISCUSSION

The The STEM-based electrochemistry e-module was implemented in the Capita Selected Chemistry course for the PSPK 22C class, which consisted of 30 students. As illustrated in Figure 1, the research results encompass pretest and posttest scores related to the cognitive domain of critical thinking ability indicators.

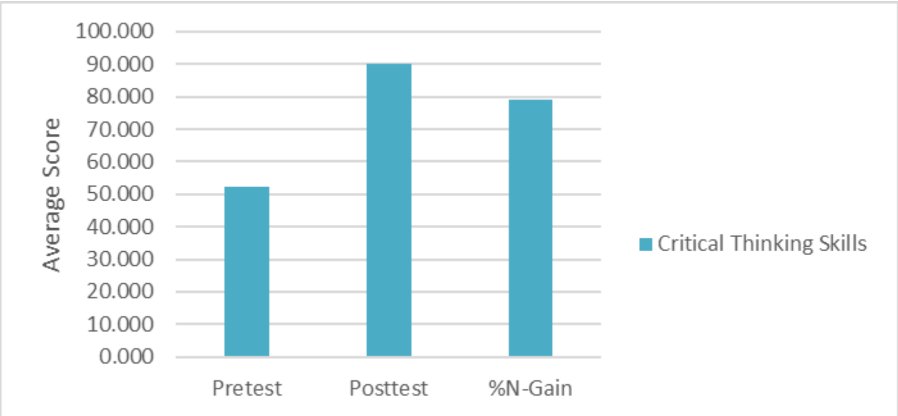

Figure 1. Critical Thinking Skills Scores Data

As shown in Figure 1, the average pretest score was 52.424, and the average posttest score was 90. The results of the N-Gain average test indicated a value of 79.229, or 0.792, with a high criterion. This demonstrates how the STEM-based electrochemistry e-module enhances students' critical thinking abilities and is beneficial for teaching. The e-module's incorporation of STEM is a creative strategy that encourages critical thinking and allowing students to connect electrochemistry ideas to useful, real-world applications. A module is considered effective in enhancing critical thinking skills if it offers certain innovations and advantages, allowing students to learn optimally and take responsibility for achieving progress and skills (Fitriani et al., 2017). According to research by Sholikhah et al. (2024), a 3D STEM-based module is quite effective at enhancing critical thinking abilities. This is attributed to the in-depth presentation of material connected to the STEM approach, as well as the presentation of contextual problems relevant to everyday life, which stimulates students to think critically.

The measurement results of critical thinking ability, using the 5 aspects proposed by Ennis and applied to students in the PSPK 22C class, are presented in Figure 2.

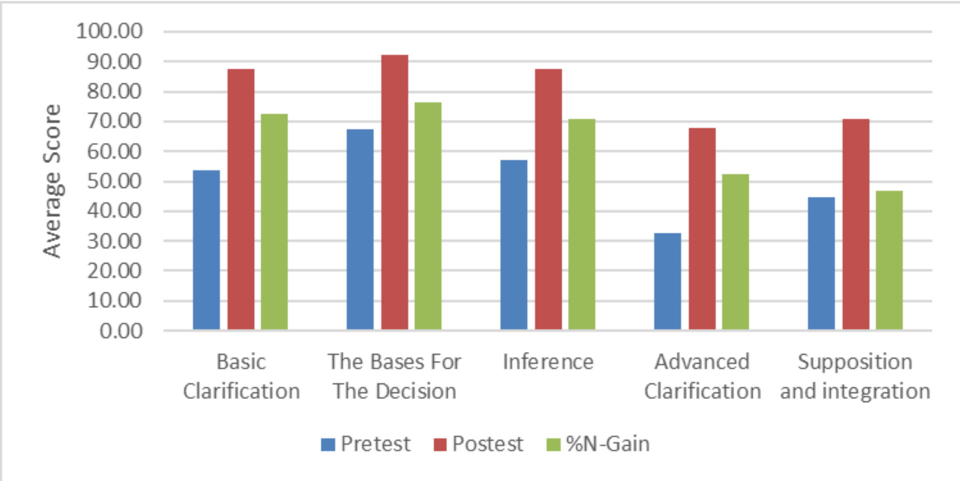

Figure 2. Critical Thinking Ability Based on 5 Aspects of Ennis

Based on the N-Gain test results, it can be observed that the aspect of providing basic clarification has a score of 72.73 or 0.727, the aspect of providing reasons for a decision has a score of 76.54 or 0.765, the aspect of inference has a score of 70.74 or 0.707, the aspect of further clarification has a score of 52.48 or 0.525, and the aspect of assumptions and coherence has a score of 46.99 or 0.469. This indicates an improvement in students' critical thinking skills with high and moderate criteria. The diagram shows that the 'providing reasons for a decision' aspect achieved the highest N-Gain score, highlighting students' ability to evaluate information credibility effectively. In contrast, the 'assumptions and coherence' aspect received the lowest score, suggesting room for improvement in constructing logical arguments.

The aspect of providing reasons for a decision, one of its indicators being the evaluation of the credibility of information sources, includes questions related to evaluating the process of removing iron content from well water based on reaction equations. Most students were able to evaluate the information correctly. This finding aligns with Che (2002), who stated that critical thinking encourages learners to observe events from various perspectives and evaluate them through intellectual reasoning processes.

The aspect of providing basic clarification, with indicators such as formulating questions, analyzing, and asking and answering questions, shows that most students were able to formulate follow-up questions related to the use of redox reactions in activated sludge for textile wastewater treatment. They also analyzed the reaction process by evaluating data on standard electrode potential values. However, for the indicator of asking and answering questions, some students provided answers that were brief and lacked detail. This is in line with Leicester & Taylor (2010), who revealed that students develop critical thinking skills gradually through habits such as formulating problems and answering questions requiring explanation.

In the aspect of inference, students were able to make and assess deductions/inductions and evaluate. They identified various elements and solved problems to draw conclusions. The conclusion drawing process aims to interpret what has been observed or occurred (Yunita et al., 2018). The aspects of further clarification and assumptions and coherence received moderate N-Gain scores, indicating that most students were able to identify assumptions correctly, but their conclusions regarding the cases were still somewhat inaccurate. According to Nosich (2009), learners are capable of making accurate decisions with confidence in their results and determining actions based on learning relevant to everyday life.

After the electrochemistry e-module based on STEM was used in the learning process, 30 students from the PSPK 22C class were given a questionnaire with 6 indicators consisting of 20 statements. The summary of student responses to the e-module is presented in Figure 3.

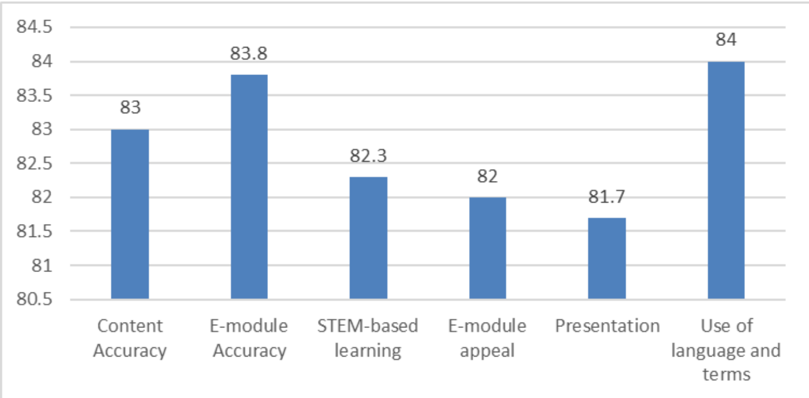

Figure 3. Recapitulation of Student Responses

As shown in Figure 3, the average student response score to the e-module across the six statement criteria was 82.8, which is categorized as very good. This demonstrates that the STEM-based electrochemistry e-module is highly effective at teaching chemistry and encourages the development of critical thinking skills. This finding is consistent with studies by Adella & Dalimunthe (2024), which showed that STEM e-modules improve students' proficiency in learning chemistry and their higher-order thinking skills (HOTS). Likewise, the study by Aisyah et al. (2019) indicated that the use of a voltaic cell e-module application encourages students to engage in critical thinking.

▪ CONCLUSION

The results of the study demonstrate that using a STEM-based electrochemistry e module significantly improves students' critical thinking skills, with an average N-Gain score of 0.792, which falls into the high category. The aspect of providing reasons for a decision received the highest N-Gain score, while the lowest score was obtained in the aspect of assumptions and coherence. The students' response on the STEM-based electrochemistry e-module yielded an average score of 82.8, which falls into the "very good" category. Students reported being interested in studying chemistry because the STEM approach connects chemistry content with other disciplines, helping them to understand the material well and improving their learning comprehension.

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