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Developing E-module based on hypothetical inquiry learning to improve students' critical thinking skills

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ABSTRACT

There is a scarcity of empirical studies that specifically examine the integration of Hypothetical Inquiry Learning (HIL) in e-modules to enhance students' critical thinking skills, particularly within the context of digital learning. This study aims to develop an e-module based on HIL to improve students' critical thinking abilities and the overall quality of learning in the digital era. The e-module is designed to facilitate students' understanding of complex concepts through an interactive Hypothetical Inquiry-based learning approach. The study employs a Research and Development (R&D) model based on Alessi and Trollip's framework, encompassing the Planning, Design, and Development stages. The study involved a population of 160 students, with a sample of 81 students from a senior high school in Sukoharjo regency, Central Java, Indonesia, and 5 validation experts, with validity assessed using the Aiken's V index. The results of the practicality test demonstrated that the e-module based on HIL is highly practical for use as a digital learning tool, achieving a practicality score of approximately 98.32%. Furthermore, the effectiveness test revealed that the e-module significantly improves students' understanding of concepts and critical thinking skills, with an N-gain score of approximately 95.23%. Thus, the e-module based on Hypothetical Inquiry Learning represent an innovative and highly effective educational resource for enhancing student learning outcome.

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Introduction

The rapid advancement of information and communication technology has significantly transformed the educational landscape, requiring the development of innovative teaching and learning strategies. One such innovation is the integration of electronic modules (e-modules), which leverage digital platforms to deliver instructional content in a more engaging and interactive manner. Within the domain of biotechnology education, the effective deployment of e-modules has the potential to facilitate a deeper understanding of intricate scientific concepts by providing students with structured, visually rich, and interactive learning experiences (Jumiarni et al., 2022). The Natural Sciences discipline emphasizes a systematic approach to understanding natural phenomena, underscoring the importance of not only mastering factual knowledge, comprising principles, concepts, and laws, but also engaging in scientific inquiry as a process of discovery (Kurniawan & Fadloli, 2016; Lukum, 2015; Mashinta et al., 2016).

The inquiry-based learning model aligns with the scientific approach, as it encourages students to actively construct knowledge through exploration and discovery (Khoiri et al., 2020; Nzomo et al., 2023). Bruner (1961) posited that inquiry learning comprises four essential dimensions: (1) learning as a cognitive process, (2) the attainment of intellectual satisfaction through discovery, (3) the utilization of scientific methodologies, and (4) the long-term retention of knowledge derived from experiential learning. Similarly, Yilmaz (2011) conceptualized cognition as an active process wherein learners continuously acquire, modify, and restructure cognitive schemas to assimilate new information. These theoretical perspectives underscore the pivotal role of inquiry-based learning in cultivating cognitive competencies, thereby fostering deep learning and critical thinking (Baumert et al., 2009).

The Hypothetical Inquiry learning model represents a specialized form of inquiry-based pedagogy that explicitly emphasizes critical thinking through the systematic formulation and empirical validation of hypotheses. This approach requires students to pose investigative questions, generate hypotheses, and rigorously test their assumptions through evidence-based reasoning (Alstein et al., 2025). By engaging in this iterative process, learners develop logical reasoning skills, enhance their problem-solving abilities, and acquire a deeper conceptual understanding of scientific phenomena (Roviati et al., 2024). A distinctive advantage of this model is its capacity to nurture higher-order thinking skills by prompting students to analyze, evaluate, and synthesize information rather than passively absorbing content (Jin et al., 2019; Simon, 2020). Given the increasing emphasis on critical thinking as a core educational competency, the Hypothetical Inquiry model serves as an effective pedagogical bridge between theoretical knowledge and its practical applications.

Integrating Hypothetical Inquiry with e-modules amplifies its efficacy by enabling students to engage in self-directed, interactive, and multimodal learning. E-modules enriched with multimedia components, such as instructional videos, simulations, and interactive assessments, facilitate hypothesis testing and data-driven reasoning (Baroody et al., 2022). This synergistic approach not only enhances student engagement and accessibility but also fosters cognitive flexibility, adaptability, and independent inquiry—key attributes for academic and professional success in the 21st century (Akhdinirwanto et al., 2020). Furthermore, by embedding inquiry-driven tasks within digital learning platforms, educators can transform traditional classroom instruction into dynamic, learner-centered environments, thereby maximizing students' critical thinking potential.

Recent study has focused on the development of e-modules to increase students' critical thinking abilities in scientific education. These e-modules, which are frequently based on an inquiry learning method, have demonstrated encouraging outcomes in developing critical thinking abilities across grade levels. E-modules often include interactive aspects like instructional games and inquiry-based worksheets (Anjarsari et al., 2023). Overall, the findings indicate that a well-designed inquiry-based e-module may be a credible, practical, and successful instrument for improving students' critical thinking abilities in scientific education (Noris et al., 2023).

Despite a growing body of research on e-module development and inquiry-based learning, limited empirical studies have specifically explored the integration of the Hypothetical Inquiry model within e-modules to enhance students' critical thinking abilities in biotechnology education. Previous studies, such as those conducted by Siew and Ahmad (2023) and Panggabean et al. (2019), have demonstrated the effectiveness of e-modules incorporating socioscientific and entrepreneurial elements, as well as biochemistry and biodiversity content, in enhancing students' higher-order thinking skills. However, a research gap remains in the systematic design, development, and evaluation of e-modules that explicitly incorporate Hypothetical Inquiry principles to cultivate critical reasoning and analytical problem-solving abilities.

The present study introduces a novel approach by integrating Hypothetical Inquiry-based e-modules within biotechnology learning contexts, thereby filling this research void. Unlike previous research, which primarily focused on content-based e-modules, this study leverages the Hypothetical Inquiry framework to actively engage students in hypothesis-driven exploration. This unique pedagogical fusion not only enhances cognitive engagement and metacognitive awareness but also fosters a more profound conceptual understanding of biotechnology concepts. Furthermore, this study contributes methodological innovation by employing a comprehensive instructional design approach, ensuring that the e-module is not only pedagogically robust but also technologically adaptive to modern educational needs.

This study aims to design, develop, and evaluate a biotechnology e-module anchored in the Hypothetical Inquiry model and assess its effectiveness in enhancing students' critical thinking competencies. By integrating diverse teaching methodologies, this study seeks to develop an e-module that is not only pedagogically effective but also engaging, interactive, and aligned with contemporary digital learning paradigms. The findings of this study are expected to yield significant theoretical and practical contributions to the field of educational technology and science education, particularly in fostering innovative digital learning strategies. Moreover, the study holds practical implications for teacher professional development in digital pedagogy and offers valuable instructional resources for educators striving to implement interactive and inquiry-driven learning environments.

Method

This study employs a Research and Development (R&D) design, specifically utilizing the Research and Development (R&D) model proposed by Alessi and Trollip (Wibawanto et al., 2022). This approach is a systematic and structured methodology for software development, consisting of three main stages: planning, design, and implementation, along with three key attributes: content analysis, prototype development, and evaluation. These stages ensure that the development process is thorough and adheres to established guidelines for creating effective educational tools.

In this study, the biotechnology e-module was developed based on the principles of Hypothetical Inquiry Learning (HIL) and implemented using the Google Sites platform. The decision to use Google Sites was informed by its user-friendly interface, accessibility, and flexibility for creating interactive learning environments. Figure 1 illustrates the developmental stages of the e-module, which are aligned with the principles of Hypothetical Inquiry-based learning, ensuring that each stage supports the inquiry-based approach integral to the module's design.

The research population consisted of 160 students from a senior high school in Sukoharjo regency, Central Java, Indonesia. A sample of 81 students was selected through a random sampling technique, ensuring a representative subset of the population for the purposes of evaluating the e-module's effectiveness and practicality. To assess the feasibility of the biotechnology e-module, a panel of 5 internal validators was engaged. These validators, who are experts in the field, evaluated the e-module's content, design, and functionality. The validation process was conducted using Aiken's V index to quantify the agreement among the validators regarding the module's feasibility. Aiken's V index is a widely used method for measuring the validity of assessment tools, and it allows for a reliable determination of the e-module's appropriateness for educational purposes. The validity of the e-module was then calculated using Formula 1 for Aiken's V index below.

$$V = \frac{\sum St}{n\,(c-1)} \quad \text{.......} \quad (1)$$

The technique of analyzing the practicality of the biotechnology E-Module based on the hypothetical inquiry learning model was carried out by distributing questionnaires to 81 respondents and then analyzed using descriptive statistics with the help of SPSS 20. The results of feasibility and practicality of the developed e-module are further categorized based on several qualification as presented in Table 1.

Table 1. Categories of Feasibility and Practicality of E-Module

Score	Description
81-100	Very High
61-80	High
41-60	Medium
21-40	High Enough
0-20	Low

The analysis of the effectiveness of the developed e-module based on the hypothetical inquiry learning model was carried out by calculating the N-gain Score value. Table 2 categorizes the N-gain score, which measures the effectiveness of the e-module in enhancing students' critical thinking skills. Scores are divided into three categories: High (g > 0.7), Medium (0.3 < g < 0.7), and Low (g < 0.3). A High N-gain score, greater than 0.7, signifies a substantial improvement in students' understanding, indicating that the e-module was highly effective in facilitating significant learning gains. A Medium score, ranging from 0.3 to 0.7, reflects moderate improvement, meaning the e-module had some positive effect on students' critical thinking skills, but there may still be areas for further enhancement, such as content or delivery. Finally, a Low N-gain score, below 0.3, indicates minimal improvement, suggesting that the e-module did not have a significant effect on student learning. This could highlight the need for revisions in the module's design or content to better engage students and foster greater understanding. These categories help assess the e-module's overall effectiveness and guide future improvements.

Table 2. N-Gain Score Categories for E-Module Effectiveness

Score	Description
g > 0.7	High
0.3 < g < 0.7	Medium
g < 0.3	Low

The data were collected by using questionnaire in the form of Google form distributed to the respondents. The questionnaire consisted of six items to measure six aspects, namely online learning, online learning model, online learning method, types of assignment, discussion, and assessment. The instruments were developed by the researchers and validated by the expert team. After developing the instruments, they were distributed to the respondents through WhatsApp group. The questionnaire was used to find out respondents' opinion about learning and evaluation system during the COVID-19

Pandemic. After collecting the data, the data was analyzed descriptively-quantitatively in the form of bar diagram.

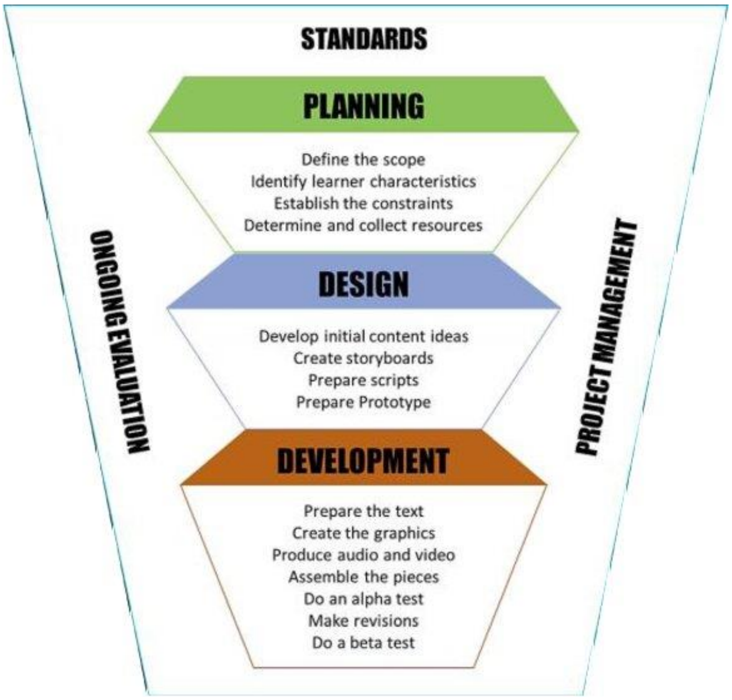

Figure 1. R&D Model of Alessi and Trollip (Wibawanto et al., 2022)

Results

A requirements analysis is performed during the analysis stage, which involves an examination of instructional materials, learning approaches, methods, models, strategies, techniques, and tactics utilized in learning, as well as the usage of technology. It also assesses the utilization of appropriate facilities and infrastructure, such as the availability of laboratories and necessary modules. At this point, the students' first critical thinking abilities were also examined, which encompassed four areas of critical thinking skills according to Facione (2011) consisting of interpretation, analysis, inference, assessment, explanation, and self-regulation.

This analysis is carried out by collecting information and identification to make the product to be developed according to the needs based on the results of observations and inclusive interviews with teachers and students which include analyzing the curriculum used, the conditions of learning activities, and the use of teaching materials to obtain a complex picture of product development tailored to conditions and needs. It is also necessary to measure the feasibility of the product to be developed in the form of an assessment instrument. At the analysis stage, the method used is observation and inclusive interviews with lecturers and students to find out their needs in teaching and learning activities in biotechnology courses.

The Product design stage is carried out in accordance with the idea and goal of e-module development. The produced e-module design was created with the Google Sites program since it was thought to be straightforward and practical to use. This program allows instructors and students to access biotechnology e-modules based on the hypothetical inquiry learning approach more readily on computers and Android devices. The instructor is consulted over the e-module design that will be created. If the design is not appropriate, it will be revised. If the design has been well evaluated, the e-module development process advances to the following level, which is the development stage. Currently, an e-module prototype that incorporates the hypothetical inquiry learning approach is being developed. This includes the following: (a) Home, (b) Usage Guidelines, (c) educational resources, and (d) assessment. This is the E-Module prototype that was created as presented in Figure 2 (front page), Figure 3 (learning materials), Figure 4 (sample of learning material evaluation), and Figure 5 (sample of learning material).

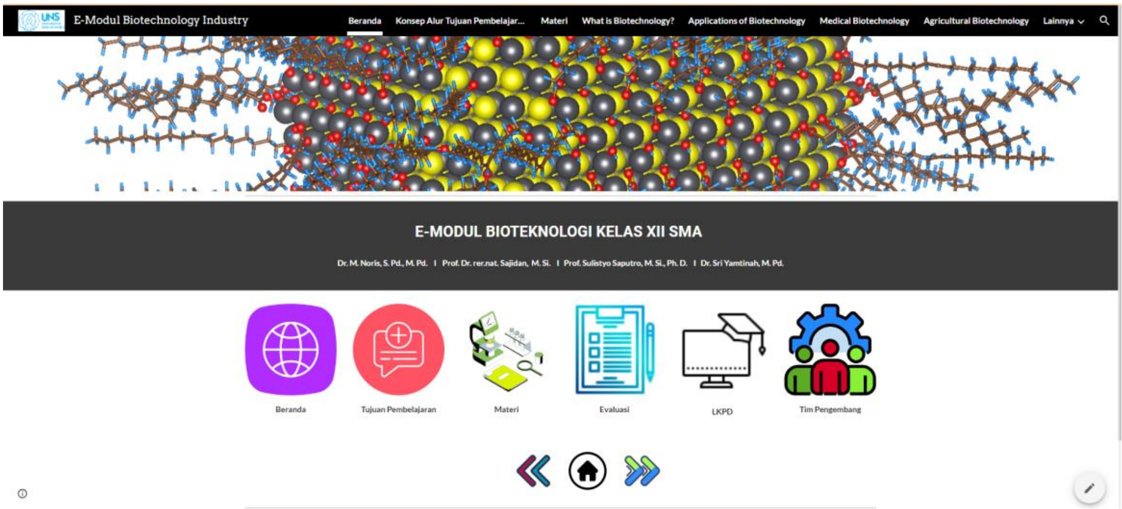

Figure 2. Front Page view of the E-Module

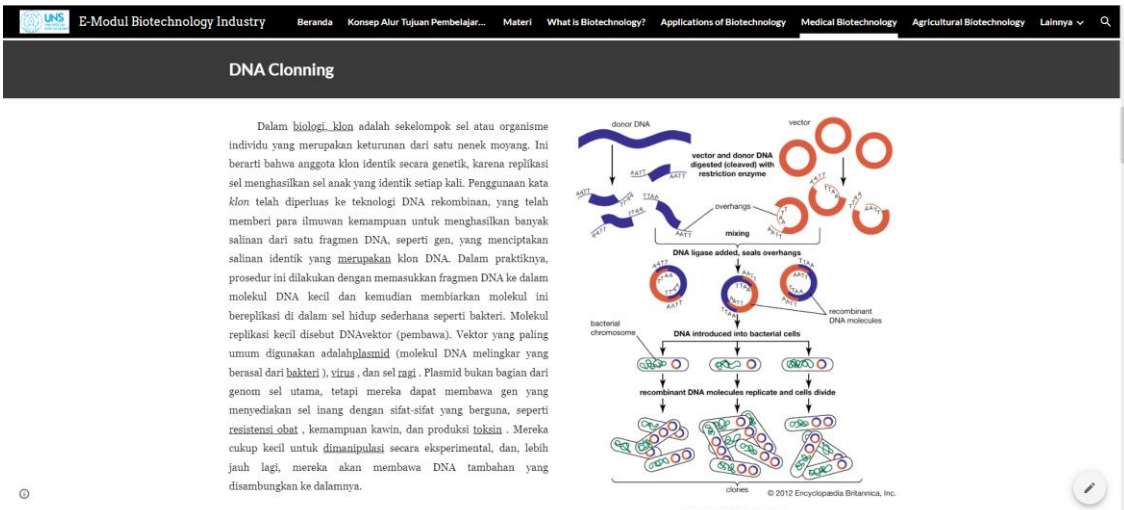

Figure 3. Display of Biotechnology Learning Materials

The developed E-Module has been integrated with the hypothetical inquiry learning model which consists of 4 main stages which include observation, manipulation, generalization, verification, and application (Wenning, 2010). The components of the module according to Irwansyah et al. (2017) are as follows: (a) Home, which is a menu that contains links and material profiles in the module, (b) Instructions for use contains guidelines on how to use the module, (c) Learning objectives are elaborated into learning indicators, (d) Learning instructions, containing an efficient explanation of how to organize learning, (e) The material page consists of material descriptions that contain concepts, (f) Process page, the aspects are images, animations, or videos that have a relationship with the material presented, and (g) The learning evaluation page contains tests that refer to the targeted learning objectives. On this page, the answer key and feedback on the results of the learning evaluation are also presented.

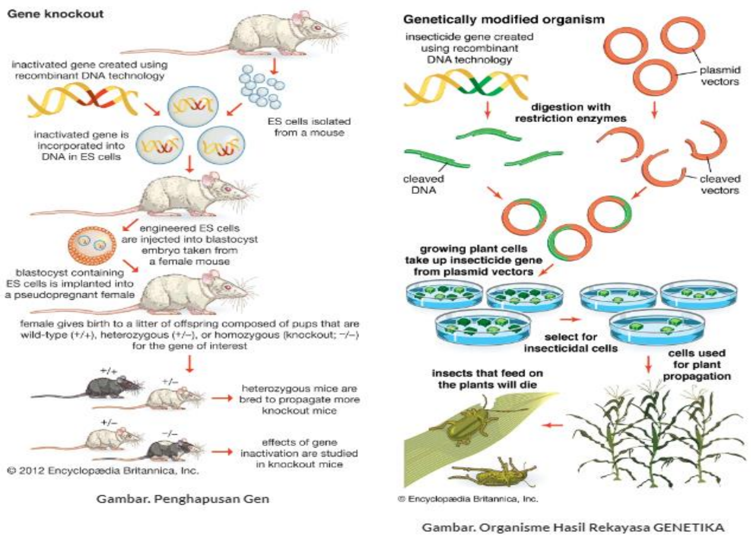

Figure 4. Biotechnology Learning Material Evaluation Display

Figure 5. Environmental Biotechnology Material on Microbiology-assisted Plastic Biodegradation

Meanwhile, the systematics of module preparation according to (Department of National Education, 2008) consists of three steps which include an opening that contains an introduction, then there is a content section, and the last is the closing section, which will be explained as follows: (a) Introduction, (b) Core, and (c) Closing. At this point, an evaluation of the created e-module is conducted, including its viability, usefulness, and efficacy using the hypothetical inquiry learning paradigm for biotechnology. The validator's evaluation of the creation of E-Modules based on hypothetical inquiry learning is presented in Table 3.

Table 3 presents the recapitulation of the feasibility values for the Hypothetical Inquiry Learning (HIL)-based e-module, as assessed through Aiken's validity index. The table includes the validity scores for four key aspects of the e-module: Media (87.13%), Material (88.96%), Language (90%), and Learning (96.34%). The scores indicate that the Media and Material aspects are considered "Worth," suggesting that they meet the necessary criteria for inclusion, while the Language and Learning aspects are deemed "Very Feasible," reflecting a high degree of suitability for educational purposes. The overall average validity score of 90.61% places the e-module in the "Very Feasible" category, demonstrating its strong potential for effective implementation in the learning process. These findings highlight the e-module's quality and readiness for use, with a particular emphasis on its learning design and language clarity.

Table 3. Recapitulation of the Feasibility Value of HIL-based E-Modules with Aikens' Validity

Aspects	Aikens Validity Calculation	
	V (%)	Description
Media	87.13	Worth
Material	88.96	Worth
Language	90	Very Feasible
Learning	96.34	Very Feasible
Average	90.61	Very Feasible

The results of the expert validator's assessment show that the e-module is feasible to use as an interactive learning media in the digital era in learning biotechnology. Furthermore, the researchers then conducted learning by implementing learning using E-Module biotechnology based on hypothetical inquiry learning on biotechnology material to improve students' critical thinking skills. Based on the results of the study, it shows that the use of biotechnology E-Modules based on Hypothetical inquiry learning is considered practical. This is indicated by the practicality value ranging from 98.32% with the practical category. The following is a recapitulation of the practicality of the E-Module based on Hypothetical inquiry learning, which is presented in Table 4.

Table 4. Recapitulation of the practicality score of HIL-based E-Modules

Aspects	Score	Description
Media	98.34	High
Material	97.87	High
Language	97.99	High
Learning	99.06	High
Average	98.32	High

The results of the descriptive statistical analysis of the E-Module based on hypothetical inquiry learning showed that the E-module was considered practical with a percentage value around 98.32% with a very practical category. While the results of the E-Module effectiveness assessment show that the biotechnology E-Module based on Hypothetical inquiry learning is considered very effective to be used to empower students' critical thinking skills. This is indicated by the Gain Score value around 95.23% with a very high category. The following are the results of the N-Gain score, which are presented in Table 5.

Table 5. Recapitulation of Gain Score value of HIL-based E-Module to improve students' critical thinking skills

Class	N-Gain Score (%)				Sig. (2-Tailed)
	Pretest	Description	Postest	Description	
Experiment	56.79	Medium	95.23	High	.000
Control	40.23	Low	69.37	Medium	

The results of the analysis show that the use of E-MODUL based on hypothetical inquiry is very effective as a learning media for biotechnology in improving students' critical thinking skills. This can be seen from the acquisition of the N-Gain Score value in the experimental class around 95.23% with a high category while before using the E-Module around 56.79% with a medium category. In addition, the use of e-modules based on hypothetical inquiry also has a significant effect on students' critical thinking skills with a Sig value. 2-Tailed value around 0.000, meaning that there is a significant influence before and after learning with E-Modul based on hypothetical inquiry learning. At this stage, researchers accommodate input and suggestions from validators to improve E-MODUL which includes aspects of media, material, language, and learning. In addition, researchers also conducted in-depth evaluations related to the limitations of developing E-Modules based on hypothetical inquiry learning. At this stage, researchers accommodate input and suggestions from validators to improve E-MODUL which includes aspects of media, material, language, and learning. In addition, researchers also conducted in-depth evaluations related to the limitations of developing E-Modules based on hypothetical inquiry learning.

Discussion

Teaching module is a learning material that is systematically designed based on a certain curriculum and packaged in the smallest learning unit and allows independent study in a certain unit of time (Herlina et al., 2022; Maksum & Purwanto, 2022; Rillero & Chen, 2019). Teaching materials in electronic form, presented systematically, equipped with images, audio, animation, video and simulations that can be used anytime and anywhere (Arantika et al., 2019). Modules make students interactive with the material presented and can present material phenomena and the process of an event that is difficult to observe directly. The module component consists of a homepage, instructions for use, learning objectives, learning instructions, material pages, process pages, and evaluation pages (Aminatun et al., 2022). Modules as teaching materials have objectives, among others, to 1) clarify and simplify the presentation of messages so that they are not too verbal; 2) overcome the limitations of time, space, and the senses of students; and 3) can be used appropriately and varied. The advantages of modules compared to printed modules are expected to increase the motivation of students in learning independently (Wardani et al., 2025).

In addition to printed modules, there are electronic modules that can be easily accessed by students with an android/laptop. Students do not have to carry books because they can access a lot of information related to learning in their spare time. The use of this e-module can optimize the use of information and communication technology by educators to support student activeness using digital technology (ICT) and students' critical thinking skills. Learning E-Modules which are then integrated with HOTS have the advantage of being able to improve students' high-level thinking skills and the formation of character as expected and help students optimize students' ICT literacy skills. E-MODUL is also another form of printed module that is only computerized digitally to be more effectively and efficiently used by teachers and students. E-MODULES that have been integrated with HOTS encourage students to play an active role in learning (Chen et al., 2017; Kuhlthau et al., 2015; Pedaste et al., 2015).

Based on the results of the study, it shows that the feasibility assessment of e-modules assessed by experts received a positive response with a percentage value of around 90.61% with a very feasible category. Because the e-module based on hypothetical inquiry learning developed has the characteristics of self-instructional, self-contained, stand alone, adaptive, and user friendly (Miftakhurrohmah et al., 2023; Noris et al., 2023). Meanwhile, according to Rosnanda (2016), the advantages of modules designed in learning activities are as follows; 1) The module is equipped with attractive images, so students will be interested in learning using the module. Modules can clarify content and add attractiveness. 2) Modules contain more specific material. 3) Modules can be used as materials for students to learn independently in class, so that students do not depend entirely on the presence of the teacher. 4) Provide opportunities for students to develop process skills.

The results of the analysis of the practicality of the e-module based on the HIL model show that the e-module is considered practical with a percentage ranging from 98.32% with a very practical category. This shows that the E-module equipped with the hypothetical inquiry model has a clear and complex instruction design in developing students' critical thinking skills. This shows that the E-module equipped with the hypothetical inquiry model has a clear and complex instruction design in developing students' critical thinking skills. Learning with hypothetical inquiry learning provides meaningful learning that can only be achieved through discovery learning where learning must be understood as an inherently communicative process (Takaya, 2008). Inquiry has stages that guide students to reconstruct new knowledge which includes observation, manipulation, generalization, verification, and application (Wenning, 2010). The observation process encourages students to carry out discovery processes. At this stage, students observe phenomena that engage their interest and elicit their responses. This response becomes a form of attention from learners to store information into short-term memory.

While the results of the analysis of the effectiveness of the E-Modul show the acquisition of the N-Gain Score value in the experimental class around 95.23% with a high category while before using the E-Modul around 56.79% with a medium category. In addition, the use of e-modules based on hypothetical inquiry also has a significant effect on students' critical thinking skills with a Sig value. 2-Tailed around 0.000, meaning that there is a significant influence before and after learning with E-Modules based on hypothetical inquiry learning. By applying the inquiry model, learning becomes learner-centered and the teacher is only a guide. By using this model, students are more active in discovering their knowledge which is oriented towards developing students' thinking and cognitive abilities (Cunningham et al., 2006; Fadzil, 2017; Hughes & Ellefson, 2013; Lee Jensen & Lawson, 2011; Peffer et al., 2015; Quitadamo et al., 2008; Saunders & Rennie, 2013).

Conclusion

The findings of this study demonstrate the effectiveness, feasibility, and practicality of the Hypothetical Inquiry Learning (HIL)-based e-module in enhancing students' critical thinking skills. The feasibility assessment, evaluated by experts, yielded a highly positive response, with a validity percentage of 90.61%, categorizing the e-module as very feasible. In terms of practicality, the practicality test result was 98.32%, indicating that the e-module is highly practical and suitable for digital learning environments. Furthermore, the effectiveness analysis revealed that the e-module significantly improved students' critical thinking abilities, with an N-Gain Score of 95.23% in the experimental class compared to 56.79% prior to using the module. Additionally, a statistical analysis (Sig. 2-Tailed = 0.000) confirmed a significant impact of the e-module on students' critical thinking skills before and after implementation. These results underscore the pedagogical potential of integrating Hypothetical Inquiry Learning with digital instructional resources, reinforcing the role of technology-enhanced learning in fostering higher-order thinking skills. This study contributes to the advancement of technology-driven education, supports the implementation of innovative pedagogical approaches, and provides a valuable digital resource for educators seeking to engage students in interactive, inquiry-based learning.

Despite its promising findings, this study is not without limitations. First, the research was conducted in a single educational setting with a limited sample size, which may affect the generalizability of the results to different educational contexts. Second, while the study measured short-term improvements in critical thinking skills, longitudinal studies are required to assess the sustainability of these cognitive gains over extended learning periods. Additionally, the study primarily focused on cognitive outcomes, leaving room for future research to explore the affective and motivational impacts of Hypothetical Inquiry-based e-modules on students. Further investigations could also examine the integration of adaptive learning technologies, such as artificial intelligence-driven personalized learning pathways, to enhance the customization and responsiveness of e-modules. Future studies should consider comparative analyses across different subject areas, educational levels, and diverse student demographics to strengthen the empirical evidence supporting HIL-based digital learning interventions.

Authors' Declaration

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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