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Development of Heyzine Flipbook-Based E-Module Integrated with *PhET*, Kahoot, and Padlet to Support Students' Scientific Literacy

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Abstract: Development of Heyzine Flipbook-Based E-Modul Integrated with PhET, Kahoot, and Padlet to Support Students' Scientific Literacy. **Objectives**: This study aims to develop an interactive e-module based on the Heyzine Flipbook platform, integrated with PhET simulations, Kahoot quizzes, and Padlet reflections. The module is designed to support students' scientific literacy, particularly on the topic of work and energy. The urgency of this research stems from the low scientific literacy performance of Indonesian students in the 2022 PISA assessment, which indicated that most students remain below the basic proficiency level in understanding science. **Methods**: This study used a Research and Development (R&D) approach with the ADDIE model, involving 32 students at SMA Negeri 1 Lhokseumawe. A one-group pretest-posttest design was applied. Data were obtained from expert validation sheets, essay-based tests, and student questionnaires. Validity and reliability were measured using Aiken's V and inter-rater agreement. Practicality was analyzed through student feedback using quartiles. N-gain analysis was used to determine posttest improvement after using the e-module. **Findings:** The developed e-module was classified as highly feasible based on expert validation, with Aiken's V scores of 0.915 for the media aspect and 0.900 for the content aspect, and inter-rater agreement values of 0.774 (media) and 0.765 (content). In terms of practicality, the e-module received very positive responses from students, with a score of 90.07%. Furthermore, the N-gain analysis yielded a score of 0.753, which falls into the high category, indicating that the e-module contributed to improving students' scientific literacy. **Conclusion**: These results indicate that the developed Heyzine Flipbook-based e-module is feasible, practical, and has the potential to support the enhancement of students' scientific literacy in 21st-century physics education.

Keywords: heyzine flipbook, e-module, science literacy, PhET simulation, kahoot, padlet.

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INTRODUCTION

Physics, a fundamental discipline in science education, is essential for fostering students' scientific literacy (Aris et al., 2024). Scientific literacy reflects an individual's ability to identify facts, apply scientific methods, and analyze as well as interpret data (Farcis, 2022). It also demands critical thinking skills to evaluate information and understand natural phenomena (Arrohman et al., 2022). In addition, scientific literacy encompasses awareness of the relevance of science to personal and social issues, reinforced by affective dimensions as the foundation for lifelong science learning (Fortus et al., 2022). According to the OECD (2019), scientific literacy entails the mastery of scientific

knowledge and skills that enable individuals to formulate questions, comprehend concepts, and formulate conclusions grounded in a critical analysis of the available evidence. The ability to integrate data and evidence to understand various scientific events is also fundamental to developing a comprehensive scientific understanding necessary for addressing 21st-century challenges (Cynthia et al., 2023; Aulia & Hardeli, 2022). Despite its critical importance, physics is often perceived by students as an abstract and difficult subject, particularly in foundational topics such as work and energy (Maghfiroh et al., 2023). These concepts, however, are essential for understanding real-world phenomena and are directly connected to global issues such as energy crises and initiatives supporting *Sustainable Development Goals* (SDGs) implementation (Annisa et al., 2023).

Although physics has the potential to strengthen scientific literacy significantly, its classroom implementation faces numerous challenges. Students' conceptual difficulties in physics reveal a disconnect between the subject's potential and the actual literacy outcomes, both nationally and internationally. According to the 2022 *Programme for International Student Assessment* (PISA), the scientific literacy of Indonesian students continues to lag behind the global average, as evidenced by the fact that merely 34% were able to attain proficiency at level 2 or above (OECD, 2023). The issue of scientific literacy in Indonesia represents a significant challenge that demands concerted efforts to address (Supriyadi et al., 2022). Field observations and interviews conducted at SMAN 1 Lhokseumawe support these findings, indicating a generally low level of scientific literacy among students. This is corroborated by the school's educational report, which categorizes scientific literacy as in need of improvement, particularly in the quality of learning strategies, with a score of 62 out of 100. One key factor contributing to this low performance is the limited use of innovative learning media and the lack of access to interactive, contextual teaching materials. As a result, students struggle to connect physics concepts to real-world contexts, highlighting the need for more instructionally appropriate media (Rahayu et al., 2022; Bakti et al., 2023; Wulandari et al., 2023). Scientific literacy, as measured by PISA, also shows a positive correlation with a country's Gross Domestic Product (GDP), reflecting broader economic activity and national development (Kumar et al., 2024). This underscores the strategic importance of scientific literacy not only in academic contexts but also in supporting socioeconomic progress.

Given the urgency of improving scientific literacy, particularly in physics education, which continues to face various limitations, there is a pressing need for innovative learning media that can bridge the gap between abstract concepts and students' real-world experiences. One promising approach is the integration of technology-based learning tools that enhance student motivation and active engagement. A potential solution is the development of digital modules in the form of interactive flipbooks. Flipbook-based e-modules refer to digital learning materials that are presented in an interactive book-like format with page-turning effects (Mukramah et al., 2023; Putri & Jayanta, 2023), while Heyzine is a digital platform that facilitates the creation of such modules by incorporating multimedia components such as videos, quizzes, and simulations to enhance interactivity and student engagement (Puspitaningrum & Witanto, 2024; Anggono & Setiawan, 2025). Prior studies have suggested that e-modules featuring interactive multimedia elements such as videos and illustrations can significantly enrich students' learning experiences and engagement, making them an effective and innovative option in technology-enhanced science education

(Yaqutunnafis & Prasetyo, 2025; Afifah & Sukasih, 2025).

The Heyzine Flipbook platform enables the presentation of engaging content using multimedia features such as videos, simulations, and quizzes, which help students better visualize abstract physics concepts (Yulyanti et al., 2022; Kamza et al., 2023). However, using flipbooks alone is insufficient to foster meaningful scientific literacy. Several previous studies have developed flipbook-based e-modules and demonstrated positive results in improving student learning outcomes and perceptions (Roemintoyo & Budiarto, 2021; Suyasa, 2021; Mukramah et al., 2023). However, these innovations remain limited as most of them only integrate a single type of supporting media, such as text or comics, without involving other interactive elements such as simulations or gamification (Mukramah et al., 2023). Another study has also developed a flipbook-based e-book integrated with PhET simulations to improve students' communication skills, but this approach still focuses on the cognitive aspect without involving reflective learning strategies or gamification that could enhance overall student engagement (Ulfa et al., 2024). Similarly, the interactive flipbook-based e-module developed by Mahendri et al. (2022) only integrates instructional videos and online quizzes, yet does not involve other interactive platforms such as simulations, gamification, or collaborative reflection spaces that could support more comprehensive learning. As a result, students' learning experiences have not fully addressed the cognitive, affective, and social dimensions. This indicates a research gap that needs to be addressed through the development of more holistic and integrated digital learning media. Therefore, the proposed Heyzine Flipbook-based e-module incorporates a problem-based learning approach, contextualized real-world issues, and the integration of three supporting platforms: (1) PhET simulations, which have been proven through previous research to strengthen students' understanding of physics concepts interactively and promote the development of scientific skills such as observation, data interpretation, and hypothesis testing (Halim et al., 2021; Olugbade et al., 2024; Diab et al., 2024); (2) Kahoot, a game-based formative assessment tool that enhances student engagement and reinforces learning through retrieval practice, has been shown in previous studies to contribute significantly to long-term scientific literacy (Wang & Tahir, 2020; Zhang & Yu, 2021); and (3) Padlet, a collaborative platform that facilitates student discussion, reflection, and evidence-based scientific communication (Zainuddin et al., 2020).

The integration of PhET, Kahoot, and Padlet platforms into the Heyzine Flipbook-based e-module is based on the principles of complementary learning theories, thus creating a holistic learning ecosystem that supports the enhancement of students' scientific literacy. PhET is used as an interactive simulation medium that refers to Cognitive Load Theory, which emphasizes the importance of managing students' cognitive load in understanding abstract concepts through effective visualization and interactivity. This simulation allows students to process information visually and kinesthetically, thereby strengthening their conceptual schemes with a more balanced cognitive load. Research shows that interactive technology-based media, such as simulations or virtual reality, can reduce cognitive load and significantly improve learning performance (Haryana et al., 2022). In addition, educational technologies like PhET are designed to present complex information by minimizing short-term memory workload, thereby supporting more efficient learning (Sweller et al., 2020).

Meanwhile, the use of Kahoot as a game-based interactive quiz platform is based on the

principle of Gamification in Education, which refers to the use of game elements (such as points, competition, and rewards) to increase motivation, engagement, and positive competitiveness in learning. Kahoot not only functions as an evaluation tool but also as a stimulus to trigger learning interest through a fun and competitive approach. Research shows that Kahoot! can significantly improve students' positive attitudes toward subjects and is perceived as enjoyable in the learning process (Öden et al., 2021). Moreover, its longer use can also develop essential skills such as attention, creativity, critical thinking, and self-directed learning (Aibar et al., 2024).

Padlet, on the other hand, is integrated as a collaborative reflection space that supports Social Constructivist-based learning, in which students build understanding through social interaction, discussion, and idea exchange. Through Padlet, students can upload their thoughts, respond to their peers' opinions, and contribute to a participatory and open learning environment. Constructivist principles in technology-based learning, such as interactive digital platforms, enable unlimited social interaction and authentic, collaborative learning experiences (Yakar et al., 2020). In addition, online learning that applies a social constructivist approach has been proven to enhance students' reflective understanding and their ability to solve problems collaboratively (Barak & Green, 2021). These three platforms, when used synergistically, form a digital learning ecosystem that is not only interactive and enjoyable but also cognitively deep and socially reflective. This integration is believed to strengthen students' overall learning experiences in terms of knowledge, critical thinking skills, and collaboration.

Therefore, this study aims to evaluate the feasibility of a Heyzine Flipbook-based e-module integrated with PhET, Kahoot, and Padlet for teaching the topic of work and energy in senior high school physics. Specifically, this research seeks to (1) determine the feasibility of the developed e-module, (2) analyze users' responses to the e-module, and (3) assess the influence of the e-module implementation on students' scientific literacy skills. The findings are expected to contribute to the development of engaging, pedagogically appropriate, and contextually relevant digital learning media that align with the demands of 21st-century education.

METHOD

Participants

This study was conducted at SMA Negeri 1 Lhokseumawe, with the research population consisting of all Grade XI students, totaling 342 students. This broad population includes students from various grade levels, representing diverse academic backgrounds and varying levels of competence in the context of science learning. Sampling was conducted purposively by considering characteristics relevant to the research objectives. The selected sample consisted of 32 students from class XI-2, considered representative for examining the feasibility and initial potential of the developed e-module in encouraging the improvement of scientific literacy. The selection of this class also took into account the readiness of digital infrastructure, active student participation, as well as the availability of time and support from subject teachers. These findings are positioned as preliminary results, which are expected to serve as a foundation for further research using a more rigorous design and involving control groups.

Research Design and Procedures

This study employed a quantitative approach with a Research and Development (R&D) design that adapted the ADDIE model as a systematic framework. This model was chosen because it provides a structured framework for producing learning products that are valid, practical, and it allows researchers to

design, develop, and evaluate the e-module comprehensively (Rizal et al., 2021; Zou et al., 2024; Adeoye et al., 2024). ADDIE consists of five core stages: Analysis, Design, Development, Implementation, and Evaluation. In the context of this study, the ADDIE model was applied to develop an interactive e-module based on Heyzine Flipbook integrated with PhET simulations, interactive Kahoot quizzes, and Padlet as a reflective medium. Each stage of this model functions to ensure content validity, practical usability, and the contribution of the e-module to improving students' scientific literacy.

The research procedure began with the Analysis stage, which included curriculum review, identification of learning needs from both students and teachers, and analysis of the readiness of supporting facilities and infrastructure at the school. The results of this analysis served as the basis for designing the structure and content of the e-module, tailored to the characteristics of students and the learning needs of physics at the senior high school level. The Design stage focused on constructing the content framework and layout of the e-module, as well as integrating multimedia features and interactivity. This design was intended to facilitate students in understanding abstract concepts contextually through a constructivist approach that enhances active engagement and meaningful learning experiences.

At the Design and Development stages, constructivist principles were implemented by designing learning activities that actively engaged students in the construction of knowledge through exploration, reflection, and collaboration. The e-module was structured using a problem-based learning approach, where each subtopic begins with a contextual problem relevant to students' daily experiences. For instance, in the topic of "Work and Energy," students are guided to analyze an energy transformation scenario involving skateboarding in a park, which then serves as a foundation for exploring the underlying concepts using PhET simulations. The sequence of student activities while interacting with PhET simulations begins with open-ended exploration, followed by guiding questions, and a task to collect and analyze virtual data in order to respond to the initial problem. These activities are supported by instructional scaffolds that help students interpret relationships among variables, identify emerging patterns, and formulate scientific conclusions. Reflective discussions are facilitated using the Padlet platform, where students are required to post their analysis or responses and provide feedback on their peers' contributions. To support this activity, a discussion rubric is provided, evaluating aspects such as argument quality, relevance of content, and the ability to pose follow-up questions. To clarify the alignment between the digital tools employed, the corresponding learning activities, Moreover, the targeted indicators of scientific literacy the mapping is summarized in Table 1 below.

Table 1. Mapping of digital features, learning activities, scientific literacy indicators

	Learning Activities	**Scientific Literacy Indicators**	**Assessment Aspects**
PhET Simulation	Independent exploration through interactive simulations, analysis of variable relations, and conclusion drawing	Interpreting data and scientific evidence; Explaining scientific phenomena.	Conceptual understanding, accuracy of data interpretation, and logical conclusion drawing
Kahoot	Game-format quiz after investigation as learning feedback	Explaining scientific phenomena	Accuracy of answers, response time, and active participation

Padlet	Uploading analysis results and engaging in open and reflective peer discussions	Evaluating and designing scientific investigations; Explaining phenomena	The rubric includes: argument quality, relevance of responses, and the ability to provide reflective feedback

During the Development stage, the e-module was developed based on the previously constructed design blueprint. The resulting e-module was then validated by subject matter experts and media experts to ensure content quality and visual presentation. After revisions based on the validators' feedback, the learning product was implemented in a limited classroom setting as part of the Implementation stage. At this stage, the e-module was directly used in the learning process to assess its applicability and user response. Finally, the evaluation stage was conducted to assess the contribution of the e-module to the development of students' scientific literacy, while also evaluating the appeal and practicality of the product through user feedback and student learning outcomes. This systematic approach allowed researchers to develop a learning product that is not only innovative but also relevant to the needs of 21st-century education. The entire research process, encompassing the stages of Analysis, Design, Development, Implementation, and Evaluation, was conducted over approximately one year.

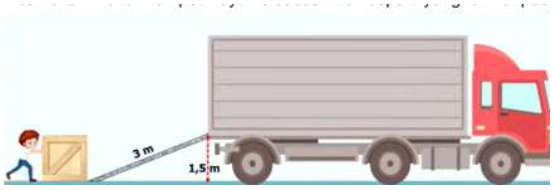
Instruments

The instruments used in this study were designed to support the processes of validation, implementation, and evaluation of the contribution of the Heyzine Flipbook-based e-module in supporting physics learning. To ensure the validity of the developed product, validation sheets were utilized and categorized into two types: (1) content validation sheets and (2) media validation sheets. The content validation sheet encompasses aspects of content substance, affective considerations, and pedagogical approach, which together assess the appropriateness of the developed learning material (Mukramah et al., 2023). It covers indicators related to the accuracy and relevance of the content, as well as its alignment with learning objectives and scientific concepts. Meanwhile, the media validation sheet includes supporting information, user interface, information navigation, and resilience, which comprehensively evaluate the media's quality in terms of the completeness of supporting information, clarity of presentation, ease of navigation, and the media's robustness under various usage conditions (Mukramah et al., 2023). Both validation sheets were distributed to experts in order to obtain feedback prior to the implementation stage.

The measurement of students' improvement in scientific literacy was conducted using test instruments in the form of pre-tests and post-tests, developed based on the scientific literacy indicators from OECD (2019), which include the ability to explain phenomena scientifically, evaluate and design scientific investigations, and interpret data and scientific evidence. The test employed open-ended questions centered on real-life scientific issues or phenomena. These questions were initially validated by subject matter experts and subsequently piloted with a limited number of students to assess their clarity, relevance, and effectiveness. The pre-test and post-test data were analyzed using the normalized gain (N-gain) formula to quantitatively assess the contribution of the e-module to the development of students' scientific literacy. The following attachment presents each type of question categorized according to scientific literacy indicators, along with the corresponding scoring rubric.

Table 2. Sample questions based on indicators and scoring guidelines

Indicator	Question Item	Scoring Guidelines
Explaining Scientific Phenomena	**Lifting Super Heavy Loads Like Superheroes** *Liputan6.com, Jakarta*. Before the invention of heavy machinery, humans used to lift heavy objects with their bare hands. According to research, the maximum safe weight a human can lift is only 23–25 kg. Nevertheless, some people have managed to lift objects weighing 6–7 times their body weight. Several individuals have attempted to lift super-heavy objects, making them appear like superheroes. Although seemingly impossible, images of people lifting weighty items are fascinating. Massive boulders, trees, and even cars have been lifted by these extraordinary individuals, showcasing superhuman strength.  Interestingly, some of these people are not athletes but laborers performing their daily tasks. Their photos have gone viral on social media. *Source: https://www.liputan6.com/hot/read/5376496/6-potret-orang-angkat-benda-super-berat-ini-bak-superhero-bikin-takjub* Based on the text and illustrations above, explain the concept of work done by these individuals when holding a load, both while stationary and while walking!	1. Complete and accurate explanation, covering two key situations: stationary and walking, using the concept of work correctly and consistently (Score 4). 2. Complete explanation but with minor shortcomings; both situations mentioned (stationary and walking), but one lacks detail (Score 3). 3. Mostly correct explanation but with conceptual errors or unclear reasoning. For example, only one situation is discussed correctly, or both are discussed with inaccurate concepts (Score 2). 4. Very brief and mostly or entirely incorrect explanation (Score 1). 5. No answer, irrelevant response, or completely incorrect answer (Score 0).
Interpreting Scientific Data and Evidence	Two men are pushing a broken-down car on the roadside with forces of 200 N and 150 N, respectively. As the car does not move, some friends join in to help with the following forces. There is a friction force of 400 N between the car's tires and the road surface. If the car needs to be moved 10 meters and requires 4500 joules of work, identify the three most suitable people to assist the two	1. Correctly identifies three people, calculates total force accurately (including the original two plus the additional three), and clearly explains using the concepts of total force and friction (Score 4). 2. Partially correct selection

<table>
<tr>
<td>Interpreting Scientific Data and Evidence</td>
<td>men so the car can move!
<table><tr><th>No</th><th>Name</th><th>Forces</th></tr><tr><td>1</td><td>Ahmad</td><td>200 N</td></tr><tr><td>2</td><td>Ali</td><td>180 N</td></tr><tr><td>3</td><td>Hafizh</td><td>100 N</td></tr><tr><td>4</td><td>Usman</td><td>150 N</td></tr><tr><td>5</td><td>Akbar</td><td>220 N</td></tr></table></td>
<td>(e.g., two correct, one incorrect) with sufficiently clear explanation (Score 3).
3. Selects three people without accurate calculation or provides a partially correct answer with inadequate explanation of the concept (Score 2).
4. Random selection without clear reasoning or only a partial response (Score 1).
5. No answer, irrelevant response, or completely incorrect answer (Score 0).</td>
</tr>
<tr>
<td>Evaluating and Designing Scientific Investigations</td>
<td>Lifting items to a higher place can be challenging, especially with heavy items. One common solution is using a plank as an inclined plane. Ikhsan wants to load a wooden crate into a truck using a plank as an inclined plane. His maximum pushing force is 400 N, while the weight of the crate is 1200 N. Ignore friction.
 

Here are several attempts Ikhsan made to solve the problem,
1. Ask a friend for help so that each person exerts a maximum of 200 N.
2. Replace the plank with one 4.5 meters long.
3. Replace the plank with a new one that is 1 meter longer than the original.
4. Assign the task to someone else with</td>
<td>1. Correctly selects the best solution and explains the reasoning clearly. Provides a complete investigation design: tools, steps, variables, and clear objectives (Score 4).
2. Selects the correct solution with a general reason. The investigation plan is present but incomplete or unclear (Score 3).
3. Chooses a solution or creates a plan, but the explanation or design is inaccurate or incomplete (Score 2).
4. Very brief or incorrect answer, only mentions the solution or plan without a clear explanation (Score 1).
5. No answer or irrelevant response (Score 0).</td>
</tr>
</table>

In addition to learning outcomes assessment, this study also utilized a student response questionnaire to evaluate the practicality and appeal of the e-module. The questionnaire was constructed using a four-point Likert scale, covering four key aspects: visual design, content feasibility, navigation ease, and contribution to learning motivation. This instrument was used to capture students' perceptions as direct users regarding the effectiveness of the media, while also providing feedback for potential future development. Overall, all instruments underwent

content validity testing using Aiken's V and inter-rater reliability testing using the Intraclass Correlation Coefficient (ICC), to ensure measurement accuracy and consistency throughout the research process (Nurjanah et al., 2023; Tong et al., 2020).

Data Analysis

The data analysis process in this study was conducted quantitatively with the main objective of evaluating the validity, practicality, and the contribution of the e-module to students' scientific literacy. The analysis was carried out in stages according to the ADDIE model phases. In the initial stage, the content validity of the e-module was evaluated using Aiken's V coefficient, which measures the level of expert agreement regarding the relevance, clarity, and appropriateness of the content and module layout. The Aiken's V score obtained served as the basis for revising and refining the product before classroom implementation. The validity of both the media and content validation instruments was analyzed using Aiken's V coefficient, calculated through the following equation $,V = \frac{\sum s}{n\,(c-1)}$ In this formula, V represents the index of expert agreement concerning the analysis of each item; *s* denotes the score assigned by each validator after deducting the minimum possible score; *n* refers to the total number of validators, which in this study involved three experts; and *c* is the number of response categories available to the experts (Mukramah et al., 2023). Next, to assess inter-rater agreement consistency, the Intraclass Correlation Coefficient (ICC) was used. This statistic ensures that the evaluation of module feasibility, both in terms of content and media, has high inter-rater reliability. ICC provides an objective measure of rating stability and serves as an indicator of data consistency during the validation phase (Landers, 2023).

To examine the impact of the e-module on students' scientific literacy, a dedicated assessment instrument was employed. The comparison of students' performance before and after the intervention was analyzed using normalized gain (N-gain) analysis (Fadaei, 2019), processed with the assistance of SPSS software. The N-gain score was determined through the formula, $N - gain = \frac{posttest - pretest}{skor\ maksimum - pretest}$

Where *posttest* represents the score attained after the e-module implementation, *pretest* is the score achieved prior to the intervention, and *maximum score* indicates the highest possible score achievable on the test. This approach was used to assess the improvement in students' scientific literacy after the intervention. N-gain values were classified into low, medium, or high categories to evaluate the extent to which the e-module impacted students' understanding. This analysis was comparative and aimed to demonstrate differences in learning outcomes before and after the use of the e-module in the context of physics learning.

The practicality of the e-module was analyzed through a student response questionnaire developed using a four-point Likert scale. The students' responses were processed descriptively using percentage and score index calculations to examine trends in students' perceptions of design, content, comprehensibility, and media appeal. The data were then categorized using quartile distribution (Q1, Q2, Q3) to provide a sharper interpretation of the practicality level based on direct user perceptions (Cooksey, 2020).

■ RESULT AND DISCUSSION

Analysis Stage

As the basis for designing the Heyzine Flipbook-based e-module integrated with PhET Simulation, Kahoot, and Padlet, an initial review was conducted on three aspects: (1) identification of students' characteristics and learning needs, (2) teachers' expectations and challenges in the learning process, and (3) the availability of supporting infrastructure in the school environment. The analysis results of student

characteristics and needs revealed fundamental challenges in science learning, particularly related to the ability to understand abstract concepts. Students often experience significant difficulties in grasping abstract concepts such as work and energy due to conventional learning approaches that tend to rely on textual explanations and static examples, without visualizing the causal relationships between physics variables (Maghfirah et al., 2023). The lack of learning resources that connect theory to real-world phenomena, such as energy efficiency in vehicles or mechanical energy transformations in students' surroundings, exacerbates this limitation (Nurmila et al., 2023). Presenting concepts in relevant contexts and utilizing interactive visualizations are essential foundations for successful science learning, creating meaningful learning experiences that help students develop mental constructions of abstract concepts (OECD, 2022). Without these elements, students are more likely to memorize formulas without a deep understanding, which results in poor conceptual comprehension and a limited ability to integrate scientific concepts in explaining everyday scientific phenomena (Banda & Nzabahimana, 2023). These findings are supported by Warlinda et al. (2022), who found that the integration of media in learning significantly contributes to improving students' scientific literacy skills.

The analysis of teachers' needs in the context of science learning reveals a strong motivation to present teaching materials that respond to the limitations of conventional approaches while addressing the complexities of strengthening scientific literacy in the classroom. Based on interviews with teachers, it was found that learning through conventional methods is less effective in fostering students' scientific literacy skills. Indicators of scientific literacy, such as interpreting scientific evidence and data, as well as designing investigations, cannot be accommodated through traditional teaching methods due to the lack of opportunities for independent exploration (Warlinda et al., 2022). From the students' perspective, the availability of teaching materials and media that can provide immediate feedback and simplify abstract concepts through visual presentation is crucial. This finding is supported by Mashudi et al. (2024), who stated that learning with interactive e-modules can increase students' average test scores by 40.6 points from their initial scores.

The analysis of facilities and infrastructure conditions shows that the school already has adequate support to facilitate digital-based learning. Most students own personal devices such as smartphones or laptops, enabling independent access to Heyzine Flipbook-based e-modules and interactive platforms. In addition, the school is equipped with a computer laboratory with stable internet access and projectors, although their use is still scheduled on a rotating basis since they are not permanently installed in every classroom. In terms of teacher readiness, the use of the Kahoot platform is not new and is often utilized in the learning process. However, the use of Padlet and PhET virtual simulations remains limited due to the lack of specific training that supports the integration of both tools in science learning. This condition indicates that although the infrastructure and supporting networks are already available, the optimal implementation of interactive e-modules still requires support in the form of teacher capacity-building through training and effective management of device utilization at the school level (Diab et al., 2024).

The analysis phase in this study not only reveals what students and teachers need to optimize science learning but also, through the ADDIE stages, integrates PhET virtual simulations that facilitate students' understanding of abstract concepts (Diab et al., 2024; Olugbade et al., 2024). PhET is used as an interactive simulation medium that refers to Cognitive Load Theory, which emphasizes the importance of managing students' cognitive load in understanding abstract

concepts through effective visualization and interactivity. This simulation allows students to process information visually and kinesthetically, thereby supporting the development of their conceptual understanding with a more balanced cognitive load. Previous studies suggest that technology-based media, such as simulations or virtual environments, can help reduce cognitive load and assist students in grasping abstract scientific phenomena (Haryana et al., 2022). In addition, educational technologies like PhET are designed to present complex information by minimizing the demand on working memory, which facilitates more manageable cognitive processing (Sweller et al., 2020). The selection of PhET simulations in this study is based on their recognized ability to dynamically visualize abstract physics concepts, thereby assisting students in constructing causal understanding through self-guided exploration (Pamungkas et al., 2024; Diab et al., 2024). Furthermore, according to the Cognitive Theory of Multimedia Learning (Mayer, 2024), PhET simulations engage students through dual channels visual and auditory which supports the construction of coherent mental models. This dual processing reduces extraneous cognitive load and fosters meaningful learning. By actively manipulating variables, students are encouraged to reflect, predict, and revise their understanding, thus reinforcing conceptual change and promoting internalization of abstract concepts such as energy

the Kahoot application to enhance student engagement, foster positive perceptions, and improve final scores (Wang & Tahir, 2020; Zhang & Yu, 2021; Garza et al., 2023), as well as learning reflection through Padlet to create more meaningful learning experiences and has been proven to improve students' understanding by intensifying engagement (Shuker & Burton, 2021; Baidoo et al., 2022). The findings from this analysis phase strengthen the argument that students' conceptual gaps in abstract physics are systemic, not merely a matter of low motivation. The lack of visual and contextual representation in conventional learning creates a cognitive gap, which can be addressed in part through instructional design that combines multimedia learning principles with a constructivist approach (Clark & Mayer, 2023; Sun et al., 2025). Multimedia technology has been proven to be an effective strategy for bridging gaps in providing unlimited access to quality education and improving student performance (Abdulrahaman et al., 2020).

Padlet is integrated as a digital reflection space that supports social constructivist-based learning, where understanding is built through interaction, discussion, and the exchange of ideas. Through features such as text, image, and multimedia uploads, students can respond to each other's thoughts, contribute openly, and co-construct shared understanding. In this context, Padlet not only facilitates the sharing of findings but also encourages students to interpret data and construct meaning together collaboratively. This aligns with Mayer's (2024) Cognitive Theory of Multimedia Learning, which emphasizes that meaningful learning occurs when learners actively select relevant information, organize it into coherent verbal and visual structures, and integrate it with prior knowledge stored in long-term memory. Padlet's multimodal interface promotes information processing through both verbal and visual channels, reinforcing key cognitive processes such as mental modeling and conceptual understanding. Thus, Padlet not only creates a participatory and collaborative learning environment but also enhances cognitive engagement and supports reflective and collective meaning-making (Yakar et al., 2020; Barak & Green, 2021). Padlet serves as a collaborative digital board that facilitates asynchronous and synchronous discussion, allowing students to share reflections, respond to peers, and build upon each other's ideas in a structured environment. Grounded in the principles of social

constructivism, Padlet enables dialogic learning where meaning is co-constructed through peer interaction and feedback. This platform supports low-barrier participation, encourages equitable contribution, and helps surface misconceptions that can be addressed collectively. By enabling students to visualize and organize each other's thinking, Padlet fosters deeper conceptual engagement and enhances collective meaning-making, which is essential in building scientific literacy and reflective thinking (Shuker & Burton, 2021; Mehta et al., 2021; Saleem et al., 2021).

Design Stage

The development of this Heyzine Flipbook-based e-module aims to strengthen students' scientific literacy through the integration of interactive educational technology. By combining visual content, PhET simulations, interactive quizzes, and collaborative discussions, the module is designed to support students' conceptual understanding in physics. The following figure shows an example of the initial design of the developed e-module as part of this innovative approach to science education.

Figure 1. Phase of designing the initial heyzine flipbook e-module

The Heyzine Flipbook-based e-module is designed to enhance scientific literacy through the integration of three core interactive features: PhET simulations, Kahoot quizzes, and collaborative reflections via Padlet. The selection of PhET simulations is grounded in their proven ability to dynamically visualize abstract physics concepts, thereby reducing students' cognitive load (Pamungkas et al., 2024) and facilitating causal understanding through self-guided exploration (Diab et al., 2024). Kahoot quizzes are incorporated for their capacity to provide immediate feedback, which reinforces metacognitive reflection and has been empirically shown to significantly improve conceptual understanding and content retention at the reasoning level (Mdlalose et al., 2022; Jankoviæ et al., 2024). Meanwhile, Padlet is employed based on the principles of social constructivism (Saleem et al., 2021), creating a collaborative discussion space to deepen students' internalization of scientific concepts (Shuker & Burton, 2021). This combination establishes a cycle of exploratory learning through simulation, discussion, and reflective activities—aligned with the findings of Maghfirah et al. (2023), which reported a 37% increase in student engagement driven by interactivity. The content structure of the e-module is methodically organized, progressing from foundational concepts to more complex applications, in order to prevent hierarchical misconceptions, such as

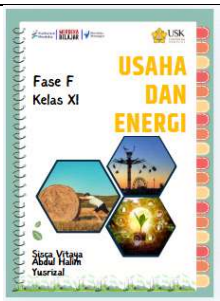
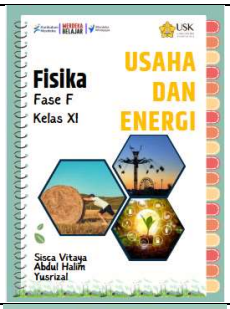
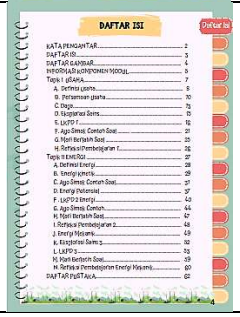
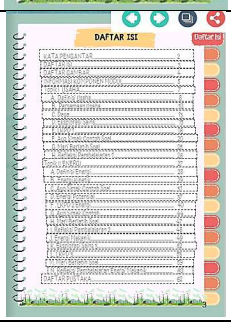
misinterpreting the definition of work, which can lead to flawed analyses of mechanical energy (Prafitasari & Candrasari, 2024). This progressive presentation also incorporates contextualized problems to ensure that students are able to transfer knowledge to real-world situations, in accordance with the OECD (2019) scientific literacy framework.

The e-module's instructional design explicitly addresses three key indicators of scientific literacy: (1) the ability to explain scientific phenomena, supported through PhET simulations and contextual videos that relate theoretical concepts to real-world energy crises, consistent with constructivist principles (Banda & Nzabahimana, 2023); (2) data interpretation skills, developed through interactive questions based on authentic datasets, which foster pattern recognition and scientific reasoning (Yuliana et al., 2023); and (3) the ability to design scientific investigations, cultivated via virtual PhET explorations that promote independent inquiry.

Development Stage

As a follow-up to the validation results conducted by subject matter and media experts, several refinements were made to the e-module in key aspects to enhance its quality and improve the user experience.

Table 3. Revised E-Module outcomes incorporating validator feedback

Validator Suggestions	Before Revision	After Revision
Inclusion of subject titles on the first page		
Insertion of explanatory information in each section		
Addition of a hyperlinked		

Replacing illustrations inaccurately		
Adding navigation to access the last page and return to the initial page		

The feedback provided by the validators reflects the necessity for an e-module that is not only valid in terms of content but also functional and visually communicative. This aligns with the principles of development research, which emphasize the critical role of expert input in ensuring the feasibility, practicality, and instructional relevance of digital learning products. (Cynthia et al., 2023). Several key recommendations were implemented, including: (1) the addition of a hyperlinked table of contents to serve as an interactive navigation feature, facilitating seamless transitions between sections; (2) the inclusion of the subject title on the opening page to clarify the identity of the learning material; (3) the insertion of explanatory notes in each section of the e-module to provide a more comprehensive context; (4) the replacement of illustrations to accurately depict the concept of work involving force in the opposite direction of displacement; and (5) the integration of navigation buttons that lead directly to the first and last pages to improve usability efficiency. These refinements also addressed aesthetic elements and fostered a more cohesive integration of digital media, thereby aiming to enhance conceptual understanding while providing a more engaging and user-friendly learning experience for students.

Table 4. Validity and reliability of the E-Module feasibility

Category	*Indeks Aiken*	Validity Standard	*Inter-Rater Agreement* (IRA)	Reliability Standard
Media	0.915	Valid	0.774	Good Reliability
Content	0.900	Valid	0.765	Good Reliability

The validation results revealed that the media component achieved an Aiken's V index of 0.915, while the content component scored 0.900, both of which fall within the valid category (Nurjanah et al., 2023). The corresponding Inter-Rater Agreement (IRA) values were 0.774 for media and 0.765 for content, indicating a high level of consistency among evaluators and

classified as having good reliability (Gwet, 2014; Landers, 2023). These results provide strong evidence that the developed media and content meet the criteria for content validity and presentation quality, as recommended by established instructional validation standards (Listiana et al., 2023). Consequently, the product is considered suitable for implementation in subsequent stages. However, some differences in expert perspectives still emerged, particularly regarding the complexity of the material for high school students. The slight variance between the validity and reliability scores of the media and content suggests that certain elements, especially the depth of content and the sequence of presentation, still require refinement. This finding aligns with the study by Maghfirah et al. (2023), which underscores the need to balance conceptual depth with students' cognitive capacity through contextually relevant learning. Moreover, this is supported by Al-Sultan et al. (2021), who emphasize that the logical sequence and interconnection of concepts in educational materials not only facilitate conceptual understanding but are also essential for fostering awareness of the relationship between science, technology, and society. These insights serve as a basis for targeted improvements, recognizing that the quality of content depth and sequencing significantly influences the instructional clarity and pedagogical value of learning materials (Munna & Kalam, 2021; Mejía & Kyriakides, 2022). Therefore, while the media and content have demonstrated overall validity and reliability, the suggestions provided by the validators should be carefully considered for further refinement, particularly in enhancing the systematic flow and conceptual coherence to optimize the learning experience.

The validation of the practicality instrument, in the form of a user response questionnaire, yielded an Aiken's V index of 0.952, indicating a very high level of validity. Additionally, the Inter-Rater Agreement analysis using Cohen's Kappa produced a score of 0.768, which falls within the category of *excellent agreement beyond chance*. This demonstrates a strong level of agreement among raters that is not attributable to random chance. These findings confirm that the instrument possesses sufficient reliability and construct validity to accurately assess user responses (Ananda & Usmeldi, 2023). Nevertheless, the potential for interpretive bias among users remains a consideration. Although Cohen's Kappa is a robust measure, it does not eliminate subjectivity in judgment (Aldilla & Usmeldi, 2024). Therefore, during the implementation phase, it is essential to provide users with clear and structured guidelines for completing the questionnaire. Doing so will help maintain the consistency and clarity of responses (Ravista et al., 2021).

Implementation Stage

The implementation phase of this study involved integrating the Heyzine Flipbook-based e-module into classroom learning, wherein students participated in interactive activities designed to align with the module's pedagogical framework. These activities incorporated simulations, quizzes, and collaborative discussions, all of which aimed to foster active engagement and deepen conceptual understanding of scientific concepts. To assess the contribution of the e-module to the development of scientific literacy, a pretest and posttest were administered to students. The analysis revealed a significant improvement in students' competencies across the core components of scientific literacy: (1) explaining scientific phenomena, (2) interpreting scientific data and evidence, and (3) evaluating and designing investigations (OECD, 2019). Figure 2 provides a visual representation of the average pretest and posttest scores for each indicator, highlighting the extent of students' progress following the intervention.

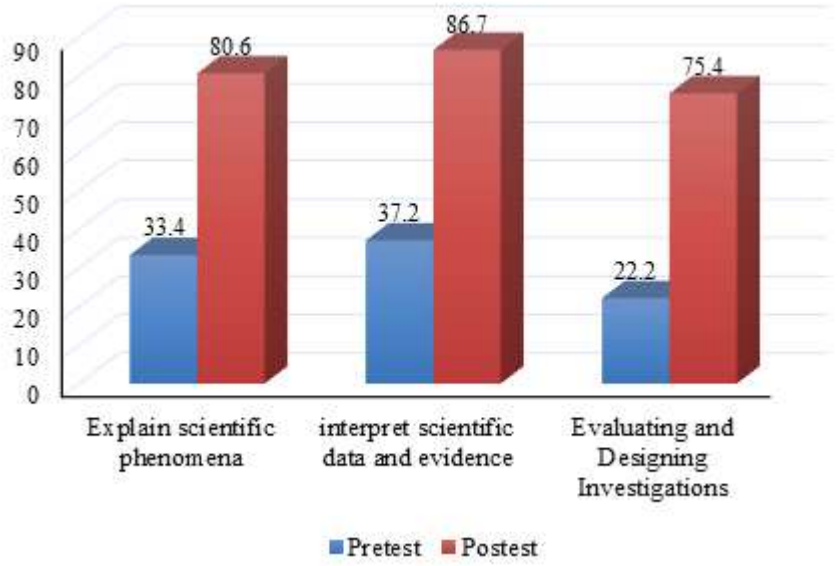


Figure 2. Mean pretest-posttest score comparison

The results of the N-gain analysis show an increase in students' scientific literacy skills, with a score of 0.753 categorized as high, indicating the potential contribution of the e-module to the learning process (Mukramah et al., 2023). This score suggests that the e-module has the potential to support learning, as reflected in individual N-gain values ranging from 0.56 to 1.00, demonstrating that all students experienced moderate to high levels of improvement in their scientific literacy. These findings are consistent with previous research, which suggests that the integration of digital technology in education not only accelerates digital transformation in schools but also enhances science learning by increasing motivation, simplifying assessments, broadening content coverage, and deepening conceptual understanding and analytical skills (Walan, 2020; Timotheou et al., 2023). The overall high N-gain score further suggests that interactive, content-based e-modules can serve as an innovative approach that facilitates the development of students' scientific literacy and has the potential to support more meaningful science learning. This is in line with earlier studies that reported significant improvements in elementary school students' scientific literacy following the implementation of interactive e-modules (Ismaniati & Iskhamdhanah, 2023).

Based on the three tested scientific literacy indicators, the ability to interpret scientific data and evidence recorded the highest N-Gain score (0.812), followed by the ability to explain scientific phenomena (0.762), and the capacity to evaluate and design investigations (0.699). Based on the analysis results, the indicator of *evaluating and designing investigations* showed the lowest gain compared to other scientific literacy indicators. This low achievement is likely due to the suboptimal design of e-module activities in

Table 5. N-gain pretest and posttest results

Descriptive Statistics	N	Minimum	Maximum	Mean	Std Deviation	Kategori
Ngain_score	32	.56	1.00	0.7531	.10596	Tinggi (Signifikan)
Ngain_persen	32	56.10	100.00	75.3077	10.59570	
Valid N (listwise)	32					

stimulating students' investigative skills. One of the main weaknesses lies in the science exploration feature, which only presents informative articles related to everyday issues such as energy shortages or renewable energy. Although the content adds to students' knowledge, it lacks follow-up activities that actively engage them in scientific practices, such as designing simple experiments or conducting basic observations, which are essential for developing investigative skills.

The superior performance in data interpretation can be partly attributed to the data visualization tools integrated into the e-module, such as graphs and simulations, which simplified students' analysis of complex information. A study by the City College of New York demonstrated that PhET interactive simulations significantly enhance students' conceptual grasp of abstract topics and cultivate positive attitudes toward science learning. These concepts are often challenging due to their microscopic nature and intricate visual representations (Halim et al., 2020; Salame & Makki, 2021). Based on previous research by Susilawati et al (2022) and Banda & Zabahimana (2023), PhET simulations in physics learning have been proven effective in strengthening conceptual understanding through interactive visual representations, as well as enhancing students' learning motivation and problem-solving skills.

However, improvements in data interpretation skills were not solely driven by PhET. The use of Padlet also played a role by enabling students to share observational findings, reflect on outcomes, and collaboratively discuss results. Padlet positively contributed to increasing student engagement and collaboration in science education (Shuker & Buton, 2021). Its features expanded opportunities for peer-to-peer data exploration, transforming interpretation from an individual task into a collective process shaped through active digital discourse (Mehta et al., 2021). These findings solidify Padlet's role as a digital tool that fosters literacy-oriented and participatory learning in modern educational settings (Zainuddin et al., 2020).

Not only do PhET and Padlet enhance student learning outcomes through e-modules, but incorporating Kahoot as a formative assessment tool also encourages quick thinking by presenting phenomenon-based questions that require connecting cause and effect, thus reinforcing conceptual memory (Mdlalose et al., 2022). As

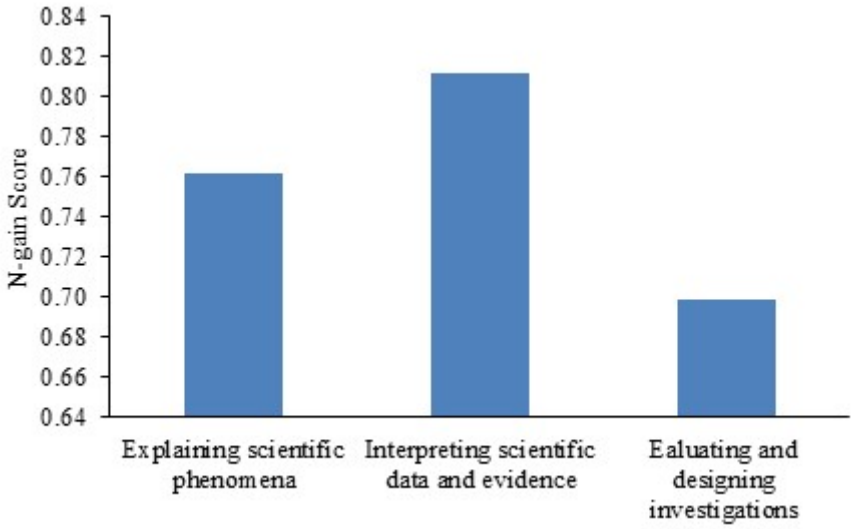


Figure 3. N-Gain score for each science literacy indicator

an interactive quiz platform, Kahoot not only boosts learning outcomes, collaboration, and the ability to quickly and engagingly reflect on data comprehension but also significantly contributes to deepening conceptual understanding and enhancing material retention in science learning (Zhang & Yu, 2021; Jankoviæ et al., 2024).

Meanwhile, the relatively lower score on the indicator of evaluation and investigation design (0.699), although still categorized as moderate, suggests that the evaluation and design aspect requires a more holistic approach, such as direct practice or collaboration, which may not be fully accommodated within the e-module. This aligns with findings showing that many students are not yet accustomed to the characteristics of scientific inquiry and have limited experience in designing experiments within relevant contexts (Mitarlis et al., 2020). This discrepancy indicates that while the e-module shows potential in enhancing conceptual understanding, higher-order thinking skills still need to be strengthened through additional learning strategies. This is consistent with findings that, although digital learning environments like e-modules can facilitate conceptual understanding, the development of higher-order thinking skills requires more complex instructional design and additional learning support to foster deep critical and reflective thinking (Kwangmuang et al., 2021).

The results of this study offer significant insights that can inform the advancement of science education through digital platforms. The high N-Gain score on the indicators of data interpretation and phenomenon explanation confirms that e-modules can be an optimal tool for training analytical skills and scientific reasoning, as evidenced by studies showing that e-modules based on scientific reasoning significantly improve students' scientific reasoning abilities in science education (Adri & Suwarjono, 2023). However, the lower scores on the indicators of evaluation and investigation design highlight the need to integrate inquiry-based experimental or project activities within the e-module to sharpen students' experimental design skills (Urdanivia Alarcon et al., 2023). In this regard, an inquiry-based project learning approach supported by information technology not only promotes 21st-century skills such as critical thinking, collaboration, and communication but also facilitates students' ability to design and conduct scientific investigations independently. Moreover, it supports a more active, reflective, and meaningful learning experience, helping to address the limitations of e-modules in fostering evaluation and experimental design skills (Chu et al., 2021; Hinostroza et al., 2024). Additionally, the variation in the N-Gain score range (0.56–1.00) requires educators to consider differentiated instruction, especially for students with lower initial abilities, to ensure that the use of e-modules is more inclusive and has an equitable impact (Sitorus et al., 2022).

Evaluation Stage

Evaluation of the practicality aspect of the Heyzine Flipbook-based e-module was conducted through the distribution of questionnaires to students, which covered four main dimensions: media, content material, pedagogical relevance, and learning motivation. The data analysis results showed that the e-module achieved a practicality score of 90.08%, which is classified as highly practical. In the media dimension, students gave positive assessments of visual elements, ease of navigation, and information organization, scoring 90.23%. This indicates that the e-module's interface design successfully supports an enjoyable and accessible learning experience. The content material aspect received the highest score, at 90.36%, with appreciation for the completeness of concepts, clarity of explanations, and the inclusion of interactive features such as videos, simulations, and external links. These findings align with the dual coding principle proposed by Weinstein et al. (2018) and reinforced by Mir et al (2023),

which states that the integration of visual and verbal elements can significantly enhance conceptual understanding.

Reflectively, the high practicality score demonstrates that the e-module not only serves as an information medium but also as a learning facilitator that supports deeper cognitive processing. The score for the pedagogical relevance dimension, at 87.76%, indicates that the use of the e-module contributes to supporting students' learning processes and is perceived as instructionally meaningful. Meanwhile, the learning motivation dimension received very positive responses, indicating that the presence of the e-module also fosters students' interest and enthusiasm in science learning. Therefore, this e-module shows strong potential to be widely implemented as a science learning medium that not only adapts to technological developments but also contributes to the improvement of comprehensive scientific literacy.

■ CONCLUSION

The results of this study show that the interactive e-module based on Heyzine Flipbook, which is integrated with PhET simulations, Kahoot quizzes, and the Padlet platform, demonstrates a high level of validity in terms of content and appearance. It was also rated as practical based on positive student responses regarding its ease of use, attractiveness, and content integration. This e-module has demonstrated potential in facilitating scientific literacy, particularly in helping students understand abstract concepts, interpret data, and connect the material to real-life contexts. The integration of various digital platforms within the e-module significantly contributes to encouraging active participation and shaping a more contextualized learning experience aligned with 21st-century demands. Some limitations identified in this study include: (1) the zoom function does not work optimally on iOS-based smartphones, and (2) the science exploration feature has not fully accommodated the indicators for evaluating and designing independent scientific investigations. Future research is recommended to further develop the science exploration feature by integrating problem-based tasks designed in a structured way and linked to virtual simulations. Additionally, further development should consider accessibility and functionality across different platforms to ensure the e-module can be used evenly on both Android and iOS devices.

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