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Development of An Interactive E-Module Based on Green Chemistry on Reaction Rate Matter

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ABSTRACT

This study aims to develop an interactive e-module based on green chemistry in the reaction rate material to improve learning outcomes and foster students' interest in learning. The research employed the Research and Development (R&D) method using the 4D development model (Define, Design, Develop, Disseminate), which in this study was limited to the Develop stage. The research subjects consisted of 2 lecturers, 1 chemistry teacher, and 32 students from from the Grade XI Science A-1 class at *State Islamic Senior High School 1 Medan (MAN 1 Medan)*, selected through purposive sampling. The research instruments included test instruments (pretest and posttest questions) and non-test instruments (validation questionnaires and student learning interest questionnaires). Based on expert validation, the interactive e-module was declared highly feasible with an overall average score of 82.00%. In the trial phase, the e-module showed an improvement in student learning outcomes with an N-gain score of 0.69, categorized as moderate, and student interest in learning reached 74%, also falling into the moderate category.

Keyword: Interactive e-module, green chemistry, reaction rate, learning outcomes, learning interest.

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INTRODUCTION

In today's rapidly advancing digital era, the integration of technology into educational practices is no longer optional but essential. The ongoing transformation within the education sector demands continuous adaptation to the evolving landscape of information and communication technologies (Siringoringo & Alfaridzi, 2024). Technology is no longer merely a supplementary tool in the learning process; it has become an integral component of modern pedagogical frameworks.

In addition to teaching methods or instructional models, learning materials used as sources of instruction also play a significant role in influencing student performance during the learning process (Panggabean & Purba, 2021). As a medium of instruction, learning materials serve to

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convey educational content to students, thus playing a critical role in enhancing the effectiveness of the teaching and learning process (Adella & Dalimunthe, 2024).

One instructional medium that is increasingly relevant in the digital age is the e-module. This medium holds great potential to deliver content in an interactive and engaging manner. Although some chemistry materials are considered complex, attractive and innovative presentation through e-modules can help students grasp the concepts more easily. Moreover, e-modules have the ability to motivate students to actively participate in the learning process. Consequently, learning is no longer solely dependent on printed textbooks as the primary source but can be enriched with electronic modules that provide variation and improve learning effectiveness (Lastri, 2023).

An interview with a chemistry teacher at State Islamic Senior High School 1 Medan (MAN 1 Medan) revealed that the learning process has yet to reach optimal levels. Students experience difficulties in understanding the material, lack focus during lessons, rarely ask questions or participate in discussions, and are unable to respond effectively to problems. These challenges are attributed to the students' low interest in learning and the limited availability of interactive and engaging learning resources. Thus, the development of an interactive e-module presents a promising solution to address these issues.

Interactive e-modules as instructional tools align with the Indonesian Government Regulation No. 19, Article 19, Paragraph (1) of 2005 concerning National Education Standards, which mandates that "the learning process in schools must be interactive, inspiring, enjoyable, challenging, and encourage active student participation." These interactive e-modules are equipped with navigation buttons and usage guides, allowing users to explore them independently according to their own pace and interest. Consequently, improvements in learning outcomes can be achieved, as increased student motivation often correlates with higher academic performance.

The topic of reaction rates is frequently perceived as one of the more difficult areas in chemistry education due to its reliance on abstract concepts—particularly those related to factors that influence reaction rates and collision theory. Many students struggle to understand changes in reaction rates during the course of a reaction and their relationship with reaction time (Hanifah & Hidayah, 2024). These concepts can be better understood by engaging students in direct laboratory experiences. Practical experiments allow students to apply and contextualize chemical theories in real-world settings, leading to deeper and more effective learning. Additionally, hands-on activities support student comprehension by contextualizing the material within authentic learning environments.

However, issues related to student laboratory practice often arise due to a lack of adherence to proper protocols. The use of hazardous chemicals, improper waste disposal, and the absence of hazard symbols, material descriptions, and equipment guides in laboratory manuals increase the potential for accidents. One solution to mitigate these risks is the integration of green chemistry principles into the instructional process.

Green chemistry is an approach that seeks to minimize the environmental impact of chemical processes. It promotes the use of safer materials and environmentally friendly procedures, while also fostering students' understanding of safety, efficiency, and ecological sustainability (Suryati et al., 2021). Its implementation also supports the achievement of the Sustainable

Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) (Azizah & Yonata, 2023). An instructional approach that incorporates green chemistry concepts helps students connect learning with their surrounding environment, thereby enhancing memory retention (Álvarez et al., 2023). Developing interactive learning modules that combine digital technology with green chemistry principles offers a solution to improve the quality of chemistry education in schools.

Previous studies have examined the development of green chemistry-based instructional materials. Yunitamara (2022) found that a green chemistry-based e-module on reaction rates achieved high levels of validity and practicality, with a validation score of 0.82 and practicality reaching 88.78%. Kusuma et al. (2021) developed a green chemistry-based acid-base practicum module that was rated highly valid (Aiken's V = 0.86) and practical (87.2%). Similarly, Rindiani (2022) reported that a green chemistry-based electrochemistry e-module demonstrated high content validity (0.92 for material and 0.85 for media) and was considered highly practical by both students (86%) and teachers (92%).

However, existing research has yet to specifically address the development of an interactive green chemistry-based e-module on the topic of reaction rates aimed at improving student engagement and learning outcomes through technology-enhanced instruction. Therefore, this study aims to develop an interactive e-module integrating green chemistry principles for teaching reaction rates, with the goal of improving academic achievement and fostering students' interest in learning. This research is significant as it provides innovative learning materials that not only support technology-based education but also incorporate sustainability principles. The resulting product is expected to be a valid, practical, and innovative e-module that can be implemented in chemistry instruction across different educational levels.

METHODS

Type of Research

This study employed a Research and Development (R&D) method with the aim of developing a product while simultaneously testing its effectiveness (Sugiyono, 2021). The product development followed the 4D model introduced by S. Thiagarajan (1975), which consists of four stages: Define, Design, Develop, and Disseminate (Wahyuningtyas, 2019). However, this study was limited to the Develop stage, which includes the validation and trial testing of the e-module.

The research subjects consisted of two chemistry lecturers from UNIMED, one chemistry teacher from State Islamic Senior High School 1 Medan (MAN 1 Medan), and 32 Grade XI students from the same school. Meanwhile, the object of this study was an interactive e-module based on green chemistry, specifically designed for the reaction rate topic in Grade XI chemistry.

Research Instruments

The research instruments consisted of both test and non-test instruments. The test instruments included pretest and posttest questions designed to assess student learning outcomes, comprising a total of 20 multiple-choice items, each with five answer options. The non-test instruments included a student needs questionnaire used during the preliminary research phase, a validation questionnaire to evaluate the product's validity, and a learning interest

questionnaire to assess whether the e-module could enhance students' motivation to learn. The sampling technique employed was purposive sampling, in which the researcher deliberately selected samples based on specific criteria aligned with the research objectives.

Data Analysis Techniques

The data analysis technique used to assess feasibility and learning interest based on questionnaires using a Likert scale involved calculating the score for each item in the questionnaire. The results obtained from these assessments were then analyzed to determine the percentage of interest and feasibility using a predetermined percentage calculation formula.

$$\text{Score (\%)} = \frac{Obtained\ Score}{Maximum\ Possible\ Score} \text{ x } 100\%$$

After obtaining the percentage results, these values can then be converted based on the criteria listed in the following tables:

Table 1. Feasibility Criteria

Percentage (%)	Category
80 - 100	Highly Feasible
60 - 80	Feasible
40 - 60	Moderately Feasible
20 - 40	Not Feasible
0.0 - 20	Highly Unfeasible

Tabel 1. Kriteria skor minat

Interest Score (%)	Category
76 - 100	High
56 - 75.9	Moderate
0 - 55.9	Low

Learning outcomes were analyzed using the Normalized Gain (N-gain) test, a widely accepted method to assess the extent to which an instructional intervention improves student learning. The N-gain score is calculated using the following formula:

$$N_{gain} = \frac{Posttest\ score - Pretest\ score}{Ideal\ score - Pretest\ score}$$

To determine the level of improvement, the gain score is interpreted based on the normalized gain categories listed in **Table 3**:

Table 3. Normalized Gain Criteria

N-gain Score (%)	Category
76 - 100	High
56 - 75.9	Moderate
0 - 55.9	Low

RESULTS AND DISCUSSION

1. Development of an Interactive E-Module Based on Green Chemistry

This research resulted in the development of an interactive e-module based on green chemistry, which was applied to the topic of reaction rates. The development process followed the 4D development model, consisting of four main

stages: Define, Design, Develop, and Disseminate.

a. Define

The primary objective of the define stage is to identify relevant aspects that align with instructional needs and the goals of product development. This stage consists of five essential activities: 1) Front-End Analysis, aimed at understanding the initial context and needs of instruction or product development; 2) Learner Analysis, focusing on identifying student characteristics and learning needs; 3) Task Analysis, which outlines the tasks required to achieve learning objectives; 4) Concept Analysis, which involves identifying and clarifying the key concepts that must be mastered; and 5) Formulating Learning Objectives, which establishes clear and measurable instructional goals.

b. Design

The design stage aims to develop a product that meets the needs of learners, functioning as both an effective learning resource and a beneficial supplementary teaching material. This stage involves four main steps: 1) Constructing assessments to measure the achievement of learning objectives; 2) Selecting appropriate media for delivering the instructional content; 3) Determining a suitable format to facilitate comprehension; and 4) Creating an initial design prototype to serve as a basis for further development.

c. Develop

The goal of the development stage is to ensure that the interactive e-module meets the predetermined feasibility standards. In this phase, the product created is an interactive e-module based on green chemistry. There are two key activities involved: 1) Expert Validation: The draft version of the interactive e-module was reviewed by experts in the field to assess its feasibility and validity. This validation was conducted by three expert validators, consisting of two chemistry lecturers from Universitas Negeri Medan and one chemistry teacher from MAN 1 Medan. The process aimed to evaluate the module's content, design, presentation, and language based on the standards set by the National Education Standards Board (BSNP). 2) Product Trial/Implementation: The validated e-module was implemented with students to assess its effectiveness in improving learning outcomes and enhancing students' interest in the learning process. The trial was conducted in Grade XI Science A-1 at MAN 1 Medan, involving 32 students. During the instructional activities, students utilized the interactive green chemistry-based e-module on the topic of reaction rates that had been developed and validated by the expert reviewers.

d. Disseminate

The disseminate stage involves the distribution and implementation of the final product to ensure it can be accepted and effectively used in chemistry instruction. In this context, the interactive e-module is intended to be disseminated for adoption and application in classroom settings. However, this research was limited to the third stage (develop) due to time constraints, which prevented the researcher from conducting broader dissemination of the developed product.

2. Feasibility of the Interactive E-Module Development

The feasibility of the green chemistry-based interactive e-module on reaction rate material was evaluated across several dimensions, including content, presentation, language, and graphic design. Validation was carried out by expert reviewers using a detailed evaluation rubric aligned with topic appropriateness standards. Each evaluation descriptor was analyzed using mean calculations to obtain the final score of the module. The results of this evaluation are presented in **Table 4**.

Table 4. Expert Validation Results

Evaluation Component	Validator 1	Validator 2	Validator 3	Average Score
Content Feasibility	80.77%	88.46%	88.46%	85.90%
Presentation Feasibility	78.57%	84.52%	86.90%	83.33%
Language Feasibility	75.00%	75.00%	78.57%	76.19%
Graphic Feasibility	75.00%	84.09%	88.64%	82.58%
Overall Average	77.34%	83.02%	85.64%	**82.00%**

Based on the expert validation conducted by three reviewers, the average scores for each evaluation aspect were as follows: content feasibility at 85.90%, presentation feasibility at 83.33%, language feasibility at 76.19%, and graphic feasibility at 82.58%. The overall average score was 82.00%, which falls into the "Highly Feasible" category. This indicates that the interactive e-module is suitable for use as instructional material. Moreover, it has the potential to serve as an effective supplementary reference, enabling students to comprehend the subject matter independently in a more interactive way.

3. Improvement in Student Learning Outcomes

Learning outcomes refer to the competencies acquired by students after completing the learning process, as reflected in behavioral changes measurable through test scores. Improvement in student learning outcomes was assessed using the **N-gain** test, a commonly used method to evaluate how effectively instruction or interventions enhance learning achievement.

Based on the research findings, data from pretests and posttests were analyzed using Microsoft Office Excel 2010. The average scores for pretest, posttest, and gain are presented in Table 5, providing a clearer view of the students' progress.

Table 5. Average Pretest, Posttest, and Gain Scores

Test Type	N	Min	Max	Average
Pretest	32	10	65	32.19
Posttest	32	70	95	79.22
Gain	32	0.45	0.92	0.69

Based on the N-gain results, the implementation of the green chemistry-based interactive e-module on reaction rate material showed a significant improvement in student learning outcomes. The N-gain score of 0.69 falls into the moderate improvement category.

4. Students' Learning Interest

Learning interest refers to the internal drive or motivation that encourages individuals to achieve learning goals. In this study, the learning interest questionnaire was developed based on four key indicators: enjoyment, focus, curiosity, and engagement during the learning process. The instrument consisted of 20 statements reflecting these indicators. The analysis results are shown in Table 6.

Table 6. Average Student Learning Interest

Indicator	N	Min	Max	Average
Student Learning Interest	32	49	68	74%

According to Table 6, the average learning interest score was 74%, which falls under the moderate category. This indicates that the use of the interactive e-module has the potential to foster and enhance students' interest in the topic of reaction rates.

CONCLUSION

The results of this study indicate that the interactive e-module based on green chemistry for the topic of reaction rates meets the feasibility criteria in terms of content, language, presentation, and graphic design, in accordance with the standards set by the National Education Standards Board (BSNP). The validation by three expert reviewers yielded an average score of 82.00%, signifying that the e-module is highly feasible for use as instructional material or a supplementary reference. This e-module supports students in engaging in more effective and interactive independent learning. The N-gain analysis demonstrated a significant improvement in student learning outcomes, with an average score of 0.69, classified in the moderate category. Additionally, the questionnaire results showed that students' learning interest reached an average percentage of 74%, also falling into the moderate category. Based on these findings, the interactive e-module based on green chemistry for reaction rate material is considered highly suitable for instructional use, and has been proven to effectively enhance student learning outcomes and foster students' interest in learning.

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