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Development of Discovery Learning E-Module Integrated with PhET Simulation on Reaction Rate Material

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Abstract: *This study aims to analyze the need for a discovery learning-based e-module integrated with PhET simulation on reaction rates for grade XI senior high school and to evaluate its feasibility based on BSNP criteria. The research employed the Research & Development (R&D) method with the 4D model (define, design, develop, disseminate), limited to the develop stage. Instruments included interview guides, student needs questionnaires, and validation sheets. The findings revealed that the chemistry learning process at SMAN 14 Medan remains teacher-centered with lecture methods, causing students to be passive and struggle with conceptual understanding. Teaching materials are confined to textbooks, with no e-modules available. The developed e-module fulfilled the BSNP criteria, achieving average validity scores of 90.27% (material aspect) and 88.68% (media aspect), both in the highly valid category. The novelty of this study lies in integrating discovery learning with PhET simulation into an e-module for reaction rate topics, offering an interactive alternative to conventional textbooks. Keywords: e-module; discovery learning; phet simulation; reaction rate*

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INTRODUCTION

Education is a consciously designed effort to create a pleasant learning atmosphere so that students can optimally develop their potential, encompassing spiritual, personality, intellectual, and skill aspects (Aulia et al., 2024). In the 21st century, chemistry education faces the dual challenge of conveying abstract concepts while fostering student-centered learning skills. The "Merdeka Curriculum" in Indonesia addresses this by encouraging exploration, experimentation, and discovery through meaningful experiences (Ap et al., 2025). This is due to a learning process that emphasizes memorizing theories and principles without developing meaning, thus undertraining students' logic and reasoning skills in problem-solving. (Panggabean & Purba, 2021). However, in subjects like chemistry, concepts such as reaction rates involve abstract ideas, complex calculations, and microscopic theories that are difficult for students to grasp (Farida et al., 2020; Juitaningsih, 2024). A preliminary study at SMA Negeri 14 Medan revealed that students' understanding of reaction rates remains low due to teacher-centered lectures, unengaging textbooks, and the inability to

conduct practical experiments because of time and laboratory constraints.

Digital teaching materials, such as e-modules, have been widely documented as effective tools to enhance engagement and comprehension compared to conventional printed materials (Inanna et al., 2021; Lastri, 2023). However, most existing studies focus on e-modules in general without integrating specific pedagogical models. For instance, Afriani et al., (2022) and Herawati & Muhtadi (2020) confirmed a positive correlation between e-module use and improved conceptual understanding, yet their studies did not examine the role of inquiry-based learning strategies within the module. Conversely, the Discovery Learning (DL) model has been shown to actively engage students in constructing knowledge, making abstract concepts more concrete concrete (Oktaviani, 2021; Sulistiyawati et al., (2024).. Research integrating DL into digital modules, such as Android-based handouts for buffer solutions Maharani et al., (2026) and e-modules using video demonstrations for reaction rates (Arifin & Ramadhan, 2025), has demonstrated promising validity and practicality. Nevertheless, none of these studies integrated PhET simulations as a core interactive component within a DL-based e-module. Meanwhile, virtual laboratories like PhET Simulations have proven effective in improving conceptual understanding and reducing misconceptions in science topics (Larashati & Supardi, (2025); Minarni et al., (2023); Muna et al., (2023). Pioneering research has begun validating PhET within a DL framework, but such integration remains limited to specific skills and has not been developed as a cohesive, self-contained e-module for reaction rates.

Thus, a critical research gap exists: while e-modules, Discovery Learning, and PhET simulations have each been studied separately, no previous research has developed and validated an integrated teaching resource that synergistically combines all three elements specifically for the reaction rate topic. The current condition reflects a fragmented approach where digital, pedagogical, and simulation tools are used in isolation whereas the desired condition is a cohesive learning experience where students actively discover concepts through simulated experimentation within a structured e-module. The novelty of this research lies in developing a specific, integrated teaching module that combines Discovery Learning with PhET simulations inside a single e-module designed explicitly for reaction rates, an innovation not yet explicitly developed or validated in existing literature.

This research has two measurable objectives: (1) to analyze the need for a discovery learning-based e-module integrated with PhET simulation on reaction rates for grade XI senior high school students, and (2) to evaluate whether the developed e-module meets the BSNP criteria in terms of material and media aspects. Based on the theoretical framework and empirical findings from previous studies, it is hypothesized that the developed e-module will achieve a validity score of at least 80% (highly valid category) based on BSNP criteria. Methodologically, this study assumes that validator assessments using standardized BSNP instruments (covering content, presentation, language, and graphics) provide a reliable measure of product feasibility prior to field testing.

LITERATURE REVIEW

E-Module as a Digital Learning Resource

An e-module is a systematically designed learning program that assists students in achieving specific objectives by organizing subject matter tailored to individual characteristics, thereby optimizing intellectual abilities (Hadi & Kriswanto, 2025). Unlike printed modules, e-modules are electronic teaching materials accessible via computers or mobile devices, enabling the integration of multimedia components such as text, images, animations, and videos (Sanova et al., 2022). The flexibility and practicality of e-modules have made them increasingly relevant in modern chemistry education, particularly for abstract topics like reaction rates. According to(Putri et al., 2023), five characteristics must be considered in developing e-modules: self-

instructional, complete, stand-alone, adaptive, and user-friendly.

Discovery Learning in Chemistry Education

Discovery learning is a student-centered teaching strategy in which material is not presented directly in its final form; instead, students are invited to organize, expand, and apply their existing knowledge to solve problems (Zakiati et al., 2023). Through active involvement in discovering concepts and conducting investigations, students develop deeper and longer-lasting understanding (Niman et al., 2024). The teacher's role is to direct students toward discovering and constructing knowledge themselves rather than delivering complete content (Nababan et al., 2023). Aldiyansyah et al., (2024), emphasize that discovery learning enables students to acquire new knowledge through experimental activities, aligning with its main goal of increasing active student engagement. In the context of reaction rates, discovery learning is particularly relevant because students can explore relationships between reactant concentration, temperature, and reaction speed through structured inquiry.

PhET Simulation as a Virtual Laboratory

PhET (Physics Education Technology) simulations are interactive virtual laboratories developed in Java or Flash formats, accessible online or downloaded for offline use (Liswar et al., 2023). These simulations display relationships between real-life events and scientific principles, encourage constructivist learning approaches, and provide immediate feedback. (Rizaldi et al., 2020), note that PhET simulations are freely available and best used on PC devices. Virtual practicum using PhET has been shown to make learning more engaging, creative, and stimulating, as students can conduct experiments virtually including observation, execution, and demonstration without physical laboratory constraints (Hasanah & Risnasari, 2025; Simbolon & Silalahi, 2023) For abstract chemistry concepts like reaction rates, PhET simulations allow students to manipulate variables (e.g., concentration, temperature, surface area) and observe the effects on reaction speed in real time, bridging the gap between theory and observable phenomena.

Reaction Rate in Chemical Kinetics

Reaction rate is a fundamental concept in chemical kinetics, defined as the amount of product formed or reactant consumed per unit time. More precisely, reaction rate is expressed as the change in molar concentration per unit time (mol L^{-1} s^{-1}). Chemical kinetics examines both the rate and mechanism of reactions, aiming to understand reaction stages and identify conditions that accelerate reactions knowledge essential for optimizing industrial production within commercially viable timeframes. Effective collisions between reactant particles determine reaction speed; the frequency of collisions increases the likelihood of reaction progression and reduces the minimum kinetic energy required. Students often struggle with reaction rates because the concept involves microscopic explanations, mathematical calculations, and multiple influencing factors (concentration, temperature, surface area, catalysts). Therefore, interactive visualization tools like PhET are particularly valuable for making these abstract relationships tangible.

METHODS

Research Design

This research was conducted at SMA Negeri 14 Medan, located at Jl. Pelajar Gg. Darmo, Binjai, Kec. Medan Denai, Kota Medan, North Sumatra 20228. The implementation period was from November 2025 to January 2026.

Subjects and Object of the Research

The subjects of this study were five expert validators, consisting of three chemistry lecturers from State University of Medan (UNIMED) and two chemistry teachers from SMA Negeri 14 Medan. The number of validators was determined based on the minimum expert judgment standard in R&D research, which recommends at least three to five experts to ensure content and media validity (Aiken,

1985; Retnawati, 2016). The object of this research was a discovery learning-based e-module integrated with PhET simulation on reaction rate material for grade XI senior high school.

Research Procedure

This research employed the Research and Development (R&D) method using the 4D development model, which includes the stages of define, design, develop, and disseminate (Barus & Purba, 2025). Due to time and resource constraints, this research was limited to the develop stage, covering product development and feasibility validation.

Research Instruments

The instruments used in this research included:

- Interview sheet for chemistry teachers to analyze initial needs and learning problems related to reaction rate material.
- Student needs analysis questionnaire to identify students' learning difficulties and preferences for digital teaching materials.
- E-module validation questionnaire developed based on BSNP (Badan Standar Nasional Pendidikan) standards, covering two aspects: material feasibility (content, presentation, language) and media feasibility (graphics, interactivity, usability).

Instrument Validity

The validation questionnaire was developed based on BSNP criteria and reviewed by three experts for content validity. The content validity ratio (CVR) was calculated following Lawshe's method, yielding values above 0.78, indicating acceptable content validity.

Data Collection Procedure

Data collection was carried out in the following steps:

- Conducting interviews with chemistry teachers to identify problems and needs in teaching reaction rate material.
- Distributing student needs analysis questionnaires to 27 grade XII students to gather information about learning difficulties and preferences for e-modules.
- Developing the e-module prototype based on needs analysis results.
- Submitting the e-module to five validators for feasibility assessment using the validation questionnaire.
- Collecting and tabulating validation scores from expert validators.

Data Analysis Technique

The validation data from material and media expert validators were analyzed using descriptive percentage analysis based on a five-point Likert scale. The Likert scale used in this study is presented in Table 1.

Table 1. Likert Scale

Answer	Score
Very Agree	5
Agree	4
Fairly Agree	3
Disagree	2
Very Disagree	1

Source: (Rohmad & Sarah, 2021)

The percentage score for each validator and each aspect was calculated using the following formula:

$$P = \sum_{i=1}^{n} f_i x\ 100\%$$

(Lestari, 2020).

Description:

P = persentage score in persen (%)

$\sum f_i$ = total score obtained from all items (sum of Likert scores across all items)

N = maximum possible total score (number of items × 5)

Concrete Calculation Example:

Assume a material aspect validator assessed 9 items with scores: 5, 5, 4, 5, 4, 5, 4, 4, 4. Then:

- $\sum f_i = 5 + 5 + 4 + 5 + 4 + 5 + 4 + 4 + 4 = 40$
- N=9 items×5=45
- P=$\frac{40}{45}\ x\ 100\% = 88\%$

The final validity score for each aspect was calculated by averaging the percentages from all five validators. The validity classification followed the criteria in Table 2.

Table 2. Validity Classification of E-Module

Percentage (%)	Validity Classification
81-100	Very Valid
61-80	Valid
41-60	Fairly Valid
21-40	Less Valid
0-20	Not Valid

(Source: Karira et al., 2023)

An e-module was considered feasible if it achieved at least 61% (Valid category) in both material and media aspects. The classification thresholds were adopted from Karira et al. (2023) and are consistent with standard educational R&D validity criteria, where ≥81% indicates excellent feasibility with no major revisions needed.

RESULT AND DISCUSSION

This research was conducted at SMA Negeri 14 Medan from November 2025 to January 2026. The product of this research is a discovery learning-based e-module integrated with PhET simulation on reaction rate material that has been validated by experts. The study employed the Research and Development (R&D) method using the 4D development model (define, design, develop, disseminate), limited to the develop stage. The following sections present the results of each development stage, followed by a discussion of their implications.

Define

The define stage identified the need for developing new teaching materials at SMAN 14 Medan through teacher interviews, student questionnaires, textbook analysis, and task analysis.

Teacher interviews revealed that despite implementing the Merdeka Curriculum, chemistry instruction remains teacher-centered, relying on textbooks and PowerPoint presentations. This results in monotonous learning and limited student engagement. Teachers expressed a strong need for a discovery learning-based e-module integrated with PhET simulation to boost engagement and improve learning outcomes.

Student questionnaires (N=27) confirmed that 59.3% struggle with reaction rate material, particularly abstract concepts like collision theory and reaction order calculations. Notably, 74.1% had never used an e-module, while 48.1% regularly use digital devices, indicating readiness for technology-based resources. Student enthusiasm was high, with 85.2% supporting the proposed e-module development and 66.7% finding simulations helpful for understanding.

Textbook analysis of five chemistry textbooks from various curricula confirmed that while books cover necessary topics, they lack interactive visualizations and virtual laboratory experiences. Task analysis, conducted by breaking down Phase F Learning Outcomes into specific Learning Objectives, identified essential knowledge and skills students must master, providing a clear framework for designing learning activities and assessments.

These findings align with Panggabean & Purba, (2021), who reported that students' learning difficulties in chemistry stem from an inability to connect material to real-world phenomena due to teacher-centered instruction. The high student enthusiasm for e-modules (85.2%) supports the shift toward digital learning resources, consistent with Inanna et al., (2021) and Lastri, (2023), who documented that e-modules enhance student engagement compared to conventional textbooks.

Design

Following the define stage, the design stage systematically planned the e-module framework. The researcher structured content according to the Merdeka Curriculum's Learning Objective Flow and organized it based on the six-step syntax of the discovery learning model: stimulation, problem statement, data collection, data processing, verification, and generalization.

Several media were selected based on their specific functions:

- Canva for layout, cover, and visual elements
- Microsoft Word for drafting textual content and chemical equations

- Google Form for interactive assessments with automated feedback
- PhET simulation ("Reactions & Rates") for virtual laboratory experience
- Flip PDF Professional to convert PDF into an interactive HTML5 flipbook with hyperlinks and QR codes.

Figure 1. Front and Back Cover of the Reaction Rate E-Module Based on Discovery Learning Integrated with PhET Simulation

Figure 1 presents the front and back covers of the developed e-module. The front cover illustrates everyday phenomena related to reaction rates (e.g., rusting iron and food spoilage) to provide contextual entry points for students. The back cover includes the module's identifying information and a brief description of its features.

The e-module format was designed in accordance with BSNP graphic standards, including consistent font usage (Times New Roman with size variations), a high-contrast color scheme, and intuitive layout. The main menu provides access to the preface, table of contents, concept map, material (divided into four learning activities), summary, evaluation, glossary, and author profile. In the data collection stage of each learning activity, students interact with the embedded PhET simulation and record observations in provided tables.

The integration of PhET simulation within the discovery learning syntax—specifically placed in the data collection stage—addresses the limitation of physical laboratories identified in the preliminary study. This design choice is supported by Hasanah & Risnasari, (2025) who found that virtual practicum makes learning more enjoyable and stimulates thinking by allowing students to conduct experiments virtually. The use of Flip PDF Professional to create an interactive flipbook also aligns with Sanova et al., 2022), who emphasized that e-modules can present multimedia components including animations and videos.

Development

The development stage began after completing the e-module draft. The draft included a cover page, preface, table of contents, usage guide, concept map, discovery learning stages, summary, competency test, bibliography, glossary, and reaction rate material divided into four learning activities. The researcher selected five validators: three chemistry lecturers from Universitas Negeri Medan and two chemistry teachers from SMAN 14 Medan. The assessment questionnaire used BSNP standards.

Material Expert Validation

Tabel 3. Material Expert Validation Results for Discovery Learning-Based E-Module Integrated with PhET Simulation on Reaction Rate

Asessment Aspect	Average Percentage (%)					Average (%)
	L1	L2	L3	T1	T2	
Konten Feasibility	86,67%	88,33%	93,33%	91,67%	90%	90%
Presentation Feasibility	88%	90%	94%	94%	92%	91,60%
Language Feasibility	90%	87,5%	90%	92,5%	87,5%	89,50%
Contextual Feasibility	88,57%	87,14%	91,42%	90%	92,85%	90,00%
Average (%)	88,31%	88,24%	92,19%	92,04%	90,59%	90,27%
Validity Statement Based on Percentage Assessment						Very valid

The overall average validity score from material experts was 90.27%, falling into the "very valid" category (81-100%). Based on the table of average percentage assessment results by each material expert validator: L1 was 86.67%, L2 was 88.33%, L3 was 93.33%, G1 was 91.67%, and G2 was 90%. The average percentage results of assessments by material expert validators on each assessed aspect obtained results of 90% for the content feasibility aspect categorized as "very valid," 91.60% for the presentation dimension categorized as "very valid," 89.50% for the language dimension categorized as "very valid," and 90% for the contextual feasibility dimension categorized as "very valid." The validity statement obtained from the percentage assessment by validators was at 90.27%, according to the product validity category, which is a very valid category for use with some improvements based on validator suggestions. The results of material expert validation are also presented in the diagram as shown in Figure 2.

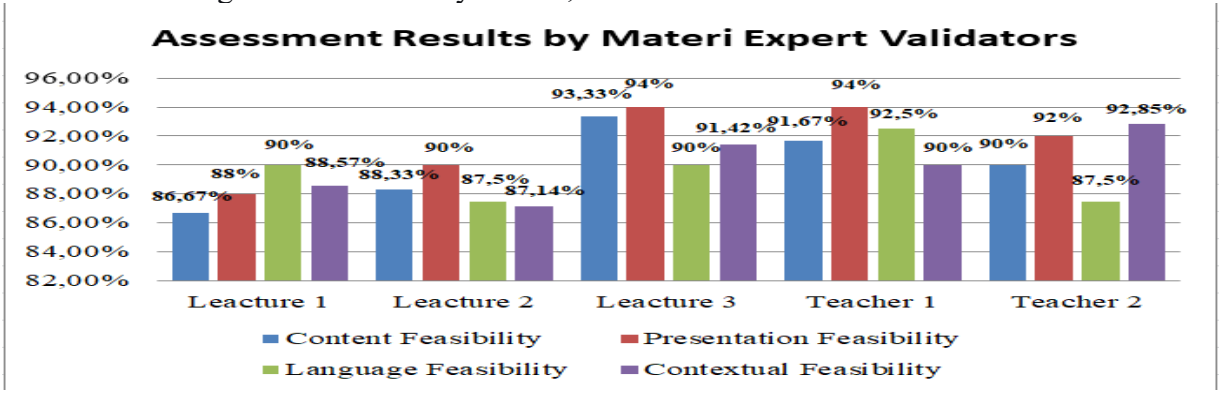

Figure 2. Diagram of Material Expert Validation Results by Aspect and Validator

Figure 2 displays a bar chart comparing the four feasibility aspects across the five validators, illustrating that L3 (lecturer 3) consistently provided the highest ratings, while L2 (lecturer 2) gave the lowest ratings in content and contextual aspects.

The lower score in language feasibility (89.50%) compared to presentation feasibility (91.60%) warrants attention. Validators noted that some chemical terms needed standardization and a few sentences were too complex for grade XI students. This finding is consistent with Putri et al. (2023), who emphasized that e-modules must be adaptive and user-friendly, including language appropriate to students' cognitive levels. The slight gap suggests that future revisions should prioritize simplifying sentence structures and ensuring consistent terminology throughout the module.

Media Expert Validation

Media validation was intended to assess the validity of the e-module media created based on BSNP references, including graphic dimensions and presentation dimensions. Validation was carried out twice as a comparison in the development conducted by the researcher at the beginning and end. The researcher selected 5 validators: 3 chemistry lecturers and 2 chemistry teachers from SMAN 14 Medan.

Tabel 4. Media Expert Validation Results for Discovery Learning-Based E-Module Integrated with PhET Simulation on Reaction Rate

Asesment Aspect	Average Percentage (%)					Average (%)
	L1	D2	L1	G1	L1	
Graphic Feasibility	81,48%	88,89%	94,07%	85,92%	87,40%	87,55%
Presentation Feasibility	90,90%	85,45%	100%	85,45%	87,27%	89,81%
Average (%)	86,19%	87,17%	97,04%	85,69%	87,34%	88,68%
Validity Statement Based on Percentage Assessment						Very valid

Based on the data table of average percentage assessment results by each media expert validator: L1 was 86.19%, L2 was 87.17%, L3 was 97.04%, T1 was 85.69%, and T2 was 87.34%. The average percentage results of assessments by media expert validators on each assessed aspect obtained results of 87.55% for the graphic feasibility aspect categorized as "very valid," and 89.81% for the presentation feasibility aspect categorized as "very valid." The validity statement based on the percentage assessment by validators was at 88.68%, according to the product validity category, which is a very valid category for use with some improvements based on validator suggestions. The results of media expert validation are also presented in the diagram as shown in Figure 3.

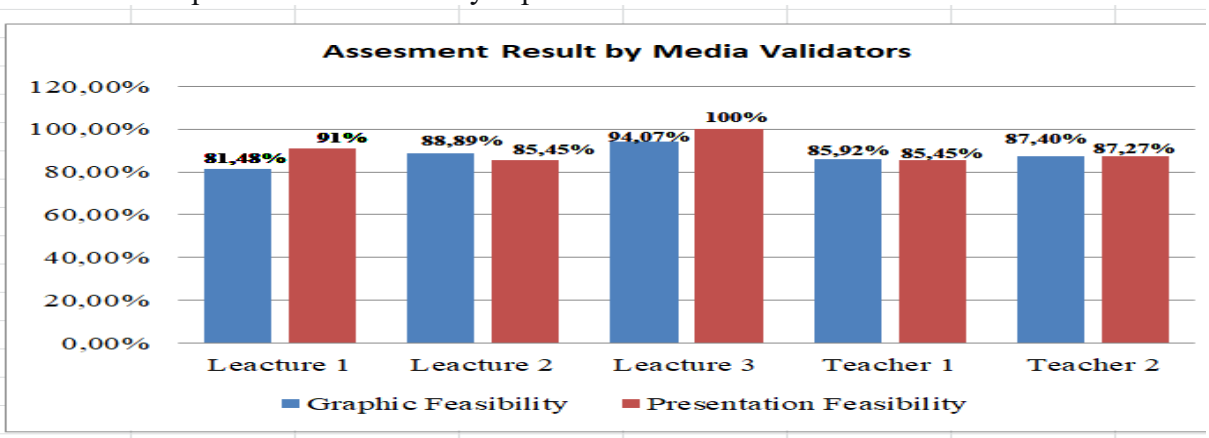

Figure 3. Diagram of Media Expert Validation Results by Aspect and Validator

The high score for presentation feasibility (89.81%) indicates that the e-module's navigation, layout consistency, and learning activity flow are well-designed. However, the lower graphic feasibility score (87.55%) reflects specific issues raised by validators, including small font sizes on some pages and the absence of the PhET logo on the cover. These suggestions were systematically implemented during revision.

The validation process also generated valuable suggestions for improvement from experts. Material experts recommended enhancing the collision theory illustration to accurately represent the $A_2 + B_2 \rightarrow 2AB$ reaction, adding sources for all images, expanding example questions particularly in learning activity 3, and improving the evaluation section with supporting illustrations. Media experts suggested adding the PhET Simulation logo to the cover, enlarging font sizes throughout the module for better readability, and ensuring all hyperlinks and QR codes function properly for seamless access to videos and Google Form assignments. These revisions were systematically implemented, resulting in an improved e-module that addresses both content accuracy and technical functionality.

The implementation of validator feedback is a critical step in R&D research. According to Simangunsong & Purba, (2025), product development must include iterative revision based on expert input to achieve high validity. The fact that material experts requested improvements in illustration accuracy indicates that content precision is non-negotiable in chemistry education, where abstract concepts like collision theory require accurate visual representations. Similarly, media experts' focus on font size and logo placement reflects BSNP graphic standards, which require consistent branding and readability across all pages.

Comparison with Previous Research

Table 5. Comparison of Validity Scores with Previous Studies

Study	Product	Material Validity	Media Validity
Ginting et al. (2022)	Discovery learning module with scientific literacy	85.4%	83.2%
Fitriyawany et al. (2023)	Science e-module with PhET simulation	85.66%	88.75%
Current study	**DL-based e-module integrated with PhET**	**90.27%**	**88.68%**

The current study achieved higher material validity (90.27%) than both previous studies and comparable media validity to Fitriyawany et al. (2023). This improvement can be attributed to three factors: (1) the systematic integration of PhET simulation within the discovery learning syntax rather than as an add-on component, (2) the use of BSNP standards for both material and media aspects, and (3) the incorporation of five validators from both university and school contexts, providing balanced perspectives on content accuracy and classroom practicality.

The higher material validity score compared to Ginting et al. (2022) suggests that integrating PhET simulation as a virtual laboratory component within discovery learning stages enhances content feasibility because students can actively verify concepts through simulated experimentation. This finding supports Simbolon & Silalahi (2023), who argued that PhET-based virtual laboratories effectively help students build understanding of abstract science material. Furthermore, the comparable media validity with Fitriyawany et al. (2023) indicates that the use of Flip PDF Professional and Canva produced media quality consistent with established standards, while the integration of discovery learning added pedagogical value without compromising visual quality.

The validation by material and media experts confirms that the developed e-module meets the criteria for a very valid teaching resource (Panggabean et al., 2024). The systematic validation process, incorporation of expert feedback, and subsequent revisions have produced an e-module that is not only theoretically sound but also practically usable in classroom settings. This aligns with the fundamental goal of development research: to create products that are valid, practical, and effective for improving learning outcomes (Purba & Sembiring, 2023).

CONCLUSION

Based on the research findings, two main conclusions can be drawn.

First, the needs analysis revealed that chemistry learning at SMAN 14 Medan remains predominantly teacher-centered, with lectures as the primary method. Data from student questionnaires (N=27) showed that 59.3% of students struggle with reaction rate material, particularly abstract concepts such as collision theory and reaction order calculations, while 74.1% had never used an e-module. Despite this, 85.2% of students supported the development of a discovery learning-based e-module integrated with PhET simulation, indicating strong readiness for technology-based learning resources.

Second, the developed e-module successfully met the BSNP feasibility criteria. Validation by five experts (three university lecturers and two high school teachers) yielded average scores of 90.27% for the material aspect and 88.68% for the media aspect, both classified as "very valid." The integration of PhET simulation within the discovery learning syntax specifically placed in the data collection stage represents a novel contribution that distinguishes this product from previous e-module developments.

Implications

Theoretical implications**.** This research contributes to the body of knowledge on chemistry education by demonstrating that the integration of discovery learning with PhET simulation within a single e-module is feasible and achieves high validity. The findings support the theoretical framework that combining

pedagogical models (discovery learning) with interactive virtual laboratories (PhET) can address the limitations of conventional textbooks, particularly for abstract topics like reaction rates. This extends previous work by Ginting et al. (2022) and Fitriyawany et al. (2023), which examined these components separately.

Practical implications**.** For chemistry teachers, this e-module provides a ready-to-use digital resource that enables student-centered learning without requiring physical laboratory facilities. Students can conduct virtual experiments, manipulate variables affecting reaction rates, and observe real-time changes—experiences previously unavailable due to time and laboratory constraints. For curriculum developers, the structured integration of discovery learning syntax with PhET simulation offers a replicable model for designing e-modules on other abstract chemistry topics (e.g., chemical equilibrium, thermochemistry).

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