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Development of an Ethno-STEM-Integrated Chemistry E-Module Based on Sleman Regency Local Wisdom for Reaction Rate Learning

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Abstract
This study aims to develop a chemistry learning e-module based on the local wisdom of Sleman Regency integrated with Ethno-STEM for reaction rate learning. The novelty of this study lies in the systematic mapping of Sleman local culinary traditions into reaction rate concepts, including fermentation kinetics, catalyst activity, temperature effects, Maillard reactions, gelatinization, and surface-area-dependent processes. This study employed the Design-Based Research (DBR) model proposed by McKenney and Reeves, consisting of analysis and exploration, design and construction, and evaluation and reflection stages. The participants involved five chemistry teachers, 30 senior high school students, five peer reviewers, one material expert, and one media expert. Data were collected through needs analysis questionnaires, peer review sheets, expert validation instruments, teacher practicality questionnaires, and student readability questionnaires using a five-point Likert scale. The data were analyzed descriptively using average scores and ideal percentages. The developed e-module was presented as an interactive flipbook containing text, images, videos, hyperlinks, evaluations, and Live Worksheets activities. The results showed that the e-module achieved an ideal percentage of 95% in peer review (very good), 78% in material expert validation (good), and 98% in media expert validation (very good). Following revisions, the teacher practicality test and student readability test each obtained an ideal percentage of 96% (very good). Thus, the developed e-module was considered valid, practical, and highly readable for supporting contextual chemistry learning through the integration of local wisdom and the Ethno-STEM approach. However, this study was limited to validity, practicality, and readability evaluation and did not examine the effectiveness of the e-module on student learning outcomes.

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INTRODUCTION

Indonesia has diverse cultures and local wisdom that have the potential to become sources of innovation in learning. Local wisdom not only functions as a cultural heritage but also has educational values that can enrich students' cognitive, affective, and psychomotor learning experiences (Selasih & Sudarsana, 2018). Learning that is connected to local cultural contexts is considered more meaningful because it helps students understand concepts based on their real-life environment and experiences (Marhayani, 2016). However, globalization and the dominance of modern culture have reduced students' knowledge of local culture, causing learning to become less connected to students' daily lives (Hartati & Kusrina, 2019; Rais et al., 2018). Therefore, the integration of local wisdom into learning is important as an effort to preserve culture while creating contextual and relevant learning experiences (Martawijaya et al., 2023).

One approach that can integrate local culture with science learning is Ethno-STEM. This

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approach combines ethnoscience with Science, Technology, Engineering, and Mathematics (STEM) to develop 21st-century skills such as creativity, collaboration, communication, and critical thinking (Sudarmin et al., 2019; Sumarni et al., 2022). Ethnoscience allows students to understand scientific concepts through cultural practices that are closely related to their daily lives, making scientific concepts more contextual and easier to understand (Dewi et al., 2021). The integration of Ethno-STEM is also in line with modern educational goals that emphasize meaningful learning and the strengthening of students' cultural identity (Setiawan et al., 2023).

Sleman Regency is one of the regions that possesses rich local wisdom in the form of traditions and traditional culinary products. Several local cultural products such as jadah tempe, apem Wonolelo, cethil (cenil), tempe pondoh, and ayam goreng Kalasan are related to chemistry concepts and can be utilized as contextual learning resources (Pemerintah Kabupaten Sleman, 2025). The utilization of local culture in chemistry learning can help connect abstract concepts with real-life phenomena, thereby increasing the relevance of learning for students (Nuraini & Aznam, 2026).

One chemistry topic that is still considered difficult for students is reaction rate. This difficulty is caused by students' low conceptual understanding, inappropriate learning approaches, and limited teaching materials that support the visualization of abstract concepts (Nanda & Handayani, 2025). The topic of reaction rate contains microscopic and symbolic concepts that require high conceptual thinking skills, causing students to frequently experience misconceptions. Therefore, innovative teaching materials are needed to present the material in an interactive, contextual, and comprehensible manner.

One alternative teaching material that can be used is an e-module. E-modules have advantages in terms of flexibility and the ability to integrate visual, audio, and animation media to help visualize abstract chemistry concepts (Sari et al., 2021; Sofyan et al., 2019). The use of Ethno-STEM-based e-modules is expected to support independent learning while strengthening the connection between chemistry concepts and students' daily lives.

Several studies have reported the effectiveness of Ethno-STEM-based e-modules and ethno-science-oriented teaching materials in improving students' conceptual understanding and engagement in science learning. For instance Maryanti et al. (2023) developed a Project-Based Learning Ethno-STEM e-module integrated with Yogyakarta local wisdom and obtained very valid and practical results. Azis & Yulkifli (2021) also demonstrated that smartphone-based Ethno-STEM e-modules have the potential to support 21st-century learning. Furthermore, Widarti et al. (2025) emphasized that ethnoscience-based chemistry learning can connect scientific concepts with students' socio-cultural contexts, while Hamsil et al. (2024) reported that multi-representation teaching materials on reaction rate possess high validity and practicality in facilitating conceptual understanding.

However, previous studies generally focused either on the development of Ethno-STEM learning materials or on reaction rate teaching materials separately. Although local culture has often been incorporated into learning, it is commonly presented only as a contextual example or cultural illustration. The scientific relationship between local cultural practices and reaction rate concepts has rarely been explained systematically through chemistry principles and Ethno-STEM components. Moreover, no previous study has specifically mapped the local culinary products of Sleman Regency into reaction rate concepts such as fermentation kinetics, catalyst activity, temperature effects, concentration, surface area, gelatinization, and Maillard reactions. As a result, the potential of local wisdom as a conceptual foundation for contextual chemistry learning has not been optimally utilized.

Therefore, the problem addressed in this study is the limited availability of chemistry learning materials that systematically integrate the local wisdom of Sleman Regency with Ethno-STEM principles in reaction rate learning. This limitation reduces opportunities for students to learn chemistry through culturally relevant, contextual, and meaningful learning experiences.

To address this gap, this study develops a chemistry learning e-module based on Sleman Regency local wisdom integrated with Ethno-STEM on the topic of reaction rate. The novelty of this study lies in the systematic mapping of local culinary traditions into reaction rate concepts and STEM dimensions. For example, the fermentation process of tempe pondoh is used to explain biological catalyst activity and fermentation kinetics. The frying process of ayam goreng Kalasan represents the effects of temperature on reaction rates and the Maillard browning reaction. The preparation of cethil is associated with the effects of heating and concentration on chemical changes, while jadah tempe and apem Wonolelo are utilized to explain factors affecting reaction rates, including temperature, surface area, and fermentation processes. Unlike previous studies in which local culture primarily served as contextual information, the local wisdom presented in this study functions as a conceptual representation of chemical phenomena that are closely related to students' daily lives.

Therefore, this study aims to develop and evaluate a chemistry learning e-module based on Sleman Regency local wisdom integrated with Ethno-STEM on reaction rate material and to examine its validity, practicality, and readability as a contextual, interactive, and meaningful learning medium to support 21st-century chemistry learning.

METHOD

Research Design

This study employed the Design-Based Research (DBR) approach proposed by McKenney & Reeves, 2012 , which consists of three main phases: (1) analysis and exploration, (2) design and construction, and (3) evaluation and reflection. The DBR approach was selected because it facilitates the systematic development of educational products through iterative cycles of analysis, design, evaluation, and refinement within authentic educational contexts.

This study focused on developing a chemistry learning e-module based on Sleman Regency local wisdom integrated with Ethno-STEM on the topic of reaction rates. The research was conducted in a single development cycle and is therefore categorized as an initial DBR cycle or preliminary design research. Although only one cycle was implemented, the study maintained the essential characteristics of DBR through continuous revisions based on findings obtained from needs analysis, peer review, expert validation, teacher practicality testing, and student readability testing.

Iterative revisions were conducted throughout the development process. The results of the needs analysis were used to formulate product specifications and learning requirements. Subsequently, the initial prototype was revised based on peer review suggestions regarding content organization, language, and visual appearance. Further revisions were made following recommendations from material and media experts. The revised product was then evaluated through teacher practicality testing and student readability testing, and the resulting feedback was used to produce the final version of the e-module. Therefore, this study not only developed a learning product but also generated preliminary design principles for developing Ethno-STEM-based chemistry learning materials integrated with local wisdom.

Research Procedure

Analysis and Exploration Phase

The analysis and exploration phase aimed to identify learning problems, student characteristics, and the need for contextual teaching materials on reaction rate topics through teacher and student needs analyses. This phase was conducted to understand the actual learning context prior to product development (McKenney & Reeves, 2012).

In addition, an analysis of Sleman Regency local wisdom was conducted to identify cultural products and practices relevant to reaction rate concepts and Ethno-STEM integration. The results showed that several local cultural products, including tempe pondoh, ayam goreng Kalasan, jadah tempe, apem Wonolelo, and cethil, possess scientific phenomena that can be systematically linked to reaction rate concepts such as fermentation, catalyst activity, temperature effects, concentration, surface area, and thermal processing.

Design and Construction Phase

The design and construction phase involved designing and developing the Ethno-STEM-integrated chemistry e-module. Activities at this stage included preparing learning content, mapping local wisdom contexts to reaction rate concepts, designing the e-module interface, integrating Ethno-STEM components, developing multimedia features, and preparing assessment instruments (McKenney & Reeves, 2012).

The e-module was developed in an interactive flipbook format containing text, images, videos, hyperlinks, Live Worksheets activities, formative evaluations, concept maps, summaries, glossaries, and self-assessment features. The initial prototype was then subjected to peer review by Chemistry Education students and validation by material and media experts. Suggestions and recommendations obtained from these evaluations were used as the basis for revising and improving the product.

Evaluation and Reflection Phase

The evaluation and reflection phase was conducted through teacher practicality testing and student readability testing to determine the quality, usability, and user responses toward the developed e-module. The evaluation results were analyzed and used to make final revisions to the product (McKenney & Reeves, 2012).

The reflection process focused on identifying strengths and limitations of the developed e-module, including aspects requiring further improvement. This phase represents the formative evaluation stage of the initial DBR cycle and provides recommendations for future development and effectiveness testing.

Research Flow

The overall research process followed the stages of the DBR model proposed by (McKenney & Reeves, 2012), as illustrated in Figure 1.

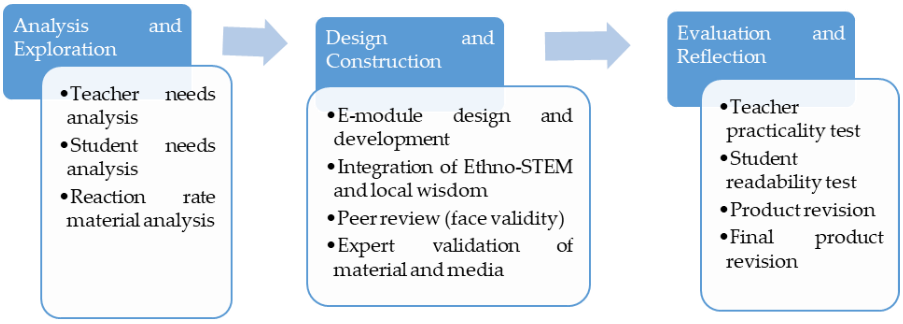

Figure 1. Research Flow of the DBR Development Model

Research Subjects and Variables

The research subjects consisted of five chemistry teachers, thirty Grade XI students, five peer reviewers, one material expert, and one media expert. The teacher and student participants were recruited from several senior high schools and Islamic senior high schools (SMA/MA) in Sleman Regency, Special Region of Yogyakarta, Indonesia. Participant selection was conducted using purposive sampling based on their relevance to the objectives of the study (Sugiyono, 2022).

The participating chemistry teachers had experience teaching reaction rate material and had previously used digital learning media in classroom instruction. The students involved were Grade XI students because reaction rate is taught at this educational level according to the Indonesian senior high school chemistry curriculum.

The peer reviewers consisted of final-year Chemistry Education students from Universitas Negeri Yogyakarta who had completed courses related to chemistry learning media development and educational research methodology. The material expert was a chemistry education lecturer with expertise in chemistry curriculum and instructional material development. The media expert was a lecturer with expertise in educational technology and digital learning media development.

The number of expert validators, consisting of one material expert and one media expert, was adjusted to the scope of this preliminary design research and was intended to support formative evaluation during the initial product development stage.

Object of Study

The object of this study was an Ethno-STEM-integrated chemistry learning e-module based on Sleman Regency local wisdom for reaction rate learning. The quality of the developed product was evaluated in terms of content validity, media validity, practicality, and readability.

Data Collection Instruments and Techniques

The research employed questionnaires adapted from previous e-module development studies conducted Laili (2024), Anggraini (2022), Nugraheni (2025), and Triani (2025). The instruments used included teacher and student needs analysis questionnaires, peer review sheets, expert validation sheets, teacher practicality test questionnaires, and student readability test questionnaires.

The teacher needs analysis questionnaire used a semi-structured format covering teaching material needs, experiences in using learning media, and expectations regarding e-modules. The student needs analysis questionnaire employed a structured format addressing learning characteristics, difficulties in learning reaction rate concepts, learning resources used, and local wisdom integration in chemistry learning.

The peer review, expert validation, practicality, and readability instruments employed a five-point Likert scale ranging from 1 (very poor) to 5 (very good). The assessed aspects included content quality, presentation, language, graphical design, Ethno-STEM integration, usability, benefits, and readability.

Data Analysis Techniques

Data obtained from teacher and student needs analyses were analyzed descriptively using qualitative analysis and inductive coding techniques to identify recurring themes and learning needs. Meanwhile, data from peer review, expert validation, practicality testing, and readability testing were analyzed descriptively using average scores and ideal percentages. The average score was calculated using the following formula:

$$\bar{x} = \frac{\Sigma x}{n}$$

The percentage score was calculated using the following formula.

$$\text{Ideal Percentage} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100\%$$

The obtained scores were then converted into qualitative categories according to the ideal assessment criteria proposed by Widoyoko (2016), as presented in Table 1.

Table 1. Ideal Conversion Guidelines

No.	Score Interval	Category
1.	X > Mi + 1,8 SBi	Very good
2.	Mi + 0,6 SBI < X ≤ Mi + 1,8 SBi	Good
3.	Mi – 0,6 SBi < X ≤ Mi – 0,6 SBi	Fair
4.	Mi – 1,8 SBi < X ≤ Mi – 0,6 SBi	Poor
5.	X ≤ Mi – 1,8 SBi	Very poor

Mi represents the ideal mean score and SBi represents the ideal standard deviation score.

RESULTS AND DISCUSSION

Analysis of Teacher and Student Needs

The initial stage of this study involved analyzing the needs of teachers and students to identify learning problems and determine the characteristics of the teaching materials required for reaction rate learning. Interviews with chemistry teachers in Sleman Regency revealed that reaction rate is one of the chemistry topics that students often perceive as difficult because it involves abstract concepts, particularly collision theory and factors affecting reaction rates. Teachers also reported that existing teaching materials were still dominated by textbooks and worksheets that emphasized theoretical explanations and algorithmic problem solving, with limited connections to students' daily experiences and local cultural contexts.

The student needs analysis supported these findings. Most students indicated difficulties in understanding reaction rate concepts and expressed preferences for learning materials that include visualizations, videos, simulations, and contextual examples related to everyday life. Students also reported that chemistry learning rarely incorporated local cultural knowledge despite the abundance of local wisdom available in their surrounding environment.

Table 2. Mapping of Sleman Local Wisdom to Reaction Rate Concepts

Context of Local Wisdom	Reaction Rate Concept
Tempe pondoh	Biological catalyst activity and fermentation rate
Apem Wonolelo	Fermentation kinetics and temperature effect
Ayam goreng Kalasan	Temperature effect and Maillard reaction
Jadah tempe	Surface area and heat transfer
Cethil	Gelatinization process and temperature effect

These findings are consistent with previous studies reporting that reaction rate is frequently associated with misconceptions because students are required to understand chemical phenomena at macroscopic, microscopic, and symbolic levels simultaneously (Johnstone, 1991). When learning materials fail to bridge these representational levels, students tend to memorize concepts rather than construct meaningful understanding. Therefore, the development of contextual teaching materials that connect chemistry concepts with real-life experiences becomes essential.

Based on these findings, an Ethno-STEM-based chemistry e-module integrating local wisdom from Sleman Regency was designed.

Unlike previous Ethno-STEM studies that generally used local culture merely as contextual illustrations, this study systematically mapped local cultural products to specific reaction rate concepts. This mapping constitutes the main novelty of the developed e-module because local wisdom functions not only as cultural content but also as a conceptual representation of chemical phenomena.

A visual depiction and QR code to access the developed e-module are presented in Figure 2. The e-module is published online in flipbook format and can be accessed via https://heyzine.com/flip-book/01ea42349d.html or by detecting the QR code displayed in Figure 2.

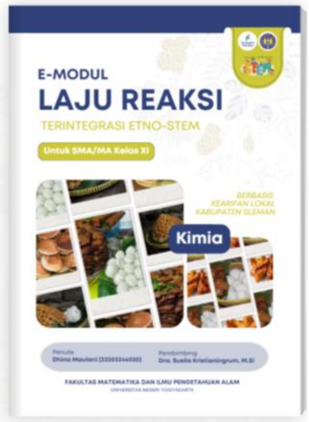

Figure 2. Visual Overview and QR Code for Accessing the Developed E-Module

The scientific basis of this mapping lies in the fact that each local culinary process involves factors affecting reaction rates. Tempe pondoh fermentation illustrates the role of biological catalysts (enzymes produced by microorganisms) in accelerating biochemical reactions. Apem Wonolelo demonstrates how fermentation duration and temperature influence the production of carbon dioxide during dough expansion. The preparation of ayam goreng Kalasan represents temperature-dependent reaction rates and Maillard reactions responsible for browning. Jadah tempe can be used to explain surface-area effects and heat transfer processes, whereas cethil preparation demonstrates gelatinization and heating effects on starch transformation.

Consequently, local wisdom in this study serves not merely as a cultural ornament but as a conceptual foundation for understanding reaction rate factors. This approach aligns with ethnoscience principles emphasizing the transformation of indigenous knowledge into scientific learning contexts (Arfianawati et al., 2016; Parmin & Fibriana, 2019).

Construction Phase

Peer Review Evaluation

The initial e-module prototype was evaluated by five peer reviewers from the Chemistry Education Study Program. The peer review focused on content quality, language, presentation, graphics, and Ethno-STEM integration. The overall evaluation achieved an ideal percentage of 95%, categorized as very good.

Despite the high rating, peer reviewers identified several aspects requiring improvement. Suggestions included providing alternative video links, improving QR code readability, refining paragraph spacing, ensuring consistency in scientific terminology, and adding supporting references for several chemistry concepts. These recommendations indicate that product quality is influenced not only by content accuracy but also by technical accessibility and readability.

The revisions made based on peer-review feedback reflect one of the essential characteristics of Design-Based Research, namely iterative improvement through formative evaluation (McKenney & Reeves, 2012). According to Mayer (2014), effective multimedia learning environments require not only accurate content but also coherent presentation and ease of information access. Therefore, the peer-review stage played an important role in improving the usability and instructional quality of the e-module before expert validation.

Validation Material Expert

Validation by the material expert produced ideal percentages of 76% for content feasibility, 78% for presentation, and 80% for Ethno-STEM integration, resulting in an overall category of good.

The expert confirmed that the reaction rate concepts presented in the e-module were scientifically accurate and aligned with curriculum objectives. Furthermore, the integration of Sleman local wisdom was considered relevant and capable of supporting contextual chemistry learning.

However, unlike the peer-review results, material validation revealed several conceptual limitations. First, some abstract chemistry concepts such as gelatinization, enzymatic activity, and Maillard reactions were not yet supported by sufficient scientific visualizations.

Second, several scientific terms required clearer explanations through glossaries or annotations. Third, some cultural illustrations had not fully demonstrated the relationship between observable cultural phenomena and underlying microscopic chemical processes.

These findings suggest that contextualization alone does not automatically guarantee conceptual understanding. Students still require adequate visual representations to connect macroscopic cultural practices with submicroscopic chemical explanations. This observation supports Johnstone (1991) theory that chemistry learning must integrate macroscopic, microscopic, and symbolic representations.

Following expert recommendations, additional visualizations and explanatory materials were incorporated into the e-module. Nevertheless, the validation results indicate that future revisions should further strengthen inquiry-based activities, such as investigating fermentation rates, comparing temperature effects experimentally, and analyzing reaction-rate data quantitatively. Such additions would allow local wisdom to function not only as contextual content but also as a basis for scientific investigation.

Validation Media Expert

Media expert validation resulted in an ideal percentage of 98%, categorized as very good. The expert evaluated the e-module as visually attractive, easy to navigate, and accessible through various digital devices. Features such as hyperlinks, embedded videos, interactive worksheets, and structured navigation were considered effective in supporting independent learning.

Nevertheless, several improvements were recommended. The expert emphasized the importance of scientific accuracy in illustrations and highlighted copyright considerations related to image sources. These comments indicate that media quality should be evaluated not only in terms of aesthetics but also regarding scientific integrity and ethical use of digital resources.

According to Moreno and Mayer (2014), multimedia effectiveness depends on the extent to which visual elements direct learners' attention toward relevant conceptual information. Therefore, revisions were conducted by replacing several images, adding source citations, and refining visual representations to better support conceptual understanding.

Final Reflection

Practical Evaluation Teacher

The practicality test involved five chemistry teachers from SMA/MA in Sleman Regency. The instrument consisted of 37 items using a five-point Likert scale. Ideal percentages were calculated using:

$$\text{Ideal Percentage} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100\%$$

The results are presented in Table 3.

Table 3. Practical Teacher Test Results

No	Aspect	The amount of goods	Maximum Score	Average Score ($\bar{x}$)	Ideal Percentage (%)	Category
1	Content suitability	4	20	18.6	93	Very good
2	Ease of use	3	15	14.2	95	Very good
3	Presentation	11	55	53.4	97	Very good
4	Benefit	13	65	62	95	Very good
5	Local wisdom and STEM	6	30	29.2	98	Very good
	Overall	37	185	177.4	96	Very good

The teacher practicality test yielded an ideal percentage score of 96%, which was categorized as very good. These results indicate that the developed e-module is considered practical and feasible for use in chemistry learning, particularly in terms of content quality, ease of use, presentation, usefulness, and the integration of local wisdom and STEM elements. The high score obtained in the presentation aspect suggests that the e-module is capable of delivering reaction rate concepts in a systematic, attractive, and contextual manner through the incorporation of local cultural products from Sleman Regency.

A distinctive feature of the developed e-module is the systematic mapping of local culinary traditions to reaction rate concepts. For example, the fermentation process of *tempe pondoh* and *apem Wonolelo* is used to explain catalyst activity, fermentation kinetics, and the influence of temperature on reaction rates. The preparation of *ayam goreng Kalasan* illustrates the effect of temperature on reaction rates through browning processes associated with the Maillard reaction. Meanwhile, *jadah tempe* and *cethil* are utilized to explain the influence of surface area, heat transfer, and gelatinization processes on chemical changes. This mapping enables students to connect abstract chemistry concepts with observable phenomena in their daily lives, thereby enhancing the meaningfulness and relevance of learning. Such findings are consistent with Gazali & Andriani (2025), who reported that ethnoscience-based learning can improve students' conceptual understanding and scientific literacy by linking scientific concepts with local cultural practices.

Furthermore, the integration of STEM components within the e-module supports contextual learning experiences by connecting science concepts with technological applications, engineering design processes, and mathematical reasoning. As a result, the e-module functions not only as a learning resource but also as an instructional medium that promotes the development of 21st-century skills. This finding is in line with Thibaut et al. (2018), who emphasized that integrated STEM learning can foster critical thinking, problem-solving, collaboration, and creativity skills.

The high practicality score obtained in the ease-of-use aspect indicates that the e-module is flexible, user-friendly, and easily accessible through digital devices. Interactive features such as videos, hyperlinks, QR-code-based resources, and online worksheets allow students and teachers to access learning materials anytime and anywhere, supporting more efficient and independent learning. This finding supports the study of Nurhasmiati et al. (2026), which reported that well-designed digital e-modules can enhance learning practicality and promote students' self-directed learning.

In terms of benefits, teachers perceived that the e-module effectively supports the development of 4C competencies, namely critical thinking, communication, collaboration, and creativity. The learning activities encourage students to analyze reaction rate phenomena, discuss scientific explanations, solve contextual problems, and relate chemistry concepts to local cultural practices. Therefore, the developed e-module is not solely oriented toward conceptual mastery but also toward the development of higher-order thinking skills and 21st-century competencies. This finding is supported by Fatma et al. (2025), who found that interactive e-modules can improve students' higher-order thinking skills and increase active engagement during learning.

Despite the highly positive practicality results, several limitations should be acknowledged. The practicality evaluation involved only five chemistry teachers from schools within Sleman Regency, which may limit the generalizability of the findings to broader educational contexts. In addition, practicality data primarily reflect teachers' perceptions rather than actual classroom implementation outcomes. Consequently, further studies involving larger samples and real classroom applications are necessary to examine whether the high practicality observed in this study can be maintained across different learning environments.

Student Readability Evaluation

The readability test involved 30 SMA/MA students in Sleman Regency. The instrument consisted of 39 items with a maximum score of 195. The readability are presented in Table 4.

Table 4. Student Readability Test Results

No	Aspect	The amount of goods	Maximum Score	Average Score ($\bar{x}$)	Ideal Percentage (%)	Category
1	Attractiveness	10	50	47.7	95	Very good
2	Material aspects	10	50	47.3	95	Very good
3	Language aspects	10	50	49.1	98	Very good
4	Benefit	9	45	43.3	96	Very good
	Overall	39	195	187.4	96	Very good

The results of the student readability test showed an ideal percentage score of 96%, which was categorized as very good. These findings indicate that the developed e-module was perceived positively by students in terms of attractiveness, content presentation, language, and overall usefulness. The high readability score suggests that the e-module can support students' understanding of reaction rate concepts through an interactive and contextual learning environment.

In the attractiveness aspect, students reported that the e-module provided a new, engaging, and enjoyable learning experience. Interactive features such as hyperlinks, images, videos, simulations, and QR-code-based resources enabled students to access learning materials more easily and actively. The integration of multimedia elements helped reduce the monotonous nature of conventional learning materials and increased students' interest in exploring the content independently. This finding is consistent with She & Chen (2009), who reported that interactive digital learning media can enhance students' motivation, engagement, and participation in science learning.

In the material aspect, students perceived that the content was presented systematically, clearly, and comprehensibly. The use of concept maps, summaries, glossaries, worked examples, and evaluation questions helped students organize and understand reaction rate concepts more effectively. Furthermore, the integration of local wisdom and STEM components enabled students to connect abstract chemical concepts with familiar cultural practices in their daily lives. For instance, the fermentation process of *tempe pondoh* and *apem Wonolelo* was used to explain catalyst activity and fermentation kinetics, while *ayam goreng Kalasan* illustrated the influence of temperature on reaction rates through the Maillard reaction. Likewise, *jadah tempe* and *cethil* were utilized to explain the effects of surface area, heat transfer, and gelatinization processes on chemical changes. Such contextual representations helped students develop a deeper conceptual understanding of reaction rate factors while simultaneously increasing their awareness of local cultural heritage. This finding supports Mayer (2014) multimedia learning theory, which emphasizes that meaningful learning occurs when verbal and visual information are effectively integrated.

The language aspect also received a very good rating because the language used in the e-module was considered simple, communicative, and appropriate for senior high school students. Clear explanations, consistent terminology, and supportive visual elements contributed to the readability of the learning materials. In addition, the combination of text, images, color variations, and videos helped students maintain attention and process information more effectively. According to Mayer (2014), appropriately designed multimedia materials can reduce cognitive load and facilitate meaningful learning by presenting information in ways that align with students' cognitive processes.

In terms of usefulness, students perceived that the e-module supported independent learning through its self-instructional, self-contained, stand-alone, adaptive, and user-friendly characteristics. The learning activities encouraged students to analyze reaction rate phenomena, solve contextual problems, and communicate scientific ideas based on local cultural practices. Consequently, the e-module was perceived as supporting the development of 21st-century competencies, particularly critical thinking, communication, collaboration, and creativity (4C skills). This finding is in agreement with Thibaut et al. (2018), who stated that STEM-based learning environments can effectively foster higher-order thinking skills and essential competencies for the 21st century.

Compared with previous studies that primarily focused on STEM integration without explicitly incorporating local cultural contexts, this study offers a more contextualized approach by systematically integrating Sleman Regency local wisdom into reaction rate learning materials. The novelty of this study lies not only in the use of local culture as a contextual example but also in its systematic mapping to specific reaction rate concepts, including fermentation kinetics, catalyst activity, temperature effects, Maillard reactions, gelatinization, and surface-area-dependent processes. Through this approach, local wisdom serves as a conceptual foundation for learning rather than merely as cultural enrichment.

Nevertheless, several limitations should be acknowledged. First, the readability test involved only 30 students from a limited number of schools in Sleman Regency, which may restrict the generalizability of the findings to broader educational contexts. Second, the readability assessment focused on students' perceptions and experiences rather than direct measurements of learning outcomes or conceptual mastery. Third, although the e-module received highly positive responses, some students suggested the addition of more interactive simulations and practice questions to further support independent learning. Therefore, future studies should involve larger and more diverse participant groups, incorporate effectiveness testing, and evaluate the impact of the e-module on students' conceptual understanding, scientific literacy, and higher-order thinking skills through experimental or quasi-experimental research designs.

Overall, the findings indicate that the chemistry learning e-module based on Sleman Regency local wisdom integrated with Ethno-STEM demonstrates a high level of readability and user acceptance. The integration of local culture with STEM learning creates a more contextual, engaging, and meaningful learning experience, enabling students to understand reaction rate concepts while simultaneously appreciating the scientific values embedded within their local cultural heritage.

CONCLUSION

This study successfully developed a chemistry learning e-module based on Sleman Regency local wisdom integrated with the Ethno-STEM approach on the topic of reaction rate. The novelty of this study lies in the systematic mapping of local cultural products of Sleman Regency, including *tempe pondoh*, *apem Wonolelo*, *ayam goreng Kalasan*, *jadah tempe*, and *cethil*, into reaction rate concepts such as fermentation kinetics, catalyst activity, temperature effects, surface area, heat transfer, gelatinization, and the Maillard reaction. The developed e-module was designed as an interactive flipbook equipped with text, images, videos, hyperlinks, exercises, and evaluation activities, while fulfilling the characteristics of self-instructional, self-contained, stand-alone, adaptive, and user-friendly learning materials. The results of expert validation, teacher practicality testing, and student readability testing indicate that the e-module is feasible, practical, engaging, and easy to understand for chemistry learning.

The teacher practicality test and student readability test each obtained an ideal percentage score of 96%, indicating highly positive responses from both teachers and students. These findings suggest that the integration of local wisdom and the Ethno-STEM approach can support more contextual, meaningful, and culturally responsive chemistry learning while promoting students' engagement and 21st-century competencies. However, this study was limited to an initial Design-Based Research (DBR) cycle focusing on product development, validation, practicality, and readability. Therefore, further studies are recommended to examine the effectiveness of the e-module in improving students' conceptual understanding, scientific literacy, higher-order thinking skills, and learning outcomes through broader classroom implementation and experimental research designs.

RECOMMENDATION

Future studies are recommended to examine the effectiveness of the e-module in improving learning outcomes, critical thinking skills, and students' scientific literacy in broader educational contexts. In addition, the development of local wisdom and Ethno-STEM-based e-modules can be applied to other chemistry topics by adding more interactive digital features such as online quizzes, simulations, and integrated learning videos. Teachers are also encouraged to utilize this e-module as an alternative contextual teaching material to connect chemistry concepts with the local culture surrounding students' daily lives.

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