JKPK (JURNAL KIMIA DAN PENDIDIKAN KIMIA), Vol. 8, No.3, 2023 pp. 407-422
Chemistry Education Study Program, Universitas Sebelas Maret ISSN 2503-4146
https://jurnal.uns.ac.id/jkpk ISSN 2503-4154 (online)

DEVELOPMENT OF CHEMICAL LEARNING ELECTRONIC MODULE BASED ON MULTIPLE REPRESENTATION IN THE REDOX TOPIC

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ARTICLE INFO

Keywords:
E-module;
multiple representations;
redox.

Article History:
Received: 2022-07-29
Accepted: 2023-07-18
Published: 2023-12-31

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doi:10.20961/jkpk.v8i3.64120

ABSTRACT

The advent of the COVID-19 pandemic in 2020 significantly shifted educational paradigms, necessitating the adoption of online learning modalities. This study, rooted in the contextual changes brought by the pandemic, aimed to evaluate the effectiveness, quality, and impact of a Mixed Reality (MR) e-module on redox reaction topics in a high school setting. The research followed a 4D model (Define, Design, Develop, Disseminate) but was confined to the development phase. Conducted in a High School in Yogyakarta, Indonesia, this study involved 98 students (30 from grade 12 and 68 from grade 11), 3 teachers, and 2 validators. The research methodology included pre-tests and post-tests alongside questionnaires to gather data. Descriptive statistical analysis was employed to process the assessments from validators, teachers, student responses, and test results. The field trial results indicated that the respondents deemed the MR e-module for chemistry learning satisfactory and effective. The analysis of the test of between-subject effect revealed no significant differences in interest and pre-test learning achievement between control and experimental groups. However, post-test results showed notable differences in interest and learning achievements, favoring the experimental group exposed to the MR e-module. The effectiveness of the MR e-module was quantified using partial eta-squared calculations. The MR e-module contributed 25.7% effectively to both learning interest and achievement. When considered separately, the contribution was 2.7% for learning interest and 21.9% for learning achievement. These findings underscore the potential of MR e-modules as valuable educational tools, enhancing student engagement and academic performance in online learning environments during the COVID-19 pandemic.

How to cite: S. Arfan and N. Aznam, "Development of chemical learning electronic module based on multiple representations on redox topic," *JKPK (Jurnal Kimia dan Pendidikan Kimia),* vol. 8, no. 3, pp. 407-422, 2023. http://dx.doi.org/10.20961/jkpk.v8i3.64120

INTRODUCTION

The COVID-19 pandemic, a significant global crisis, has profoundly affected education, particularly evident in Indonesia, where ten cases were confirmed as of March 16, 2020 [1]. This situation necessitated a shift from traditional learning methods, challenging students to adapt to new educational environments [2]. Specifically, in chemistry education, the inherent abstractness of many concepts, which are difficult to perceive directly, adds to the learning challenges [3]. The teaching methodologies and textbooks often exacerbate these complexities [4-8]. Therefore, there is a critical need for effective teaching strategies and instructional tools that cater to the unique nature of chemistry learning. Implementing instruction and integrating educational content significantly influence students' understanding of chemistry [9]. These innovative teaching approaches and educational media are essential in conveying chemical principles effectively, enhancing student engagement, and improving learning outcomes, particularly in making complex chemical concepts more comprehensible and countering the monotony associated with studying these abstract phenomena [10].

Integrating media assistance in educational content is crucial to enhancing students' understanding of chemical principles, particularly in environments with limited traditional learning resources [11]. E-modules: With their numerous benefits, E-modules are becoming increasingly important in modern education. These digital modules offer versatility, allowing access from any location, and present a practical alternative to traditional print instructional media [12,13]. They allow students to learn independently, reducing educators' need for constant guidance and enabling learning outside scheduled class hours [14-16].

In a study by [17] involving three classes of grade 12 students totaling 68 participants, using multiple representations in e-modules significantly enhanced students' cognitive structural abilities from pretest to posttest [18]. This aligns with existing research highlighting incorporating multiple representations into learning chemical concepts. However, conventional printed content often needs to be revised. It needs to be revised to effectively present A deep understanding of chemistry, which simultaneously engages concepts at macroscopic, submicroscopic, and symbolic levels [19]. There is a noted research gap in how students at different stages of their education, such as first- and third-year university chemistry students, interpret various atomic representations [20]. Addressing this gap, the MR e-module is designed based on the concept of multiple representations, offering a comprehensive and versatile educational tool for students.

The pursuit of science education aims to understand natural phenomena. According to Johnstone's theory, chemistry is comprehended through three distinct representation levels: the symbolic level (involving equations and diagrams), the particulate level (focusing on the molecular, which is invisible), and the macroscopic level (observable and tangible elements). These levels are crucial as they help overcome learning challenges and enhance understanding by linking concepts across these domains [21-27]. However, students often need help to make these inter-domain connections, requiring significant educational intervention [23]. Creating and evaluating representations that simplify nature's complexities is essential [28]. Learning resources that effectively convey chemistry through multiple representations are still being developed; content operating these representations can significantly impact chemistry education and improve students' cognitive achievements [29,30].

This study aims to develop an innovative MR e-module to expand students' understanding of chemical concepts. The MR module's unique advantage lies in presenting a single concept through various formats, including verbal, visual, symbolic, graphic, and numerical representations. This approach helps clarify and correlate concepts across the macroscopic, microscopic/ submicroscopic, and symbolic levels [31-35].

The newly introduced MR e-module is a pioneering tool in chemistry education, uniquely integrating content across the symbolic, submicroscopic, and macroscopic levels. It combines equations and diagrams, animated molecular visuals, and tangible phenomena imagery into a single application compatible with Android and Windows platforms [11-36]. This MR e-module offers ease of use and epitomizes practicality and conciseness, thereby transforming the educational experience. Through the MR e-module, students gain the freedom for self-guided learning, accessible from anywhere. This method not only alters students' perceptions of interactive learning but also enhances their comfort and engagement. While traditional printed modules include images, narratives, and graphics, e-modules incorporate audio, music, animations, and videos [37,38], offering a diverse and engaging learning experience

METHODS

1. Research Design

This study employed the Research and Development (R&D) approach, utilizing the 4D model by Thiagarajan as the developmental framework. The 4D model, a structured product development methodology, comprises four main phases: Define, Design, Develop, and Disseminate [39-41]. The process flow of these phases is depicted in Figure 1.

2. Participants and Instruments

Participants were selected through random sampling. The legibility test for the developed Chemistry Learning MR e-module involved 30 eleventh-grade students enrolled in the Science Program at a public high school in Yogyakarta. These students also participated in the empirical validation phase, including learning achievement essays and learning interest questionnaires.

Three teachers from various public high schools in Yogyakarta were randomly chosen to assess the practicality of the e-module. Additionally, two validators from Universitas Negeri Yogyakarta were involved in the prototype trial, evaluating the module's media and content.

The Chemistry Learning MR e-module was implemented in two classes for field trials at a public high school in Yogyakarta. One class, comprising 34 students, served as the experimental group, utilizing the e-module. The other class, with 34 students, acted as the control group, learning without the e-module. In total, 68 students across both groups participated in the study. Instruments measuring student learning achievement included pre-test and post-test essays aligned with basic and content competencies and study chemical concepts. From an initial set of 13 essay questions, 8 were selected based on meeting the testing criteria. The learning interest was measured using a 26-question questionnaire, which was fully validated. The assessment of learning achievement and interest involved 30 students from the eleventh-grade Science Program class.

3. Data Analysis

This research and development study processed data from validator assessments, student responses, and test results using descriptive statistical analysis. This approach involved quantitatively scoring and analyzing the data to draw meaningful conclusions. In contrast, qualitative descriptive analysis focuses on interpreting and understanding the nuances of the data, providing insights into facts, ideas, and suggestions for improvement from the validators.

Multivariate tests were employed to determine differences in student interests and learning achievements, including Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root. These tests analyze variance across multiple dependent variables to identify any significant differences. The Test of Between-Subject Effects was used to analyze differences in pre-test and post-test interests and learning achievements between the experimental and control classes. The Partial Eta Squared statistical measure was utilized to determine the effective contribution percentage of the E-module to the observed outcomes.

4. Development Model

The development of the MR e-module began with a needs assessment phase, which involved distributing questionnaires, conducting interviews, and making observations in the classroom setting. This phase was crucial to understanding the specific needs of students and the effectiveness of current teaching chemical concepts and models in the educational process. The insights gathered from this initial phase informed the customization of the educational approach to suit student requirements better.

A significant part of the development process was the creation of submicroscopic animated videos. These videos were designed to provide a detailed and comprehensible representation of chemical reactions at the submicroscopic level. The aim was to foster student interest, improve understanding, and address potential misconceptions inherent in the abstract nature of chemistry. These videos are intended to enhance students' engagement and comprehension by visually representing chemical processes.

The final phase of this study evaluated the effectiveness of incorporating teaching animation videos within the MR e-module. This assessment was critical in determining whether introducing animated content into the e-module significantly impacted students' learning experiences. The entire development procedure for the MR e-module adhered to the 4D development model [40], as depicted in Figure 1. This model provided a structured approach to the e-module, ensuring that each development phase was methodically planned and executed to meet the project's goals

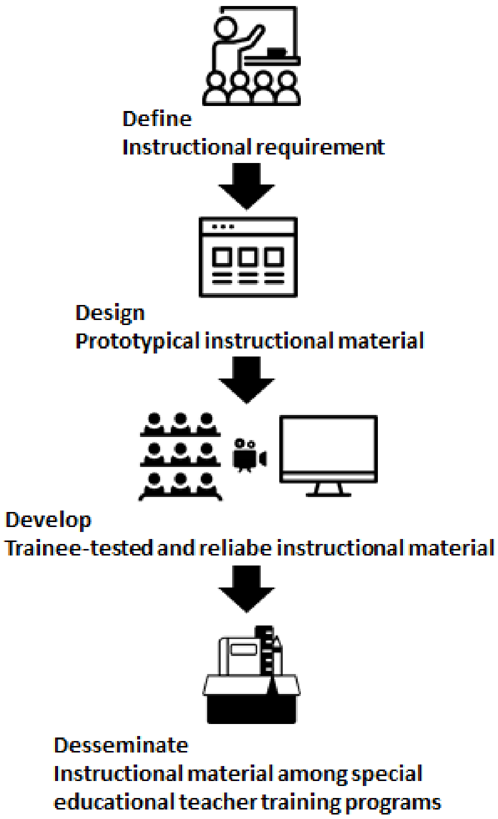


Figure 1. Stages of 4D model development

The content validity testing instrument involved a nine-question questionnaire focusing on aspects related to learning and chemical concepts. The concept underwent assessment by two chemical content experts from Yogyakarta State University on January 19, 2022. A questionnaire containing 11 questions was employed for the media validity testing instrument evaluating aspects like images, videos, and software engineering. Two media experts from Yogyakarta State University conducted this assessment on January 19, 2022.

The practicality of the media was evaluated using a questionnaire with 20 questions that addressed aspects such as visual and audio components, software engineering, and learning chemical concepts. This practicality assessment was conducted with the participation of 3 chemistry teachers from Yogyakarta High School between January 18 and 20, 2022. Additionally, the media's readability was assessed through a readability questionnaire of 14 questions focused on visual and audio aspects, software engineering, and chemical concepts. This questionnaire was administered to 30 students from a public high school in Yogyakarta on January 31, 2022.

Theoretical validation was performed through expert judgment, while empirical validation was conducted using Cronbach's alpha analysis with the QUEST program. This program offers a comprehensive test and questionnaire analysis environment, incorporating the latest advancements in Rasch measurement theory and traditional analysis procedures. The Rasch analysis produces item estimates, case estimates, and fit statistics, with results presented through various tables and maps [42].

Experts provided assessments to evaluate the product's quality, content, and media, and teachers and students were also involved in the evaluation process. The pre-test and post-test results for interest and learning achievement were analyzed using multivariate and between-subject effect tests [43]. Additionally, effect size calculations were performed using partial eta-square [44,45].

RESULTS AND DISCUSSION

In this study, the 4D model by Thiagarajan was employed, focusing on the defining, designing, developing, and

Disseminating stages of product development. This section details the defined stage of the MR e-module development:

1. Definition Stage

The initial step involved defining various needs in the learning process. This stage included interviewing two chemistry teachers at Yogyakarta High School via WhatsApp Messenger to ascertain their perspectives on online learning media, the effectiveness of current resources, and the feasibility of developing MR E-Modules. Teacher feedback suggested more diversified and engaging learning media during online sessions. One teacher noted, "Good, can add more ways to the delivery analysis revealed that online learning posed concentration challenges. Students reported that learning through multiple representations, particularly submicroscopic animation videos, provided a comprehensive understanding from various angles and was simple and engaging. This analysis, supported by research [46,47], showed that multiple representations could significantly enhance student understanding.

Assignment analysis, based on a questionnaire about student needs, indicated a demand for additional learning resources beyond standard online tools like WhatsApp Groups, Google Classroom, Google Meet, Microsoft Team, Edmodo, YouTube videos, and Schoology. The proposed MR e-module for Chemistry on Redox was developed in response to this need, offering a more varied learning experience [48]. This development was particularly timely given the unforeseen necessity of online learning due to COVID-19 [49].

Concept analysis involved reviewing the core competencies (CC) and basic competencies (BC) of the revised 2013 curriculum. Resources for the MR e-module were collated from various sources, including content descriptions, images, and videos related to the Redox topic. This comprehensive approach aimed to fulfill the learning objectives set out in the curriculum, ensuring that students achieved the competency indicators aligned with the formulated BC [50].

2. Design

In the design stage [40], the objective was to create a prototype of the MR e-module. This involved preparing tests on redox, including d, developing grids, and scoring rubrics. The aim was to ensure that the topic tested aligned with the learning objectives [51]. Media selection was conducted to identify learning media relevant to the topic and the problems faced by teachers and students. The research findings indicated that electronic modules with multiple representations were viable for developing as a medium for delivering chemistry concepts. The concept section adhered to vocational Education's book criteria format (2008) and the BNSP's textbook criteria format. The product was developed in Android and Windows application formats. The initial product design was based on previously prepared guidelines, flowcharts, and storyboards, resulting in an MR e-module for chemistry learning on Redoxx. The MR E-module features include a table of contents accessible by clicking on the title and pop-up features for enlarged images and videos depicting submicroscopic events of the reaction.

3. Development Phase:

The development phase focused on enhancing the items from the design stage. The final output was achieved by refining revisions based on feedback from experts, chemistry educators, and students. The content expert suggested, "The module's footnotes should not be referenced within the book; they should only appear in the bibliography." For symbolic representation, it was noted, "The format of a compound (solid, solution, liquid, and gas) in symbolic representation should not be written as a subscript; it should be presented in the same font size as the atomic/compound font." This precise depiction of symbols is essential for clear comprehension. Following these revisions, the module was evaluated by a chemistry teacher, who found it satisfactory but recommended omitting the section on equalization of redox reactions as it is not covered in the 10th-grade curriculum. Additionally, feedback from 11th-grade students confirmed the module's positive reception. This process aligns with symbolic interaction theory, emphasizing the importance of cultural symbols or signs acquired through interaction, shaping attitudes and behaviors [52].

4. Analysis

The assessment by chemical content experts was conducted using a questionnaire focusing on learning and chemical concepts—this process, detailed in Figures 2 and 3, thoroughly evaluated content and learning aspects.

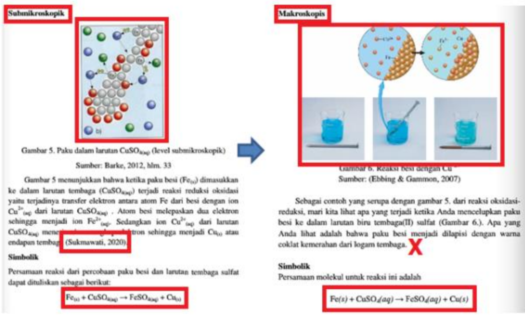


Figure 2. E-module Content Improvement

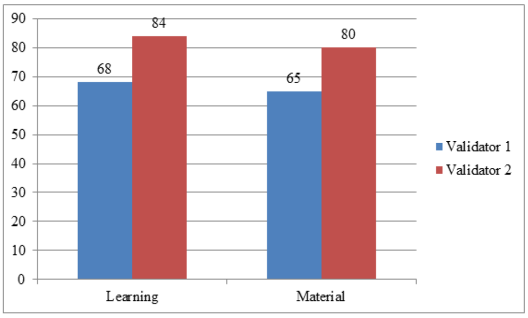


Figure 3. Average Percentage of Content Expert Validation Results on Learning and Chemical Aspects

In the validation results, the chemical content experts provided an average percentage score that reflected their overall assessment. As depicted in Figure 3, the feedback included suggestions for improvements like revising chemical content preparation, updating chemical reaction images, avoiding quotations within the text, and correctly presenting chemical formulas (Figure 2).

Figure 3 shows that the learning media received a favorable classification, particularly in content alignment and media accessibility. However, improvements were recommended in aligning indicators with content, clarifying user objectives, and enhancing interactive learning engagement within the media (Figure 4).

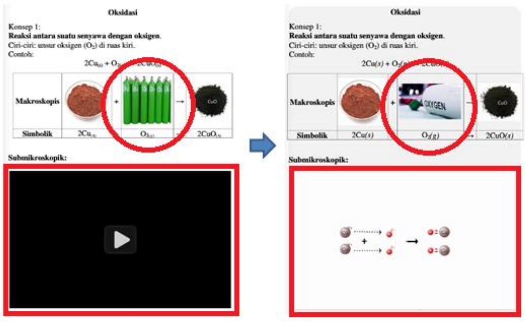


Figure 4. E-module Display Improvements

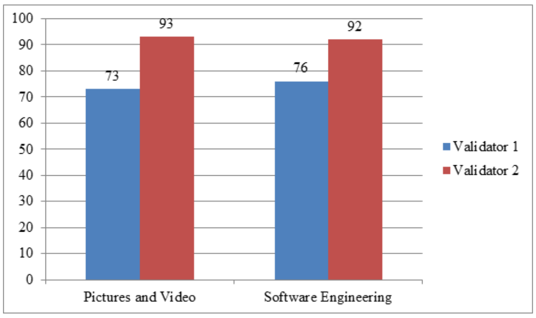


Figure 5. Average Percentage of Media Expert Validation Results on Pictures and Video and Software Engineering

Media experts assessed aspects of images, videos, and software engineering using a questionnaire, as detailed in Figures 5 and 6. The validators suggested improvements in the picture and video sections, including modifications to certain images and video thumbnails, as highlighted in Figure 4.

Figure 6 summarizes the validation results by media experts, focusing on each assessment aspect. The revisions suggested by the experts significantly enhanced the attractiveness of the media's appearance. Media experts categorized the pictures, video aspects, and software engineering components as excellent. Chemistry teachers evaluated the practicality of the MR e-module, considering visual and audio aspects, software engineering, learning, and chemical aspects. This comprehensive assessment is detailed in Figures 6 and 8. These assessments and subsequent revisions were crucial in ensuring the MR module's effectiveness and suitability for educational purposes, aligning with the study's aim to enhance students' understanding and interest in chemistry through innovative learning media.

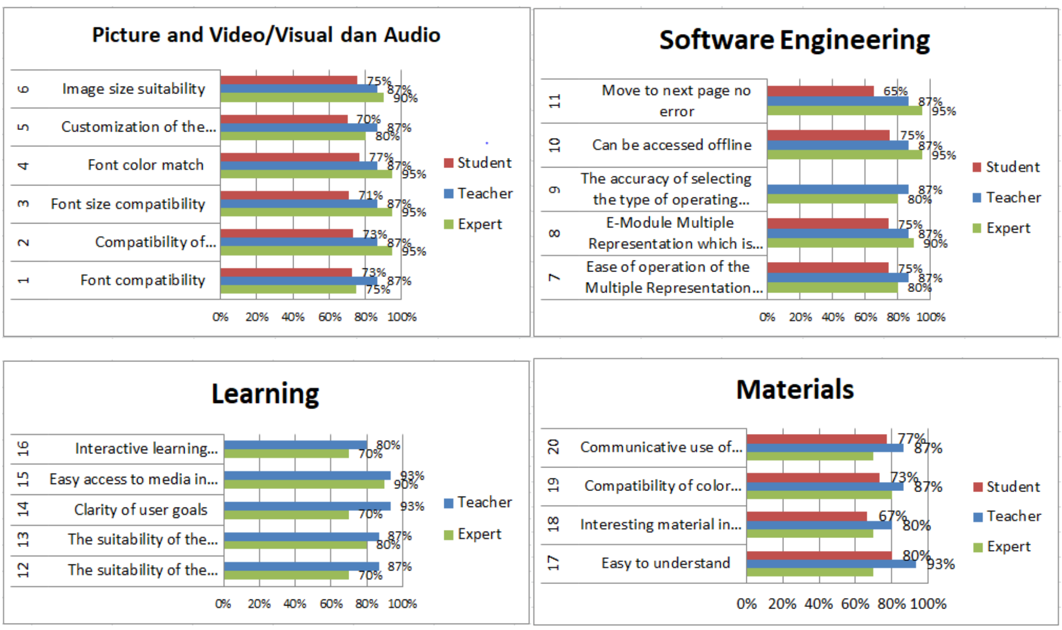


Figure 6. The Results of The Assessment by The Expert, Teachers, and Student.

Based on Figure 6, all aspects assessed from the learning media were stated as very good by the teacher. The improvement given by the teacher was to reduce the topic redox reaction because it was not delivered in grade 10, which can be seen in Figure 7. A summary of the results of the validation by the chemistry teacher for each aspect of the assessment is presented in Figure 8.

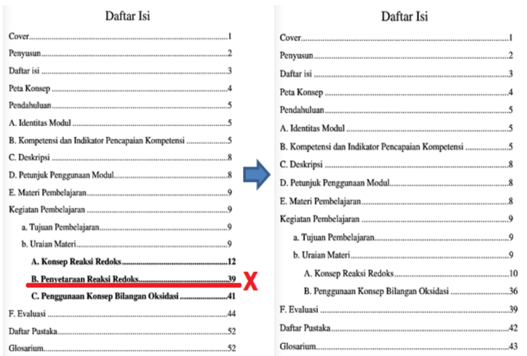


Figure 7. Content Improvement by Teacher.

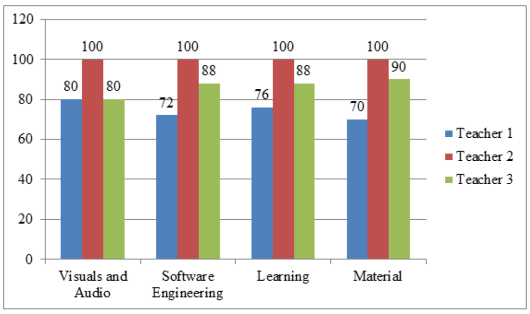


Figure 8. The Percentage of Practicality Assessment by Chemistry Teachers.

A readability test was conducted with 30 students from the 11th grade at a Public High School in Yogyakarta. This test evaluated students' perceptions of the MR module's visual and audio components, software engineering quality, and educational content. As outlined in Figure 9, the assessment results revealed that the students rated all aspects of the MR e-module positively. The detailed analysis of each aspect, based on the average assessment of 30 students, is presented in Figure 9.

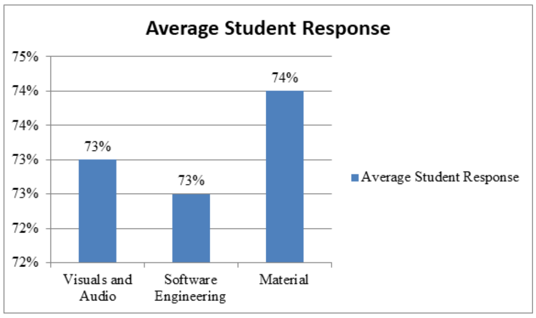


Figure 9. The Percentage of Readability Assessment by Students

The video of chemical reactions displayed on the module can be seen in the animation section in the screenshot in Figure 10.

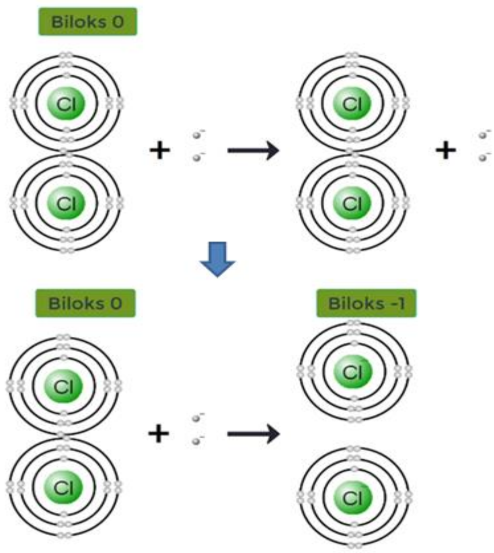


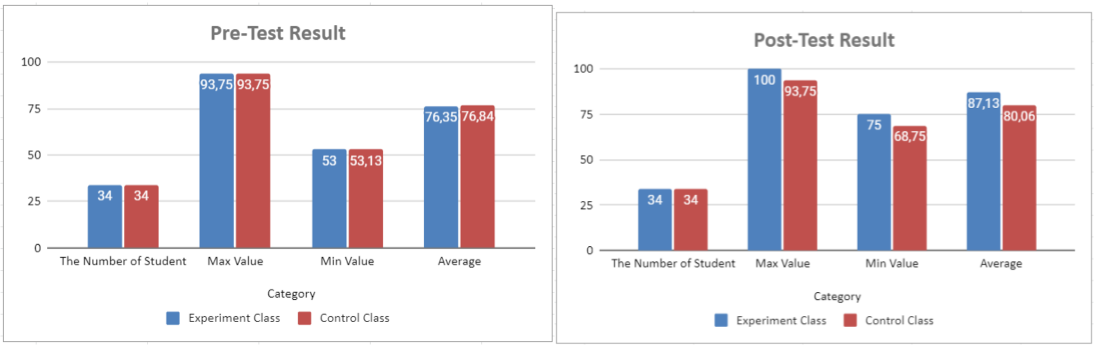
Figure 10. Examples of Animated Videos

The developed MR e-module offers a realistic portrayal of chemistry, effectively bridging macroscopic, symbolic, and submicroscopic levels. This multilevel approach aligns with Johnstone's concept of 'multilevel thinking,' emphasizing the importance of integrating different types of knowledge for comprehensive chemistry learning. The MR e-module facilitates understanding by presenting chemistry concepts across the 'macro' level (visible attributes like density or volume), the 'symbolic' level (formulas and equations), and the 'submicron' level (behavior of atoms and molecules) [23,26]. This approach significantly reduces students' misunderstandings about chemistry.

Disseminate

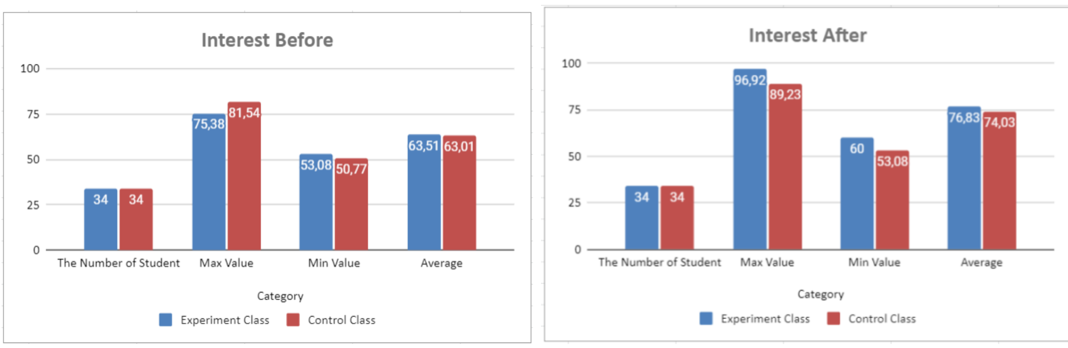
The MR e-module, focusing on redox and incorporating multiple representations, was disseminated by providing the module's web address to chemistry teachers and students at the Public High School in Yogyakarta. This initiative aimed to enhance the accessibility and usage of the module in educational settings.

Research conducted in both experimental and control classes provided insights into the impact of the MR e-module on students' cognitive learning achievements and interests. Figures 11 and 12 illustrate the results of the pre-test and post-test assessments in both classes. The pre-test showed no significant difference in cognitive understanding between the classes. At the same time, the post-test revealed higher achievements in the experimental class, indicating a positive effect of the MR e-module on students' cognitive understanding of redox implementation of the MR e-module implementation, thus significantly contributing to improving students' comprehension and interest in chemistry.



(a) Pre-test (b) Post-Test

Figure 11. Cognitive Achievement Result (a) Pre-Test and (b) Post-Test



(a) Pre-test (b) Post-Test

Figure 12. Interest Achievement Result (a) Pre-Test and (b) Post-Test.

The study evaluated students' learning interests before and after implementing the MR e-module in Chemistry, focusing on redox topics. This assessment utilized a questionnaire to gauge students' interest. The findings revealed no significant difference in initial learning interest (pre-test) between the experimental and control classes. However, the post-test results showed a marginal increase in learning interest in the experimental class compared to the control class. This indicates a positive influence of the MR e-module on enhancing students' interest in the subject matter. The integration of learning videos within the MR e-module contributed to this increased engagement [53]. Smartphones also facilitate teachers' and students' learning and evaluation [54].

The multivariate analysis of pre-test data indicated no significant differences in cognitive learning achievements and affective learning interest between the experimental and control classes before introducing different teaching content (significance > 0.05). Conversely, the post-test multivariate analysis demonstrated significant differences in these areas between the two classes after the intervention (significance <0.05), underscoring the effectiveness of the MR e-module in improving cognitive learning outcomes and affective learning interest. These results are detailed in Table 2.

.

Table 2. Results of Multivariate Data Analysis of Learning Achievement

Pre-Test						
Effect		Value	F	Hypothesis df	Error df	Sig.
Class	Pillai's Trace	.004	.116[a]	2.000	65.000	.891
	Wilks' Lamda	.996	.116[a]	2.000	65.000	.891
	Hotelling's Trace	.004	.116[a]	2.000	65.000	.891
	Roy's Largest Root	.004	.116[a]	2.000	65.000	.891
Post-Test						
Effect		Value	F	Hypothesis df	Error df	Sig.
Class	Pillai's Trace	.234	9.932[a]	2.000	65.000	.000
	Wilks' Lamda	.766	9.932[a]	2.000	65.000	.000
	Hotelling's Trace	.306	9.932[a]	2.000	65.000	.000
	Roy's Largest Root	.306	9.932[a]	2.000	65.000	.000

Table 3. Results of data analysis with Independent Sample T-test

Test of Between Subject Effect of Pre-Test Data						
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Class	Achievement Pretest	4.165	1	4.165	.035	.852
	Interest Pretest	4.210	1	4.210	.088	.767
Test of Between Subject Effect of Post-Test Data						
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Class	Achievement Pretest	851.582	1	851.582	18.472	.000
	Interest Pretest	133.756	1	133.756	1.825	.182

Table 4 . Effect Size Analysis Results

Test of Between Subject Effect of Pre-Test Data							
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Square
Kelas	Posttest Achievement	851.582	1	851.582	18.472	.000	.219
	Posttest Interest	133.756	1	133.756	1.824	.182	.027
Multivariate Tests							
Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta-Squared
Kelas	Pillai's Trace	.257	5.441[a]	4.000	63.000	.001	.257
	Wilks' Lamda	.743	5.441[a]	4.000	63.000	.001	.257
	Hotelling's Trace	.345	5.441[a]	4.000	63.000	.001	.257
	Roy's Largest Root	.345	5.441[a]	4.000	63.000	.001	.257

The Independent Sample T-test applied to the pre-test data showed no significant differences in cognitive learning achievements and initial learning interest scores between the experimental and control groups (significance > 0.05). However, the post-test results revealed significant differences in cognitive learning achievements and learning interest between the groups after the learning process (significance <0.05), suggesting that the MR e-module positively impacted learning outcomes. These findings are summarized in Table 3. The effective contribution of the e-module to learning outcomes was analyzed using partial eta square, as shown in Table 4. The module's contribution to learning achievement was 21.9%, to learning interest was 2.7%, and the simultaneous contribution to both was 25.7%. These results demonstrate that the learning media, particularly the MR e-module, significantly enhances learning achievement and interest in the subject matter [55].

CONCLUSION

The MR e-module for Learning Chemistry, specifically on the redox reaction, has been established as a viable, practical, and effective learning medium. Its feasibility has been endorsed by content experts categorized in terms of content. Media experts have rated it very highly for its media quality. Chemistry teachers have acknowledged its practical utility, deeming it suitable for instructional use. Additionally, a group of 30 students evaluated its readability positively. The study demonstrates that the MR e-module significantly enhances students' learning interest and achievement in redox and general chemistry topics. Specifically, it has shown a positive impact on student learning interest by 2.7%, reduced by 21.9%, and a combined effect of 25.7%. These findings suggest that the MR e-module bee is an innovative and interactive supplement to traditional chemistry teaching methods. The MR e-module for Learning Chemistry should be adopted in the context of redox reactions to provide a diverse and engaging learning experience. The development of MR e-modules for other chemistry topics is suggested to broaden the scope of interactive and effective learning tools for enhancing student engagement and understanding of the chemical concept.

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