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Development of Chemistry E-Modules Based on Augmented Reality Technology on Hydrocarbon Material

Nur Fitri Fadhilah[1] and Haqqi Annazili Nasution[2]*

[1,2]*Chemistry Education Study Program, Universitas Negeri Medan, Medan*

**Email*: haqqiannazili@unimed.ac.id

Abstract: *This study aims to develop an Augmented Reality (AR)-based chemistry e-module on hydrocarbon material for use in learning at SMAS Cerdas Murni. Hydrocarbons are considered a challenging topic for students due to their abstract nature. The research adopts a Research and Development (R&D) approach using the 4D model (Define, Design, Develop, Disseminate), but is limited to the Develop stage. The development process involved expert validation and user responses to determine the module's feasibility. Validation results showed scores of 90.91% from material experts and 92% from media experts, both categorized as highly feasible. Additionally, teacher responses reached 99% and student responses 91.34%, indicating a strong positive reception. These results demonstrate that the AR-based e-module is not only valid and practical but also effectively supports interactive and innovative learning. It is suitable for enhancing students' understanding of abstract chemical concepts, particularly hydrocarbons, and shows promise for broader implementation in the classroom.*

Keywords: *e-module; augmented reality; hydrocarbons*

INTRODUCTION

The Industrial Revolution 4.0 has transformed human life, placing information technology at the forefront, particularly in education. To prepare students for rapid changes, teachers must possess technological competencies aligned with current developments (Lase, 2019). The development of science and technology today requires teachers or educators to adapt in order to address challenges in the learning process. Learning media must be designed as attractively as possible so that students can easily understand the material (Silaban & Panggabean, 2022). Creativity, innovation, and critical thinking are essential, as students are expected to generate new ideas and solutions. As noted by Shahroom & Hussin, (2018), technology-based learning, especially online, enhances flexibility and access to educational resources.

Research indicates that in science learning, students often focus on memorizing concepts, theories, and principles without truly understanding how these ideas are developed (Panggabean & Purba, 2021). In fact, learning should be a transformative process that brings about changes in behavior,

encompassing knowledge, attitudes, and skills, shifting learners from not knowing to understanding. The effectiveness of this process relies on the synergy of various key components, including students, educators, learning objectives, instructional models and methods, tools, assessments, and the learning environment (Adenolira et al., 2020). Each of these elements plays a vital role in achieving learning success. Among them, learning objectives serve as the foundation, outlining the specific competencies that students are expected to master after undergoing a particular instructional process. These objectives are directly tied to the measurement of success in education. To realize these targets, the learning process must be organized with clarity and structure, highlighting the importance of deliberate and strategic planning to ensure its effectiveness (Purnasari & Sadewo, 2020).

Chemistry can be found in everyday life, yet many students consider it to be an uninteresting subject. This perception arises because chemistry is closely related to abstract ideas or concepts that require a high level of reasoning (Purba & Fitri, 2021). Hydrocarbons are one of the topics in chemistry that are considered difficult to understand because they have abstract properties, so a more concrete learning approach is needed to make them easy to understand. In studying this material, students are required to be able to classify hydrocarbon compounds based on the level of bond saturation, name the compounds, explain their physical and chemical properties, and identify isomers. This ability is not enough just by memorizing, but requires a deep understanding of concepts and the support of innovative and interactive learning media. Thus, students can more easily understand the material presented (Hastuti et al., 2021).

Based on the results of interviews conducted with teachers at SMAS Cerdas Murni, it was found that there were several problems in the learning process in the classroom, especially in the Hydrocarbon material. Students tend to have difficulty understanding the concepts taught and lack adequate technological literacy. This is due to the limited learning tools used, where the learning media available in the classroom are only textbooks and Student Worksheets. In addition, the learning methods applied by teachers are mostly still focused on lectures and discussions, without being supported by varied and innovative learning media. As a result, students easily feel bored and lose interest during the chemistry learning process. The lack of integration of technology and alternative learning media in teaching and learning activities further worsens the effectiveness of learning, so that student learning outcomes are less than optimal.

Teaching materials are an important part of the learning process because they can help facilitate students' learning. Teaching materials are a collection of content organized in a structured manner to support teachers or instructors in the learning process and to facilitate students in their learning. According to Sutiani et al. in (Panggabean & Harahap, 2020), teaching materials also serve as an essential component in developing students' skills. A high level of thinking skills reflects science as a way of thinking, and attitudes that illustrate the interaction between science, technology, and society (Purba & Sembiring, 2023).

One of the practical and concrete teaching materials used during the learning process is e-modules. E-modules provide students with the opportunity to learn independently while evaluating their understanding of the material. In it, there is a clear formulation of learning objectives, so that students can understand what competencies must be mastered in order to achieve the desired results. As a form of teaching material, e-modules are compiled using interactive and communicative language, which helps students understand the contents of the material (Lastri, 2023). When e-modules are combined with technology as a learning tool, this can be an innovative approach to the learning process. One of the advantages of e-modules is their flexibility,

because they can be accessed anytime and anywhere via devices such as cellphones or laptops (Inanna et al., 2021). The use of e-modules in learning is expected to encourage students to think logically and creatively and improve their ability to solve problems.

One form of technology that can be utilized as an interactive learning medium and has the potential to improve student learning outcomes is augmented reality (Reski et al., 2022). The use of this technology in teaching and learning activities can make it easier for students to understand concepts and theories, stimulate conceptual thinking skills, and provide visual experiences in three dimensions. In addition, augmented reality can also strengthen students' representation and perception, and create a more interesting, interactive, and enjoyable learning atmosphere. E-Modules based on Augmented Reality (AR) technology allow students to visualize difficult concepts interactively, so that teaching materials in this electronic format are expected to not only help students' understanding but also accelerate the digitalization process in schools (Alfitriani et al., 2021).

Research shows that augmented reality (AR)-based e-modules are very effective and feasible to use in learning. Inanna (2021) and Reski et al. (2022) reported that augmented reality-based e-modules on vector material scored very well (89% and approaching 4), indicating that their effectiveness was good. Agung et al. (2020) and (Lase, 2019) found that augmented reality applications for chemistry learning, such as molecular shapes and hydrocarbon compounds, facilitate learning (77.1% of students agree) and increase learning interest (86.7%), and are declared valid, practical, and effective. Nasya *et al.* (2023) reported that the validation of augmented reality-based chemistry e-modules on molecular shape material reached 97%, 94%, and 90%, with trial results showing feasibility of up to 95%. These findings emphasize the importance of augmented reality-based e-modules in improving the quality of education.

METHODS

This research adopts the Research and Development (R&D) approach, which aims to create and validate an educational product—in this case, an Augmented Reality (AR)-based chemistry e-module focusing on hydrocarbon material. The development model used is the 4D model introduced by Thiagarajan, Semmel, and Semmel, which includes four stages: Define, Design, Develop, and Disseminate. However, this study was limited to the third stage, Develop.

Define Stage: This initial stage involved identifying and analyzing the problems found in the classroom through interviews with chemistry teachers at SMAS Cerdas Murni. The main issues identified included students' difficulty in understanding hydrocarbon material and the lack of varied and interactive learning media. Additionally, a literature review and curriculum analysis were carried out to ensure that the module content aligns with the existing syllabus.

Design Stage: At this stage, the blueprint of the e-module was created, including determining the structure, layout, and instructional design. The researcher developed learning objectives, material content outlines, evaluation instruments, and user interface concepts. A significant component of the design was planning the integration of Augmented Reality (AR) to help visualize hydrocarbon structures in 3D. The AR content was designed using the Assemblr Edu platform.

Develop Stage: The chemistry e-module was developed as a web-based interactive media that can be accessed using various devices such as smartphones, tablets, and computers. The content was adapted from the national chemistry curriculum and enriched with interactive features and embedded AR markers. After the initial development, the e-module underwent validation by two expert reviewers: one material expert and one media expert. Validation instruments referred to BSNP standards and included multiple assessment

aspects such as content accuracy, language clarity, graphic quality, and AR integration. Based on expert input, the module was revised to address feedback before conducting limited trials with users.

Data Collection and Analysis: Instruments used included interview guides for the need analysis, validation checklists for expert reviews, and structured questionnaires for collecting teacher and student feedback. The validation scores were analyzed using percentage formulas to determine feasibility levels, which were categorized into appropriate quality levels. The results provided quantitative measures of the module's validity and practicality from the perspective of experts, teachers, and students.

Through these stages, the development process ensured that the e-module was aligned with learning goals, responsive to user needs, and innovative in integrating AR technology into the chemistry learning experience..

RESULT AND DISCUSSION

This research was conducted at SMAS Cerdas Murni and followed the development stages based on the 4D model (Define, Design, Develop, Disseminate), although it only reached the third stage, namely the Develop stage. The E-Module development process involved assessments from various parties, including material expert validators, media expert validators, teachers, and students. Assessment of the quality of teaching materials was carried out by distributing questionnaires to all parties involved in order to obtain relevant input and feedback. This evaluation aims to ensure that the developed E-Module meets the eligibility standards as an effective learning medium. In addition, e-modules can also be used to achieve learning objectives that can be adjusted to the abilities of each student (Irfandi et al., 2018).

I. Development of Augmented Reality-Based Chemistry E-Module on Hydrocarbon Material

Based on the results of observations conducted at SMAS Cerdas Murni, it is known that teachers have prepared learning by preparing teaching modules that are adjusted to the conditions and needs of the school. The teaching materials used so far are in the form of textbooks and student worksheet as the main sources. In implementing teaching and learning activities, teachers tend to use the lecture method, although occasionally interspersed with the application of the Problem Based Learning learning model. During the learning process, E-Modules have never been used, and the concept of augmented reality is still unknown to teachers, so its use as a learning medium has not been applied in the school.

The results of the student needs analysis show that most students have difficulty understanding the contents of the textbooks used in schools. The textbooks are considered less helpful because the number of questions available is limited, so they are not enough to strengthen students' understanding of chemical concepts. The most dominant difficulty felt by students when studying chemistry material, especially hydrocarbons, is the inability to understand the concept in depth. In addition, students also show limitations in technological literacy, which is a challenge in itself in participating in digital or interactive-based learning.

At the design stage, the researcher first drafted a module design that included the physical form, introduction, content, and conclusion. Next, the researcher designed a three-dimensional visualization application based on augmented reality using the Assemblr Edu application. After all the designs at this stage were completed, the researcher continued to the media creation stage according to the procedures that had been set in the design. The module creation process, from printing to developing augmented reality media, was entirely carried out by the researcher himself.

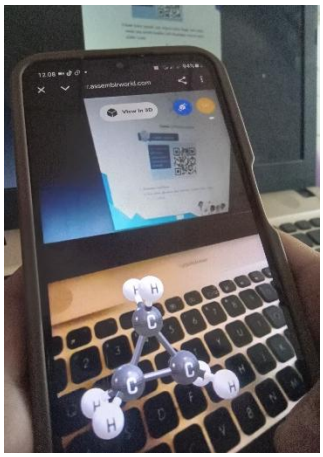

Figure 1. Examples of alicyclic compounds in the AR form.

In the development stage, researchers created a product in the form of a chemistry e-module that integrates Augmented Reality technology. This development process is based on an analysis of chemistry books used in schools, taking into account aspects that need to be improved according to the eligibility criteria. This e-module was developed through a web platform and can be accessed using a laptop, computer, or smartphone, allowing users to access it anytime and anywhere without time constraints.

After the development of the e-module is complete, the next step is to conduct a validation test by experts. Validation was carried out by two chemistry education lecturers, each as a material expert and a media expert, using a feasibility assessment instrument that had been modified from the BSNP standard. Input and comments from the validators during the validation test process were used as a basis for revising the initial product. Thus, the final product can be declared feasible for use in learning activities.

The findings in the development research utilizing augmented reality technology are in line with the research results of Mustaqim, (2017), which stated that through the use of augmented reality, educators can create interesting, interactive, and easy-to-use learning media. This technology also functions as an alternative to replace learning modules that are not yet available in schools in digital or muvirtual form. With augmented reality, students can access and utilize learning modules as if they were using physical modules, even though they are actually in virtual format. Product assessment aims to obtain recognition or validation of the product's suitability to needs so that it is suitable for use in learning (Destiara, 2020). The assessment questionnaire by the material expert validator consists of 14 statement items, while the media expert assessment questionnaire consists of 16 statement items, both using a Likert scale of 1-5.

II. Quality of Development Results

a. Feasibility Results of Augmented Reality-Based Chemistry E-Modules on Hydrocarbon Material

In the material experts, the Augmented Reality-based chemistry e-module developed was validated by referring to the eligibility standards of the National Education Standards Agency (BSNP), which have been adjusted to the assessment aspects including content eligibility, language eligibility, presentation eligibility, graphic eligibility, and eligibility of using Augmented Reality. Tabulation of the analysis results from the validity test of the material experts on the Augmented Reality-based chemistry e-module is presented in Table 1.

Table 1. The results of the expert material validator's assessment of e-module

Assessment Aspects	Validator 1		Validator 2	
	Total Value	Precentage	Total Value	Precentage
Curriculum Suitability	17	85%	17	85%
Material Accuracy	13	87%	14	93%
Learning Presentation	23	92%	22	88%
Language Use	10	100%	10	100%
Total	63	90,91%	63	90,91%
Category	Very Worthy		Very Worthy	

The comparison of validation results between material expert 1 and material expert 2 can be seen in the following graph:

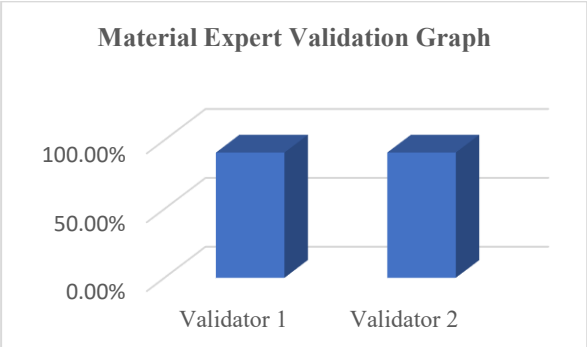

Figure 2. Material Expert Validation Graph

Based on table 1, the results of the feasibility test by two expert validators of the material on the chemistry e-module based on Augmented Reality technology on hydrocarbon material show that overall the e-module is included in the Very Feasible category. Validator 1 gave a total score of 63 with a feasibility percentage of 90.91%, while Validator 2 also gave the same total score, namely 63, with an identical percentage of 90.91%. The assessment was carried out based on four aspects, namely curriculum suitability, material accuracy, learning presentation, and language use. These results indicate that the developed e-module has met the criteria for good and relevant material substance, and is feasible to be used in the chemistry learning process, especially on the topic of hydrocarbons.

In validation by media experts, the Augmented Reality-based chemistry e-module developed was assessed using a multimedia learning assessment instrument. Tabulation of the analysis results from the media expert's feasibility test is presented in Table 2.

Table 2. The results of the expert media validator's assessment of e-module

Assessment Aspects	Validator 1		Validator 2	
	Total Value	Precentage	Total Value	Precentage
Presentation Components	20	80%	21	84%
Graphics	33	94%	33	94%
Augmented Reality Media	20	100%	20	100%
Total	73	91,33%	73	92,67%
Category	Very Worthy		Very Worthy	

The comparison of validation results between media expert 1 and media expert 2 can be seen in the following graph:

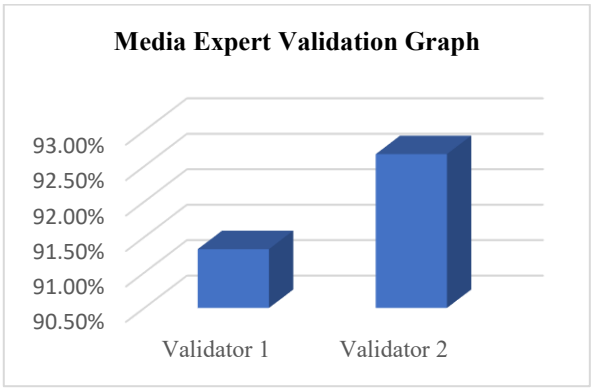

Figure 3. Media Expert Validation Graph

Based on Table 2, the validation results from two media experts on the Augmented Reality-based chemistry e-module show that the developed media is included in the Very Feasible category. Validator 1 gave a total score of 73 with a feasibility percentage of 91.33%, while Validator 2 gave the same score with a slightly higher percentage of 92.67%. The assessment includes three main aspects, namely component presentation, graphics, and Augmented Reality media. These results reinforce that the e-module is not only superior in terms of material content, but also in terms of appearance and utilization of learning support technology.

This finding is in line with research conducted by Anapia et al. (2024), which emphasized that validation from experts has an important role in assessing the feasibility of technology-based learning media. In this study, the evaluation results from two expert validators showed that the developed augmented reality-based chemistry e-module was declared valid. The assessment from material experts showed a percentage of 94% with a very valid category, while the assessment from media experts reached 75% with a valid category. Based on these results, it can be concluded that the e-module as a whole has met the feasibility criteria both in terms of material and media, so that it can be used in the learning process.

b. Teacher Responses and Student Responses to Augmented Reality-Based Chemistry E-Modules on Hydrocarbon Material

At the teacher response stage, the Augmented Reality-based chemistry e-module developed was assessed using the instrument for assessing the feasibility of learning devices by teachers. This assessment was carried out by two teachers as respondents. Tabulation of the results of the analysis of teacher responses to the Augmented Reality-based chemistry e-module is presented in Table 3.

Table 3. Teacher Response Results

Assessment Aspects	Teacher 1		Teacher 2	
	Total Value	Precentage	Total Value	Precentage
Content Eligibility	9	90%	10	100%
Language	15	100%	15	100%
Presentation	10	100%	9	90%
Graphics	20	100%	20	100%
Effective	15	100%	15	100%
Total	69	98%	69	98%
Category	Very Worthy		Very Worthy	

The recapitulation of teacher responses to the chemistry e-module can be seen in the following graph.

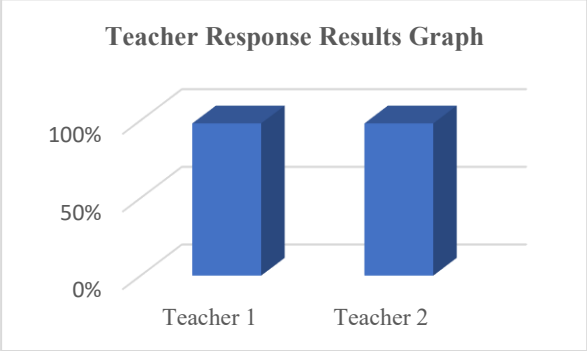

Figure 4. Teacher Response Results Graph

Based on the recapitulation results in the Teacher Response Results Table, it can be concluded that the responses of the two teachers to the Augmented Reality-based chemistry e-module show a very high level of feasibility. Teacher 1 gave a total perfect score of 69 with a feasibility percentage of 98%, while Teacher 2 gave a score of 69 with a percentage of 98%. The assessment was carried out based on five aspects, namely the feasibility of content, language, presentation, graphics, and effectiveness. Overall, both teachers agreed that this e-module was very feasible to use in the learning process, both in terms of content, appearance, delivery, and effectiveness of its use in improving students' understanding of hydrocarbon material.

Next, a response questionnaire was given to students in class XI-1. The response questionnaire used consisted of 11 statement items arranged into 3 categories including appearance, presentation in e-module and presentation of augmented reality media in e-module. The average percentage of student responses to the Augmented Reality-based chemistry e-module is presented in Table 4.

Table 4. Students Response Results

Aspects	Total Value	Precentage	Category
Appearance	380	90,47%	Strongly Agree
Presentation	625	89,28%	Strongly Agree
AR Presentation	396	94,28%	Strongly Agree
Total	1401	91,34%	Very Worthy

The recapitulation of students' responses to the chemistry e-module can be seen in the following graph.

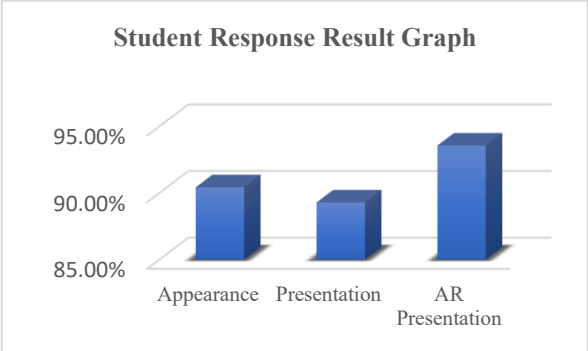

Figure 5. Students Response Results Graph

Based on the student response table, data was obtained that 28 students gave a very positive response to the Augmented Reality-based chemistry e-module that had been

developed. Overall, the total value of all aspects was 1401 with an average percentage of 91.34%, which is included in the Very Eligible category. These results indicate that this e-module is very well received by students and is considered effective and interesting as a learning medium for hydrocarbon material.

This study is in line with the findings of Reski et al. (2022), which revealed that the use of technology-based learning modules, such as augmented reality, has a high level of practicality because it can increase student interest and involvement in the learning process. The results of student responses to the developed e-module showed a percentage of 80.38% with a high category, while the response from teachers reached 100% and was included in the very high category. Student responses reflect a great interest in the appearance of the e-module, which also contributes to increasing their learning motivation. The material in the e-module is presented in a structured and systematic manner, while the use of augmented reality technology makes it easier for students to understand concepts more realistically. This is also reinforced by the opinion of Nasution et al. (2025), which states that the suitability of a teaching material is determined by factors such as ease of use, time efficiency, clarity of content, relevance to the teaching material, and the attractiveness of the media used.

Suryani et al. (2018) stated that the use of teaching materials in the form of modules makes it easier for students to follow chemistry learning, so that the learning process becomes more effective. Modules also allow students to learn independently and help shorten the time needed to understand the material. This statement is reinforced by the results of Wagiran's research (2006), which shows that learning using modules can reduce misconceptions in students, and can increase learning activities and learning outcomes achieved by students.

CONCLUSION

The development of an Augmented Reality (AR)-based chemistry e-module on hydrocarbon material has proven valid, practical, and feasible based on expert evaluations and user feedback. The integration of AR enhances conceptual understanding, boosts student engagement, and supports digital literacy in chemistry learning. The module aligns with curriculum goals, is accessible on multiple devices, and offers interactive, self-guided content. Although limited to the Develop stage, the results suggest strong potential for wider implementation. Future studies can examine its effectiveness in classroom settings and its adaptability to other chemistry topics or education levels.

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