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Integrating Multiple Representations and Augmented Reality in Maritime Chemistry E-Module Based on IMO 7.04

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Abstract: *Chemistry is essential for maritime engineering students, but many concepts are abstract and difficult to understand due to limited resources that integrate macroscopic, microscopic, and symbolic representations. This study aimed to develop and validate a maritime chemistry e-module that combines multiple representations with Augmented Reality (AR) technology, aligned with IMO Model Course 7.04. The research employed the ADDIE development model, consisting of five stages: analysis, design, development, implementation, and evaluation. Data were collected through expert validation sheets and student response questionnaires, and analyzed using percentage analysis. The results showed that the e-module achieved very valid criteria, with average feasibility values of 92.75% for material and 98.09% for media aspects. Student responses indicated high acceptance in terms of appearance, design, ease of use, content comprehension, interactivity, engagement, and perceived benefits, with an overall score of 87.36% classified as very good. In conclusion, the multiple representation-based AR e-module provides maritime engineering students with a practical, contextual, and engaging learning tool, enhancing conceptual understanding in maritime chemistry.*

Keywords: *E-module; maritime chemistry; multiple representations; augmented reality; IMO 7.04.*

INTRODUCTION

Maritime higher education plays a strategic role in producing professionals in the shipping sector, particularly in meeting international competency standards as outlined in the IMO Model Course 7.04. Engineering students are prepared not only theoretically but also practically to understand disciplines supporting ship operations, including maritime chemistry. However, observations indicate that students often struggle to comprehend chemical concepts due to their abstract nature and the lack of visual and contextual approaches, particularly at the microscopic and symbolic levels (Candido & Cattaneo, 2025; Safitri & Dwiningsih, 2020). This difficulty is compounded by the need to integrate information across three levels of chemical representation macroscopic, microscopic, and symbolic as described in the chemical triangle (Pardosi & Situmorang, 2024), requiring spatial and reasoning abilities that many students find challenging (Behmke et al., 2018; Johnstone, 1997).

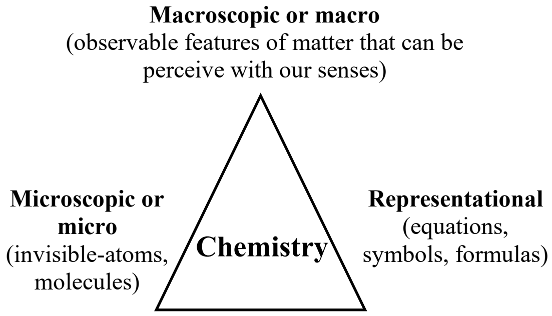

Figure 1. Levels or modes of representation used in chemistry (Johnstone, 1997)

Visualization strategies, such as 3D representations, have been shown to improve understanding of abstract chemical phenomena (Anggriawan et al., 2017; Mekwong & Chamrat, 2021). In addition, students are able to absorb knowledge more effectively when learning media are well-designed and appropriately used by lecturers (Agustina et al., 2023). Building on this, integrating technology particularly Augmented Reality (AR) can further enhance both motivation and comprehension of abstract concepts, providing interactive and engaging learning experiences (Puspitarini & Hanif, 2019; Sianturi & Abdurrahman, 2019). Previous studies have developed multiple-representation e-modules with AR to support topics such as chemical bonds and molecular shapes (Apriani et al., 2021; Hurrahman et al., 2022).

This research differs from previous studies because it specifically develops a multiple representation-based e-module with AR tailored for maritime chemistry content aligned with the IMO Model Course 7.04. Unlike prior modules, this e-module enables independent, structured learning for Engineering students while supporting Student-Centred Learning (SCL) and enhancing creativity in line with digital learning trends (Harefa & Sumiyati, 2024; Yuni & Afriadi, 2020). The aim of this study is to test the validity of the e-module and obtain student responses, with the expectation that it will improve conceptual understanding in maritime chemistry more effectively.

LITERATURE REVIEW

AR is a system that combines virtual elements with real objects in real-time, providing images or information that can be more easily understood by users. In chemistry learning, AR allows students to visualize abstract concepts, such as molecular structures, chemical reactions, and submicroscopic phenomena, which are often difficult to comprehend using traditional 2D media (Candido & Cattaneo, 2025; Nechypurenko et al., 2018). AR also offers advantages such as easy accessibility, high efficiency as a visualization medium, and the potential to reduce cognitive load while enhancing student engagement and curiosity (Barta et al., 2023; Rebello et al., 2024).

Several studies have explored the use of AR as an assistive technology in chemistry education. For instance, AR applications have been developed to support learning in molecular formation reactions (Handoyo et al., 2024), molecular geometry (Irwansyah et al., 2018), hydrocarbon materials (Nur Fitri Fadhilah & Haqqi Annazili Nasution, 2025), medicinal chemistry, and industrial chemical processes (Rebello et al., 2024). In addition, web-based AR platforms, such as molecule AR web, provide interactive content that can be accessed on consumer devices like smartphones, tablets, and laptops (Cortés Rodríguez et al., 2022). Another innovative approach is EthnoVLab, which integrates ethnoscience-based virtual simulations with AR to facilitate inquiry-based learning, encouraging students to actively explore and discover answers independently (Rizki et al., 2025). These studies consistently show that AR can enhance learning outcomes, increase engagement, and simplify complex chemical concepts (Nurdiyanti, 2017; Ratna Ningsih, 2020; Weng et al., 2019).

Previous research demonstrates the benefits of AR in making abstract chemistry concepts more tangible and engaging. Similarly, multiple representation-based teaching materials have been shown to facilitate understanding of abstract science concepts and improve representational abilities, particularly across macroscopic, submicroscopic, and symbolic levels (Auliza et al., 2019; Sianturi & Abdurrahman, 2019; Wiyarsi et al., 2018). However, few studies have integrated multiple representation approaches with AR technology into a structured e-module specifically for maritime chemistry aligned with the IMO Model Course 7.04. Most existing AR modules focus on general chemistry topics or single representations, leaving a gap in resources tailored for maritime engineering students. This research aims to fill this gap by developing a multiple representation-based e-module with AR to support conceptual understanding in maritime chemistry.

METHODS

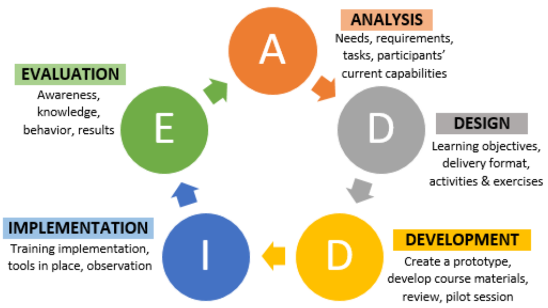

Figure 2. ADDIE Model

This research is a research and development (R&D) project that aims to produce an integrated maritime chemistry e-module with a multiple representation approach and Augmented Reality (AR) in accordance with the IMO Model Course 7.04 curriculum, as well as to validate the resulting product. The development model used in this study is the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009).

Analysis

This stage aims to identify learning needs, student characteristics, curriculum analysis, and gaps between ideal and actual conditions in maritime chemistry learning. Data was collected through document review (IMO Model Course 7.04 and Maritime Chemistry RPS), interviews with course lecturers and practitioners in the shipping field, and a questionnaire assessing Engineering students' needs for interactive and contextual learning media. The analysis results were used to formulate e-module requirements specifications, including the selected material (adjusted to IMO 7.04 requirements), student learning styles, and the devices used (Android-based devices or tablets).

Design

During the design stage, the initial design of the e-module structure was developed, encompassing navigation flow, multiple representation-based content, and AR integration scenarios. This design also involved determining learning objectives, selecting maritime chemistry topics, searching for relevant literature and references, determining the material content, and developing e-module storyboards and flowcharts. In addition, user interaction design and media layout were developed simultaneously with the design of the AR application, chemARine (the AR application is discussed in a separate journal). This stage also involved the development of an evaluation instrument in the form of a questionnaire, which was subsequently used in validation tests by subject matter experts and media professionals, as well as to gather student responses.

Development

During the development stage, the e-module, integrated with the AR application, is developed based on the storyboard design. One of the principles of multiple representations in the e-module is implemented by determining the AR markers that will be integrated into the e-module. The learning media prototype will be validated to determine its level of validity. Validity testing is conducted by two subject matter experts (a maritime chemistry expert and a marine chemistry lecturer) and two media experts (a computer science and ICT lecturer). The e-module prototype is then revised based on input and suggestions from the subject matter experts and media experts.

Implementation

In the implementation stage, the validated e-module integrated with the AR application was trialed on 40 students from the Teknika Department, Teknika Study Program, aged 19–22 years, who had completed the basic chemistry courses. Participants were selected using purposive sampling to ensure they were familiar with the course content and capable of using AR-based learning tools effectively. The trial was conducted across several maritime higher education institutions to assess the e-module's usability and effectiveness in a real learning environment.

Before the learning process begins, students receive the e-module and AR application, which can be used both independently and in class. The implementation stage includes socialization of the use of the e-module and AR devices, and learning to use the e-module independently and with guidance. After the learning, students were asked to complete a response questionnaire to assess their understanding of the AR application integrated e-module.

Evaluation

In the evaluation stage, an assessment is conducted to determine the quality of the e-module product integrated with the AR application based on the results obtained in the previous stage. The evaluation consists of two types: formative evaluation, conducted at each stage of development for continuous improvement, and summative evaluation, conducted at the end of the e-module's use. This evaluation also focuses on identifying obstacles and constraints that arise during the use of the e-module and AR application, allowing revisions to be made based on input and suggestions from respondents.

Data collection in this study was conducted through indirect communication techniques using a validity test questionnaire and a student response questionnaire. Each validator and respondent provided an assessment of the measured aspects. The assessment used a Likert scale with scores of 4 (strongly agree), 3 (agree), 2 (disagree), and 1 (strongly disagree). Data obtained from the validation questionnaire and the response questionnaire were analyzed using qualitative and quantitative analysis methods. The expert assessments and student responses were processed using this formula (Akbar, 2013).

$$V - ah = \frac{TSe}{TSh} x\ 100 \qquad (1)$$

Description:

V-ah : Expert validity

TSe : Total empirical score of the validator

TSh : Maximum score

The calculation results are then interpreted based on the product validity level criteria listed in **Table 1**.

Table 1. Product Validity Conversion

Achievement Criteria (%)	Validity Level
85.01-100	Very Valid
70.01-85.00	Fairly Valid
50.01-70.00	Less Valid
01.00-50.00	Not Valid

(Source: Akbar, 2013)

Respondents' assessments were analyzed using this formula (Akbar, 2013).

$$V - pg = \frac{TSe}{TSh} x\ 100 \qquad (2)$$

Description:

V-pg : User Validity

TSe : Total empirical score of the validator

TSh : Maximum score

The calculation results are then interpreted based on the response test criteria presented in **Table 2**.

Table 2. Student Response Test Criteria

Achievement Criteria (%)	Qualification
85.01-100	Very Valid
70.01-85.00	Fairly Valid
50.01-70.00	Less Valid
01.00-50.00	Not Valid

Reliability testing (e.g., Cronbach's alpha) was not conducted, as the focus was on expert and user validation. The instruments were carefully reviewed to ensure clarity, appropriateness, and meaningful assessment of the e-module.

RESULT AND DISCUSSION

The analysis phase is the first step undertaken to determine the urgency of developing a learning medium. The results of the analysis indicate that most students struggle to understand chemical concepts. This is evident from the Final Exam scores of students in the Industrial Chemistry course in the Engineering department, which are still below the Minimum Completion Criteria (KKM), which is the same as previous research (Damanik et al., 2024). Additionally, learning resources for maritime chemistry courses that comply with IMO 7.04 are not readily available. One of the problems frequently encountered in chemistry learning is that learning resources cannot fully visualize all three levels of chemical representation. Furthermore, representation at the microscopic level is still limited to a two-dimensional format and has not been widely developed in three-dimensional form. Based on the above problems, it is necessary to develop learning resources that include all three levels of representation and can visualize chemical concepts, especially in the form of 3D animation.

The design phase involved the initial design of the initial structure, which included multiple representation-based content and navigation flow, determining learning objectives, selecting maritime chemistry topics, conducting literature searches, developing materials in accordance with IMO 7.04, creating storyboards, and creating flowcharts. Additionally, questionnaires and evaluation tools were prepared for validation by subject matter and media experts, as well as for collecting student feedback. In the design phase, markers were also identified in the e-module that would be integrated through the AR application. At this stage, the preparation of materials in accordance with IMO 7.04 was carried out to enable students to adapt to the competencies required of prospective sailors.

The chemistry material developed in this e-module has been adjusted to the provisions of the International Maritime Organization (IMO) 7.04, thus covering essential topics such as Fundamentals, Acidicity/Alkalinity, Corrosion, Water Testing and Treatment, and Introduction to Fuels and Lubricants (Organization, 2014). The selection of AR integration is done selectively on sub-materials that require visualization support to clarify abstract concepts (difficult to observe directly) (Irwansyah et al., 2018) and complex information (Elford et al., 2023), such as atomic models, acid-base theory, ocean acidification phenomena, corrosion reactions, molecular structures that cause water hardness, fuel combustion processes, and lubricant viscosity. This finding aligns with previous research, specifically the application of AR (ARchemy) to elucidate molecular structures and 3D chemical transformations (Abdinejad et al., 2021) as well as molecular geometry (Irwansyah et al., 2018). Visualization of 3D structures is crucial in understanding the chemical and physical properties of molecules (Elford et al., 2023).

In the development stage, product development is carried out in accordance with the designed storyboard. The product is an e-module featuring multiple representations of maritime chemistry, as per IMO 7.04, in PDF (Portable Document Format) format, with a file size of 34.7 MB. The AR application (ChemARine) in .apk (Android Package Kit) format with a file size of 66.7 MB is also integrated with the e-module (a more detailed discussion of the

ChemARine application is available in another journal). The developed e-module consists of 3 parts (a total of 103 pages), namely introduction, content, and closing. The introduction includes the cover, foreword, table of contents, list of AR integrations, instructions for using the module, and chemistry materials in accordance with IMO Model Course 7.04.

Figure 3. Cover view of the Maritime Chemistry Multiple Representation E-Module

The content section of this e-module comprises five chapters, each featuring a total of 26 AR-integrated maritime chemistry materials. The description of the material in the e-module is based on multiple representations, allowing the three levels (macroscopic, microscopic, and symbolic) to be conveyed effectively. The closing section comprises a bibliography and an author profile. The e-module display is shown in **Figure 3**.

Next, the product entered the validation stage by subject matter and media experts. The average validation percentage results are shown in **Figure 4**.

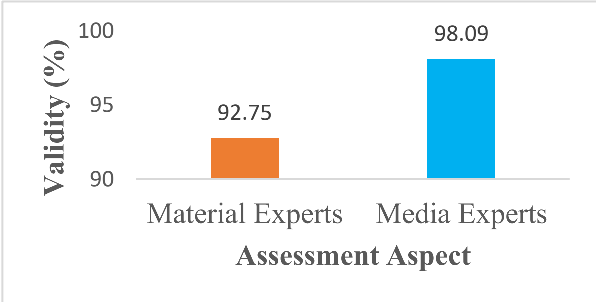

Figure 4. Average Assessment Percentage of Material Experts and Media Experts

The validation by material and media experts on the developed product, as shown in Figure 3, shows an average feasibility percentage of 92.75% and 98.09% for each validation stage, respectively, resulting in an overall average of 95.42%. These data indicate that the validity of both validation stages is categorized as very valid and can therefore be used without revision (Akbar, 2013). Therefore, based on the validation results above, it can be concluded that the resulting product meets the theoretical feasibility criteria in terms of material and media. The feasibility of an instrument or product can be determined based on the expert assessment results in the field (Ramadhan et al., 2019). Material validation encompasses aspects such as content feasibility, integration of multiple representations, AR technology integration, language, and usability. The results of the material validation are presented in **Table 4**.

Table 4. Material Validation Results

	Explanation of Aspect	**Criteria**	**Material Experts**		**Average Score**	**Average Ideal Score**	**Ideal Percentage (%)**	**Category**
			1	**2**				
A	Content Feasibility	1,2,3,4,5	4	3.6	3.8	4	95	Very Valid
B	Integration of Multiple Representations	6,7,8,9	4	3.5	3.75	4	93.75	Very Valid
C	Integration of AR Technology	10,11,12,13	3.75	3.25	3.5	4	87.5	Very Valid
D	Language	14,15,16	4	4	4	4	100	Very Valid
E	Usability	17,18,19,20	4	3	3.5	4	87.5	Very Valid
	Overall Score				18.55	20	**92.75**	**Very Valid**

The content feasibility aspect shows that the results are categorized as not requiring revision. This aspect indicates that the material aligns with the Basic Competencies (KD) of Maritime Chemistry, as outlined in the IMO 7.04 standard (Organization, 2014). This means that the material covers all topics relevant to learning maritime chemistry. The scientific concepts presented are accurate and error-free, and the depth of the material is appropriate for the level of understanding of Engineering students. Overall, the material in this e-module supports the achievement of learning objectives. Validation of the content feasibility aspect is expected to ensure the suitability of the device in relation to the characteristics of the presented content and to avoid conceptual errors.

The integrated aspect of multiple representations consists of four criteria: narrative text presentation supports and clarifies visual representations (images, animations, and simulations); animations and chemical reactions are used in accordance with the material being taught; interactive simulations help explain abstract concepts; and multiple representations are arranged systematically and mutually supporting each other. The three levels of chemical representation in the developed e-module product comprise macroscopic aspects, which are demonstrated by the presentation of sample images of related chemical materials. Microscopic aspects are presented in the form of 3D animated visualizations or illustrations integrated with AR technology through markers on the e-module. Symbolic aspects are presented in the form of chemical compound/molecule symbols, usually represented by chemical formulas. Multiple representations in e-modules aim to explain chemical concepts in a gradual and coherent manner, starting with macroscopic observations, followed by a more detailed explanation of the microscopic aspects, and ending with symbolic ones. Good learning media is where concepts are explained in stages and categorized according to their basic concepts. This allows students to explore the relationships between concepts and develop skills (San et al., 2020). The multiple approaches to chemical representation in the presentation of material within the e-module are illustrated in **Figure 5**.

The language of the e-module has met the established criteria. The language used is communicative, clear, and easy to understand, chemical and maritime terms are presented accurately and consistently, and the material explanations are free from ambiguity. In terms of usability, the material in the e-module can be used for both independent and guided learning, supports the development of critical thinking skills, encourages active student involvement, and is relevant for use in project-based learning and problem-solving.

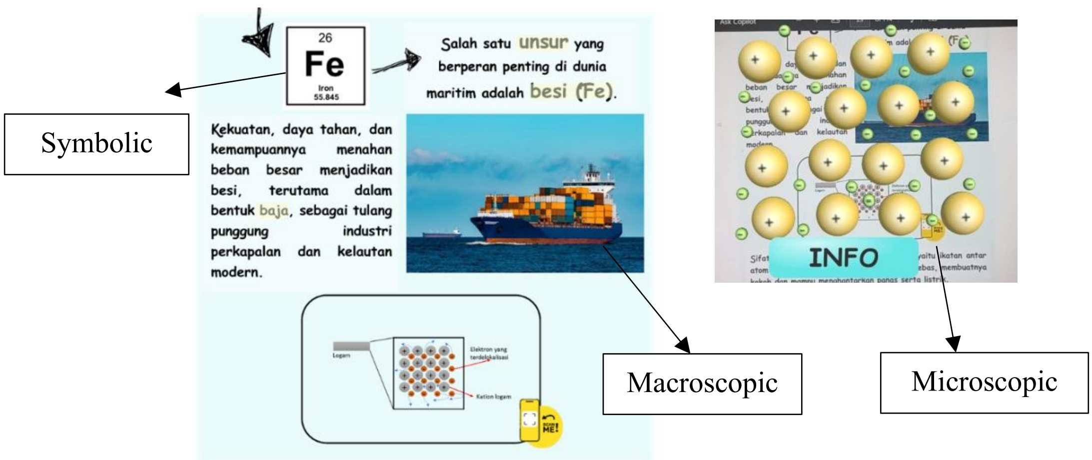

Figure 5. Example of Multiple Chemistry Representation Displays in an E-Module

The next stage is media validation, which aims to obtain data on the validity of the e-module product, reviewed in terms of display design, navigation, and interactivity, as well as the integration of multiple representations, Augmented Reality technology, technical quality, and usability. The results of the media validation are shown in Table 5. Based on the media validation results, the e-module received a rating of 98.09%, categorized as Very Valid.

Table 5. Media Validation Results

	Explanation of Aspect	Criteria	Media Experts 1	Media Experts 2	Average Score	Average Ideal Score	Ideal Percentage (%)	Category
A	Display Design	1,2,3,4	4	3.75	3.875	4	96.875	Very Valid
B	Navigation and Interactivity	5,6,7,8	4	4	4	4	100	Very Valid
C	Integration of Multiple Representations	9,10,11	4	4	4	4	100	Very Valid
D	Integration of AR Technology	12,13,14	4	3.67	3.83	4	95.83	Very Valid
E	Technical Quality	15,16,17	4	3.67	3.83	4	95.83	Very Valid
F	Usability	18,19,20	4	4	4	4	100	Very Valid
	Overall Score				23.54	24	**98.09**	**Very Valid**

The e-module's display design was assessed as good across four criteria. The e-module's display is attractive and appropriate for the characteristics of Engineering students. The colour selection is harmonious and pleasing to the eye, the typography is clear and easy to read, and the media elements are neatly arranged and proportional. These results indicate that the e-module meets the instructional design principles that support readability, comfort, and ease of learning. The presentation of engaging learning materials is believed to increase students' interest in reading, especially those with a visual learning style (Mumpuni & Nurbaeti, 2019). An engaging display design is expected to provide a more motivating learning experience, thus encouraging students to actively participate in the learning process.

The navigation and interactivity aspects of the e-module also met the established criteria. Navigation was easy to understand and use; menus and buttons functioned well without errors. Media interactivity supported active learning, and the instructions were clear and easy to follow. This demonstrates that the e-module is not only visually appealing but also practical and effective in supporting the learning process. The integration of multiple representations in the e-module was well-executed. Text, images, graphics, animations, and simulations are presented in a mutually supportive manner, with clear visual quality and seamless integration of animation and simulation. This facilitates a more comprehensive understanding of concepts among students.

Furthermore, the integration of Augmented Reality (AR) technology was also deemed satisfactory. The AR feature was accessible and functioned well on the device used. This finding aligns with previous research, which has shown that the distance to the marker influences the speed of object appearance, with an optimal distance of 20 cm (Putra et al., 2020). Furthermore, the criteria for this aspect were to provide visualizations that clarify the material and remain integrated without disrupting navigation or user comfort. This indicates that the integrated ChemARine application can be used easily and smoothly, displaying visualizations and animations of maritime chemistry material effectively, without errors, and with optimal button functions.

The technical quality of the e-module demonstrated good results, with the media running smoothly without lag or crashes, a relatively appropriate file size for easy downloading, and compatibility across various devices. In terms of usability, the e-module has been shown to facilitate students' understanding of the material, increase learning motivation, and is considered suitable for use as a medium for learning maritime chemistry.

Material experts and media experts provided several recommendations for improvements to ensure the e-module presented a visual appeal that fosters a positive image and perception (Desintha, 2019). Some of the revisions suggested by the material experts included writing chemical formulas in the info menu, adding water and oil compounds to the animation, and changing the font color in the Thomson atom. Meanwhile, revisions from the media experts included the font type in the menu display, changing the animation on viscosity because the application often lagged, and the need to add a QR Code to each marker. These inputs were then implemented in product improvements.

In the implementation phase, the validated and revised product was tested on a limited basis among Engineering. This phase aimed to elicit student feedback on the product based on predetermined aspects. Data was then collected through a student response questionnaire distributed using a Google Form link. Student responses covered aspects of appearance and design, ease of use, understanding of the material, interactivity and engagement, as well as usability and benefits.

The evaluation phase aimed to measure student responses to the AR-integrated e-module. The results of the response test are shown in Table 6. Based on the student response test, the average rating for all aspects was 87.36%. Students gave positive responses, indicating that the product helped visualize maritime chemistry material, facilitated understanding, and encouraged motivation for independent learning.

The appearance and design of the e-module were deemed to have met the established criteria. The e-module's layout is attractively designed to motivate students to learn. The selection of colors, fonts, and layout is presented proportionally, making the material easy to read and understand. Furthermore, the images, graphics, and animations used are of high quality and clearly displayed, thereby enhancing readability and strengthening the understanding of the concepts presented in the e-module. Virtual representations are widely used in higher education to visualize design models or simulations (Scaravetti & Doroszewski, 2019)

Table 6. Student Responses

	Explanation of Aspects	**Criteria**	**Average Score**	**Average Ideal Score**	**Ideal Percentage (%)**	**Category**
A	Appearance and Design	1,2,3	3.49	4	87.28	Very Good
B	Ease of Use	4,5,6	3.48	4	87.06	Very Good
C	Material Understanding	7,8,9	3.55	4	88.81	Very Good
D	Interactivity and engagement	10,11,12	3.42	4	85.52	Very Good
E	Usability and Benefits	13,14,15	3.52	4	88.15	Very Good
	Overall Score		17.47	20	**87.36**	**Very Good**

The usability aspect of the e-module showed good results. The e-module's navigation is designed to be simple for users to understand. The instructions are presented clearly and are easy to follow, helping students operate the media independently. Furthermore, the e-module and its AR features can be accessed smoothly on the device used, thus supporting a smooth learning process. AR as an alternative media that utilizes smartphones without the need for additional devices (Smith & Friel, 2021).

The understanding aspect of the material suggests that the use of AR-based e-modules can facilitate students' understanding of maritime chemistry concepts more easily. The presentation of multiple representations, including text, images, animations, and simulations, helps clarify parts of the material that are considered difficult. Mastery of chemical representations at the macroscopic, microscopic, and symbolic levels is a crucial requirement for developing a comprehensive conceptualvisualizing abstr understanding in chemistry learning (Mekwong & Chamrat, 2021; Mindayula & Sutrisno, 2021). In maritime chemistry learning, the macroscopic level can be observed through real-world phenomena such as corrosion on ship hulls, color changes due to chemical reactions in the marine environment, and the distinctive odors of certain compounds in ports. At the microscopic level, these phenomena are explained through the interactions of particles such as atoms, molecules, and ions involved, for example, chloride ions that accelerate the corrosion process on ship metals. Meanwhile, the symbolic level is manifested in the form of formulas, reaction equations, symbols, and graphs that represent maritime chemistry processes, such as electrochemical reaction equations for corrosion or diagrams of salt solubility in seawater (Stojanovska et al., 2017).

Furthermore, AR integration plays a crucial role in act concepts more realistically, thereby enhancing students' understanding of the material being studied. AR technology has the potential to enhance science learning by fostering positive emotions, motivating independent learning, and improving learning outcomes (Zhou et al., 2020). This also aligns with previous research, which found that AR-based games with macroscopic, microscopic, and symbolic chemistry content effectively enhance understanding, strengthen positive affect, reduce negative affect, and foster interest in learning chemistry from an early age (Câmara Olim et al., 2024).

The interactivity and engagement aspects of the e-module were considered excellent. The e-module was able to encourage students to be more active in the learning process and foster interest in learning other topics using the same media. The presence of interactive features also provided a more enjoyable learning experience, thereby increasing student motivation and engagement during the learning process. Previous studies have shown that exploring the role of AR in creating an interactive, engaging, and immersive learning environment (Handoyo et al., 2024).

The usability and benefits of the e-module received positive reviews. This e-module can be used for both independent and guided learning, providing flexibility for students. Furthermore, the e-module helps students prepare for exams by presenting the material in a systematic manner. Due to the quality and relevance of its content, the e-module is considered suitable for use as a learning medium for maritime chemistry in the future. This flexibility aligns with modern AR studies that help anyone learn chemistry and explore the microscopic world through smart devices (Macariu et al., 2020).

The integration of AR technology has great potential in education because it can enhance student engagement, motivation, and learning performance through pedagogical impacts on physical, cognitive, and contextual aspects, particularly through object manipulation, which strengthens spatial understanding and memory (Silva et al., 2023). AR, which combines real objects with digital visualizations, is also considered relevant in innovative learning spaces such as makerspaces, as it can help overcome various learning challenges (Radu et al., 2023). The importance of AR integration is increasingly apparent because not all students are interested in learning with long texts and less interesting content, so conventional learning is recommended to be replaced with an AR-based approach (Liono et al., 2021), so that abstract materials such as the particles that make up atoms, ions, and molecules can be visualized well (Djoa & Kusumaningtyas, 2021).

The findings of this study align with those of previous studies, which have shown a positive correlation between students' spatial reasoning abilities and their understanding of chemistry content (Cole et al., 2021). The implementation of AR in trials also received very positive responses regarding student learning motivation in the digital age, as this technology has proven effective in maintaining high motivation and increasing engagement, especially among generations accustomed to interacting with technology (Ibáñez & Carlos, 2018). Other research confirms that combining appropriate teaching methods with modern technology can make learning more engaging, encourage creativity, and increase learning motivation (Rizki et al., 2025). In the context of chemistry, 3D visualization has also been shown to have positive outcomes for understanding medicinal chemistry concepts and advanced drug design (Abdel-Halim, 2020).

The novelty of this research lies in the application of multiple representation integration and AR technology specifically to the maritime chemistry context, in accordance with IMO 7.04 standards, which has been rarely developed to date. Thus, the resulting interactive e-module not only addresses the need for concrete, visual, and applicable learning media but also provides a new contribution to the development of chemistry learning relevant to international maritime standards. Further research can be conducted with large-scale trials to measure the long-term effectiveness of this e-module, as well as explore its influence on practical skills and technical problem-solving.

CONCLUSION

This study employed the ADDIE development model to create a maritime chemistry e-module, in accordance with IMO 7.04, utilising multiple representations integrated with AR technology for students in the Engineering Department. The results showed that the product was highly valid, with scores of 92.75% and 98.09%, respectively, in terms of material and media validity. Additionally, the product received a positive response from students, with a percentage of 87.36% and a rating in the very good category. This indicates that the e-module can help students visualise and understand abstract maritime chemistry concepts. These findings contribute to the advancement of educational technology by demonstrating the potential of AR-based learning to enhance understanding and innovation in maritime science education.

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