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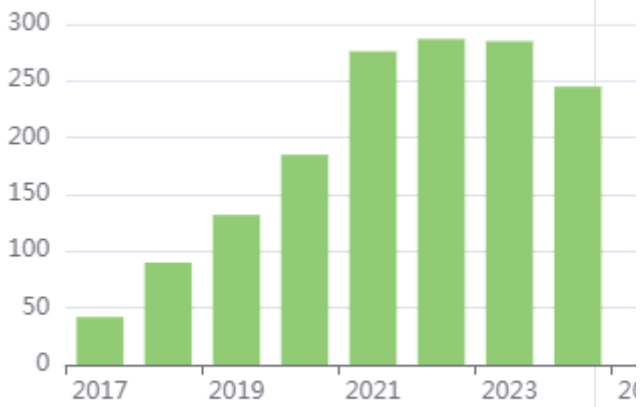

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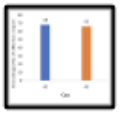

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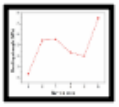

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Original Research Article

Development of an augmented reality-based chemical bonding module assisted by the assemblr EDU

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ABSTRACT

Conventional media, like textbooks, lack interaction explaining chemical bonding, hindering dynamic learning. They're static and unable to visualize bonding effectively. Moreover, unengaging teaching methods cause student disinterest, hindering learning, particularly in complex subjects like chemical bonding. To address this issue, developing augmented reality-based chemical bonding modules is a potential solution to help students learn about chemical bonding. This study aims to accomplish the following objectives: (1) Develop a chemical bonding module based on augmented reality using the Assemblr EDU, following the ADDIE development model. (2) Determine the feasibility of the augmented reality-based chemical bonding module. The research methodology employed in this study is Research and Development (R&D), utilizing the ADDIE development model. The study's findings reveal the following: (1) The module was developed using the ADDIE development model with the Assemblr EDU. (2) The augmented reality-based chemical bonding module is highly valid, achieving a material validity score of 89.33% and a media validity score of 93.5%. It is also convenient, earning an average practicality rating of 88.14% with an "excellent" response from users. Additionally, the module is effective, as evidenced by a student evaluation score averaging 70, which falls within the high criteria range. The augmented reality-based module is a valuable tool for enhancing the understanding of chemical bonding during learning.

Introduction

Education is a multifaceted process involving three key dimensions: individuals, society, and national communities. The 2013 curriculum provides teachers with opportunities to enhance classroom learning effectiveness, ultimately improving teaching quality and teacher competence (Agustin and Sugiyono, 2018). Learning modules that align with the curriculum play a pivotal role in elevating the quality of education. When tailored to students' needs, these modules significantly impact the attainment of learning objectives. Modules serve as educational tools designed to meet predetermined competency standards within the applied curriculum (Wartika et al., 2021).

Chemistry is widely recognized as one of the most challenging subjects for high school students (Kausar et al., 2022). One of the major challenges in studying chemistry is visualizing and understanding abstract concepts such as chemical bonding. Students often struggle to comprehend the interactions and bond formations between atoms that cannot be seen directly. Chemical bonding, a challenging topic in the 10th-grade chemistry curriculum, is characterized by its complexity and abstraction. Chemical bonding is a crucial concept in chemistry that describes the relationship between atoms within molecules or compounds (Othman et al., 2008). Understanding chemical bonding requires clear visualization and accurate conceptualization, which is often difficult to grasp solely through textbooks or static media. Therefore, there is a need for more interactive and innovative learning methods to bridge the gap between abstract concepts and concrete understanding.

Furthermore, education in the digital era demands continuously evolving innovations, especially in the teaching of complex subjects such as Chemistry. One promising approach is the utilization of Augmented Reality (AR) technology in learning as an innovative learning (Supriyanto et al., 2023). Augmented Reality (AR) is a digital technology that can seamlessly integrate virtual objects in two-dimensional (2D) or three-dimensional (3D) forms into real-world environments in real-time (Krisnandy and Bahri, 2020). AR can be harnessed to visualize abstract concepts and improve the comprehension of complex object models. The fundamental concept behind AR involves the integration of computer-generated virtual elements, including text, visuals, three-dimensional models, audio, and videos (Chen et al., 2019). AR can enhance interactivity, student engagement, and understanding of abstract concepts, such as chemistry courses (Silva et al., 2023). Research by Supriono and Rozi (2018) highlights the potential of augmented reality-based learning tools, particularly

those centered on chemistry, to enhance students' understanding of molecular structures. Integrating augmented reality with a project-based learning approach can stimulate an expansion in student creativity dimensions (Harefa et al., 2024).

In this context, Assemblr EDU plays a role as a platform that supports the creation of AR content that can be used in chemistry learning. The use of Assemblr EDU is expected to help students better understand the concept of chemical bonding through the visualization of molecular structures in 3D (Octaviani et al., 2022; Whatoni and Sutrisno, 2022). Related research has also shown that AR has a positive impact on students' knowledge growth and can be a good basis for future mobile learning applications. The development of this AR learning media aims to visualize and facilitate the understanding of abstract concepts, particularly in the topic of chemical bonding. Research that has been conducted shows that the AR products developed are considered highly valid and effective in improving conceptual understanding, as well as practical based on positive user feedback. Additionally, the use of this AR module also has the potential to increase students' interest and motivation in learning (Fitriani et al., 2019).

In light of these challenges, the researchers intend to develop augmented reality-based modules for chemical bonding, featuring 3D visual illustrations. The aim is to provide students with visual aids that enhance their understanding of chemical bonding concepts. The goal is to actively engage students and deepen their understanding of chemical bonding independently, thereby supporting their mastery of the subject. The module's purpose is to facilitate students' comprehension of topics such as atomic stability, Lewis structures, ion bonding, covalent bonding, the polarity of covalent compounds, and metallic bonding, all while relating these concepts to real-life applications. This research is expected to contribute to the development of innovative and effective learning media for chemical bonding material. By utilizing AR technology and the Assemblr Edu, the developed modules can become a solution to enhance the quality of chemistry education in schools.

Methods

The research commences in February and continues through July 2023. The research to be conducted falls under the category of research and development (R&D), specifically following the ADDIE development model, which stands for Analysis, Design, Development, Implementation, and Evaluation. Here is an explanation of those stages.

Analysis

The stages in the ADDIE development process in this research include analyzing performance gaps or existing problems, setting learning objectives, analyzing the learners, and analyzing the material. The initial analysis phase focuses on the core issues in chemistry education that underpin this research. During this phase, the researcher interviewed a chemistry teacher to identify common problems in high school chemistry instruction.

Design

The goal of the design phase is to ensure the proper testing methods are used. Upon completing this design phase, teachers should be able to prepare specific activity materials to address gaps in the learning process. Creating a teaching module requires a title, core competencies, basic competencies, learning objectives, content, practice questions, and illustrations to engage students in learning. The teaching module is based on augmented reality using the Assemblr EDU application. Students independently seek and acquire information, while the teacher acts as a guide.

Development

The goal of the development phase is to create and validate the selected learning resources, specifically the teaching modules that have been developed. Teachers must identify the desired outcomes of this phase. According to Lee and Owens (2004), the ADDIE model development includes functions for implementing product design, in this case, the teaching materials. The development phase in this research involves creating and editing teaching materials. During the planning stage, a conceptual framework for the development of teaching materials is created. At this stage, expert validation of the product was conducted in terms of both content and media. The methodology employed for data collection in this research involved utilizing a questionnaire-based assessment tool. Four separate sets of questionnaires were used for assessment, including material validation and media validation. Data analysis techniques were employed to ensure the development of high-quality products that meet the criteria of feasibility. Data sources included expert validation sheets. The data will be calculated using the following formula, and then these resulting percentages will be compared with the criteria outlined in Table 1.

$$P = \frac{\sum x}{\sum x_i} \times 100\%$$

P = Percentage of validity, practicality, and effectiveness
∑x = Total number of answers in all items
∑xi = The total number of ideal values in all items

Table 1. Product validity assessment criteria (Akbar, 2013)

Level Achievement	Criteria	Description
81 – 100 %	Very valid	Totally worth it, no need to revise
61 – 80 %	Valid	Requires minor revision
41 – 60 %	Enough	Not recommended for use due to significant revision needed
21 – 40 %	Not enough	Not suitable, should not be used
< 20 %	Very less	Not worth it, and should not be used

Implementation

The steps for implementing the design of teaching materials are developed in a real classroom setting. The developed teaching materials are taught in a learning-oriented manner. After the teaching, an initial assessment is conducted to gather feedback on the implementation of the developed materials. The main objectives of the implementation phase include: supporting students in achieving their learning goals, ensuring opportunities to address problems faced by students during the learning process, and ensuring that students' skills improve by the end of the learning process (Lee and Owens, 2004). During the implementation stage, data was collected from student response questionnaires and test results. The test results were used to assess the effectiveness of learning media utilizing AR technology or applications, which will then be converted into percentages. The study's target population comprises 10th-grade students at Santa Maria High School in Yogyakarta. Purposive sampling techniques are applied to obtain a representative sample.

Evaluation

Evaluation is conducted to measure students' mastery of the learning material. Assessments are carried out to provide feedback on the learning process and to measure success using learning indicators. Additionally, in this phase, the researcher also seeks information on the feasibility of the teaching materials. The product's effectiveness was tested through a limited trial involving 12 students. Table 2 outlines the criteria for assessing the product's effectiveness. The method used in this study involves analyzing students' performance after they have completed their study of chemical bonding materials. This analysis entails comparing the percentages of their responses with the criteria specified in Table 2.

Table 2. Product effectiveness criteria (Akbar, 2013)

Score (%)	Effectiveness
81 – 100	Very High
61 – 80	High
41 – 60	Enough
21 – 40	Low
0 – 20	Very low

Results and Discussion

This research aimed to create an augmented reality-based module on chemical bonding using Assemblr Edu. The ADDIE model by Lee and Owens (2004) was utilized, which includes the phases of Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected for its systematic structure, which allows for easy customization to meet the specific requirements of the researchers. This flexibility not only conserves research time but also facilitates the conducting of small-scale trials. Below, we provide a detailed explanation of the outcomes from each stage of the analysis.

Analysis

Issues and potential opportunities are identified at this stage to provide initial information and support the research background. In response to identified educational challenges and curriculum analysis, researchers have embarked on the development of modules based on augmented reality, to enhance students' comprehension of chemical bonding materials. The utilization of augmented reality in the learning process has been demonstrated to stimulate students' interest and offer them opportunities to engage with study materials through AR (Amelia et al., 2022). This module is envisioned to empower students by involving them more actively in their learning experiences, particularly in grasping the concepts of various chemical bonding. It is anticipated that students will be able to distinguish between ionic bonding, covalent bonding, coordination covalent bonding, and metallic bonding, while also understanding how these concepts relate to the properties of matter. Furthermore, students are expected to cultivate independent learning skills through the use of these modules, with the assistance of 3D illustrations provided by the developed module.

Design

This stage is undertaken to create modules based on augmented reality focusing on the chemical topics of chemical bonding. Modules centered around augmented reality are created in the B5 paper format utilizing the Canva application. Canva is an online design program that provides an array of tools and editing features, allowing for the effortless creation of diverse graphic designs, and eliminating the need to start from the ground up. Specifically, the module for instructing on chemical bonding through augmented reality is crafted using the Canva application. The design of the module is presented in Fig-1.

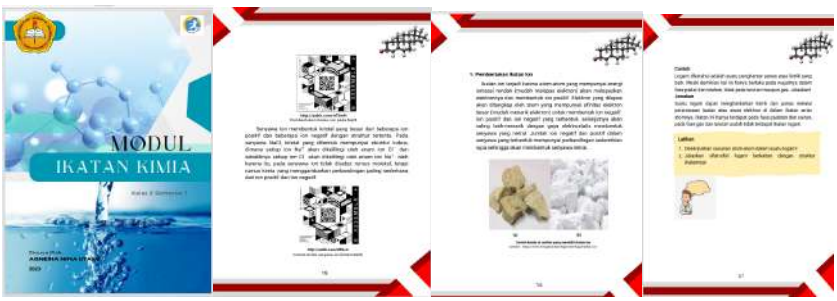

Fig-1. Design of module

Development

In the development stage, two key steps are undertaken: product development and expert evaluation. The development of this augmented reality-based module on chemical bonding incorporates 3D models representing ionic bonding, covalent bonding, and metal bonding. These 3D models were generated using the Blender application. Fig-2 illustrates the process of creating a 3D model using the Blender application. Blender 3D is comprehensive 3D visualization software that is both free and widely popular. Blender 3D serves as a versatile software for creating 3D animations, compatible with Windows, Macintosh, and Linux operating systems (Katatikarn, 2024). Then, the completed 3D models were integrated into Assemblr Studio, as shown in Fig-3.

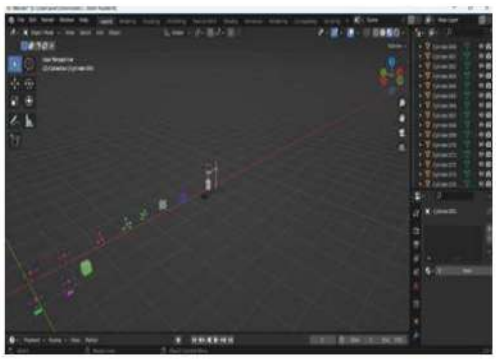

Fig-2. Creating 3D models in blender

Fig-3. AR creation in assemblr studio

The 3D representations of ionic bonding, covalent bonding, and metal bonding, which were initially generated using the Blender software, were subsequently imported into the Assemblr EDU application through Assemblr Studio to obtain barcodes or links. When these barcodes or links are accessed using a smartphone, the 3D models will appear as shown in Fig-4. Assemblr EDU is an educational application suitable for use by both educators and students. This application leverages augmented reality technology to facilitate the creation and sharing of interactive educational content, thanks to its captivating 3D visuals and animations (Nugrohadi and Anwar, 2022).

Fig-4. Use of module

The developed product is an augmented reality-based module. Subsequently, validators assess the product to ensure its readiness for actual use. The validation process for the module involves a further step before implementation, during which the module's accessibility and appropriateness are examined. This validation encompasses both material and media aspects. Material validation involves assessing the chemical content integrated into the module, while media validation evaluates the design and functionality of the media used. Media validation plays a pivotal role in appraising the feasibility of the media concerning aspects such as presentation, language, and the practicality of the developed modules.

Validation is conducted by completing a validation form for each assessment aspect, which includes material content, construction, and language. The validation of augmented reality-based modules assisted by Assemblr EDU in terms of content and media, as depicted in Table 3, indicates that the developed modules are valid and suitable for use. The average validation results for content stand at 89.33%, meeting the criteria for high validity, while for media, the average validation results reach 93.5%, also meeting the criteria for high validity. Subsequently, the modules underwent revision based on the validators' suggestions to enhance their quality.

Table 3. Material and media validation results

Validator	Results (%)		Category
	Material	Media	
Validator I	88	94.7	Very Valid
Validator II	88	90.4	Very Valid
Validator III	92	95.6	Very Valid
Average	89.33	93.5	Very Valid

Implementation

The subsequent phase involves performing a trial test, which aims to evaluate the practicality and effectiveness of the developed products. The product was tested on a small scale with a group of 12 tenth-grade science students at Santa Maria High School. These participants were chosen through purposive sampling, based on teacher recommendations, and included students with different levels of academic performance. The average student evaluation score was 70%. Among the respondents, namely A1, A6, and A7, only three students met the established standard for learning outcomes with scores of 80, 90, and 90, indicating successful completion of the learning objectives. While the average evaluation score of 70% demonstrates high learning outcomes, it falls short of the specified standard. In contrast, respondents A4, A9, A11, and A12 achieved evaluation scores of 60, 50, 60, and 60, respectively, meeting the criteria for minimum learning completeness but still falling below the defined standard. Upon analyzing the student evaluation results, it became evident that the most challenging concept for students to grasp was the topic of covalent bonding, specifically the explanation of Lewis structures in covalent bonding formation. Twelve students provided incorrect answers in this area, as they struggled to understand the Lewis structure of paired elements that combine to form covalent compounds.

Table 4. Student evaluation results and the results of product practicality

Respondent	Evaluation Result	Criteria	Student Responses (%)	Criteria
A1	80	High	84.44%	Very good
A2	70	High	91.11%	Very good
A3	70	High	95.55%	Very good
A4	60	Enough	91.11%	Very good
A5	70	High	91.11%	Very good
A6	90	Very high	80%	Very good
A7	90	Very high	86.66%	Very good
A8	70	High	88.88%	Very good
A9	50	Enough	88.88%	Very good
A10	70	High	73.33%	Good
A11	60	Enough	88.88%	Very good
A12	60	Enough	97.77%	Very good
Average	70	High	88.14%	Very good

According to the data presented in Table 4, students' average evaluation of the developed module stood at 88.14%, indicating a very positive reception. Students provided valuable feedback and expressed their appreciation for several aspects of the module. They found the module's content to be particularly beneficial, especially for those who may be averse to extensive reading, as it effectively condensed and simplified complex chemistry topics related to chemical bonding. The module successfully captured students' interest and engagement in chemistry studies, thanks in part to its use of augmented reality. Students found the 3D models within the module to be engaging, and the incorporation of visualizations accessible through the Assemblr EDU contributed to its comprehensibility. Notably, students expressed enthusiasm for the module's ability to present atoms in three dimensions.

From Table 5, the satisfaction assessment of users of augmented reality-based modules can be observed. Participants' questionnaire responses can provide insight into the level of satisfaction users have with the utilized modules. User satisfaction can be gauged from the completion of the questionnaire regarding the appropriateness, readability, clarity, and relevance of the material. Some of them include illustrations within the module related to the content material, scoring an average of 97%, meeting the criteria for excellence. The use of modules facilitates understanding of chemical bonding topics with an average of 87%, meeting the criteria for excellence. The use of modules equipped with augmented reality aids visualization during the learning of chemical bonding, 93% of participants agree with this statement. User satisfaction with modules is a measure of the success rate of implementation or use of modules (Doll et al., 2004).

Table 5. Results of completing student response questionnaires

Statement	Results (%)	Criteria
Display-based module interesting augmented reality	92%	Very good
The images in the module are interesting	92%	Very good
Illustrations in related modules with the content of the material	97%	Very good
The use of modules makes it easier to understand the topic of chemical bonding	87%	Very good
Delivery of material in the module teaching is related to life daily	85%	Very good
The 3D model of ionic bonding, covalent bonding, and metallic bonding can be accessed using the Assemblr EDU	82%	Very good
The use of modules equipped with augmented reality helps visualization during learning chemical bonding	93%	Very good
Instructions given inside the module are very clear	83%	Very good
Grammar and sentence construction is easy to understand	83%	Very good
Average	88.14%	Very good

Students' understanding of chemical bonding material in modules based on questionnaire responses through the statement that the use of modules facilitates understanding of chemical bonding topics with an average percentage score of 87%, meeting the criteria for excellence. Based on these statements, the modules developed are effective in conveying the desired information and concepts by the researchers. According to Nuswowati and Purwanti (2017), the effectiveness of the developed modules is measured by learning outcomes and student responses after using the modules.

Evaluation

This stage involves the evaluation of the developed student worksheet products to assess their suitability. While students provided predominantly positive feedback, there were also constructive suggestions for future product development and research. Some students reported occasional issues with the Assemblr EDU, such as occasional slowdowns. The application cannot run stably if the device used lacks storage memory, causing the application to be forcibly closed. Additionally, there was a perceived need for further enhancements in the visualization of chemical bonding materials, although students still found the current presentation interesting. Students also recommended making the language within the module more accessible for improved understanding and providing clearer explanations of the subject matter. Furthermore, there was a consensus that the use of the Assemblr EDU could benefit from refinement and improvement in future iterations.

The integration of augmented reality into the development of these learning materials has brought about substantial advantages, both in terms of their appeal and usefulness to educators and students. The augmented reality-based module also demonstrates the practicality of students' responses to learning environments that utilize augmented reality technology. Furthermore, the incorporation of augmented reality into educational media has been found to enhance students' enthusiasm for learning (Perifanou et al., 2023). The findings of the Wulandari et al. (2021) investigation suggest that incorporating augmented reality into educational resources and instructional approaches can effectively aid the learning process and enhance student academic achievements.

Conclusion

Based on the outcomes of our research and development efforts related to an instructional module for teaching chemical bonding through augmented reality, we can draw the following conclusions: The product is a module on chemical bonding using augmented reality, and it utilizes the Assemblr EDU, which was created following the ADDIE development model, consisting of Analysis, Design, Development, Implementation, and Evaluation stages. The results demonstrate that this module is a viable tool for educational purposes. The product's validity rating for its content is 89.33%, while its media validity stands at 93.5%, both falling within the "very valid" and "highly feasible" categories. Furthermore, based on student responses, the augmented reality module is exceptionally practical, with an 88.14% rating indicating a "very positive response." Additionally, the effectiveness of this module is affirmed by a high average evaluation score of 70 from participating students.

Conflict of Interests

The author(s) declares that there is no conflict of interest in this research and manuscript.

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