



Development of an Augmented Reality-Assisted E-Module as an Interactive Visualization Medium for Atomic Model Development Concepts

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Abstract: Development of an Augmented Reality (AR)-Assisted E-Module for Interactive Visualization of Atomic Model Development. Atomic model development is considered an abstract topic, making it difficult for students to understand. One approach to facilitating the visualization of these concepts is the use of an Augmented Reality (AR)-assisted e-module. This study aimed to describe the validity, practicality, and effectiveness of an AR-assisted e-module on atomic model development concepts for tenth-grade senior high school students. The study employed a Research and Development (R&D) method using the 4D model (Define, Design, Develop, and Disseminate), which was limited to the Develop stage. Product validity was assessed through evaluations by material and media experts. Practicality was measured using teacher perception questionnaires, student response questionnaires, and learning implementation observation sheets. Effectiveness was determined based on the N-gain score. The research participants were students of class X.1 at SMA Negeri 1 Abung Semuli. The results showed that the e-module achieved validity percentages of 90.75% from material experts and 90.00% from media experts, both categorized as very valid. The practicality assessment yielded percentages of 96.20% from teachers, 89.85% from students, and 89.28% from learning implementation observations, all categorized as very practical. The effectiveness of the e-module was indicated by an N-gain score of 0.43, which falls into the moderate category. Based on these findings, the developed AR-assisted e-module is considered valid, practical, and effective, making it suitable for use as a chemistry learning medium on atomic model development concepts.

Keywords: e-module, augmented reality, assemblr edu, atomic model development, discovery learning

Abstrak: Pengembangan E-Modul berbantuan Augmented Reality (AR) sebagai Media Visualisasi Interaktif pada Materi Perkembangan Model Atom. Materi perkembangan model atom bersifat abstrak sehingga peserta didik sering mengalami kesulitan dalam memahaminya. Salah satu upaya untuk membantu visualisasi konsep tersebut adalah melalui e-modul berbantuan Augmented Reality (AR). Penelitian ini bertujuan untuk mendeskripsikan tingkat kevalidan, kepraktisan, dan keefektifan e-modul berbantuan AR pada materi perkembangan model atom untuk peserta didik kelas X SMA. Penelitian ini menggunakan metode penelitian dan pengembangan (Research and Development) dengan model 4D (Define, Design, Develop, Disseminate) yang dibatasi hingga tahap Develop. Kevalidan produk diperoleh melalui validasi ahli materi dan ahli media, kepraktisan diukur menggunakan angket persepsi guru, angket respons peserta didik, dan lembar observasi keterlaksanaan pembelajaran, sedangkan keefektifan ditinjau berdasarkan skor N-gain. Subjek uji coba penelitian adalah peserta didik kelas X.1 SMA Negeri 1 Abung Semuli. Hasil penelitian menunjukkan bahwa e-modul memperoleh persentase kevalidan sebesar 90,75% dari ahli materi dan 90% dari ahli media dengan kategori “sangat valid”. Kepraktisan e-modul memperoleh persentase sebesar 96,2%

dari guru, 89,85% dari peserta didik, dan 89,28% dari observasi keterlaksanaan pembelajaran dengan kategori “sangat praktis”. Keefektifan e-modul ditunjukkan oleh nilai N-gain sebesar 0,43 dengan “kategori sedang”. Berdasarkan hasil tersebut, e-modul berbantuan AR yang dikembangkan dinyatakan valid, praktis, dan efektif sehingga layak digunakan sebagai media pembelajaran kimia pada materi perkembangan model atom.

Kata kunci: e-modul, augmented reality, assemblr edu, perkembangan model atom, discovery learning

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▪ INTRODUCTION

The development of science, particularly in the field of Information and Communication Technology (ICT), has progressed very rapidly in the twenty-first century. Unlike previous centuries, this phenomenon has brought society into a new era known as the digital era. In this digital era, technological advancement has led to significant changes in various aspects of life, including education (Nachsyahbandi et al., 2022). Education is required to adapt to these developments through the integration of technology into the teaching and learning process. This adaptation is essential to ensure that students possess the ability to adjust to changing conditions, access information effectively, and compete in a continuously evolving global environment (Yusuf et al., 2023).

Technological advancement has not only influenced educational systems but has also transformed the way students learn. Developments in information technology have shifted learning practices from conventional methods to more open and flexible approaches (Puteri et al., 2025). Easy access to information through the internet has encouraged a shift in educational focus, from merely mastering basic knowledge to developing thinking skills, practical competencies, and cross-cultural communication abilities (Manoarfa et al., 2025). In this regard, the utilization of technology in education enables students to learn without limitations of time and place. These changes require teachers and educational institutions to adapt curricula, improve digital literacy, and establish effective collaboration between educators and students to ensure that learning activities are more effective and aligned with contemporary need (Rizal, 2023).

In response to these developments, the government encourages the emergence of more creative and independent learning innovations, one of which is the implementation of technology in the teaching and learning process (Sari & Munir, 2024). Technology-assisted learning not only provides students with flexibility to learn without spatial and temporal constraints but also requires teachers and educational institutions to actively develop digital literacy and foster effective collaboration within dynamic learning environments (Rizal, 2023). The development of e-modules functions not only as a technical learning aid but also as an instrument for fostering student independence. Consequently, the use of e-modules as self-learning materials encourages students to actively review and reinforce the knowledge they have acquired at school in an independent and interactive manner (Idayanti & Suleman, 2024). Technological support enables modules to be developed in a more interactive format by integrating visual, audio, and user-friendly interface elements, thereby increasing students' learning interest and active participation in the learning process (Wardhana et al., 2022).

The implementation of technology-assisted learning still faces various challenges, particularly in subjects characterized by abstract concepts such as chemistry. Chemistry is often perceived as a difficult subject because many of its concepts cannot be directly observed and require strong visualization abilities (Koeper et al., 2020). One of the topics that frequently causes learning difficulties is atomic structure (Afrianis & Ningsih, 2022). Students' low level of understanding of this topic is attributed to the limited availability of learning media that can help them visualize atomic particles and understand the differences among atomic theories (Widodo, 2021). As a result, students are prone to misconceptions and encounter difficulties in connecting the concepts they learn with appropriate visual representations.

The results of an interview with a chemistry teacher at SMA Negeri 1 Abung Semuli revealed that digital instructional media had not been utilized in the learning process, resulting in classroom instruction that was still dominated by conventional teaching methods and limited to the use of textbooks. This condition was caused by the limited facilities and infrastructure available at the school, including the minimal use of e-modules or other learning media and the absence of supporting facilities such as projectors. As a result, students tended to be passive, easily became bored, and relied solely on text and two-dimensional images provided in textbooks. The interview findings also indicated that the school had occasionally used e-modules as alternative learning materials, however Augmented Reality (AR) technology had never been implemented in the learning process. Although the topic of atomic model development is inherently interesting because it discusses the fundamental concepts of atomic structure, students often experience difficulties in visualizing abstract atomic models.

The findings from a questionnaire distributed to 35 students supported the interview results. A total of 77.1% of respondents considered the topic of atomic model development difficult to understand, while 71.4% stated that learning media consisting of text and two-dimensional images were insufficient to support their understanding. Furthermore, 97.2% of the students indicated that the use of technologies such as Augmented Reality (AR) would facilitate their understanding of atomic concepts while making chemistry learning more enjoyable. Therefore, the development of learning media should not be limited to conventional modules but should include AR-assisted e-modules capable of providing interactive visualization and supporting independent learning (Sa'diah et al., 2022). Consequently, the challenges faced by students are closely related to the role of teachers in integrating technology into the learning process.

Teachers play an important role as facilitators in utilizing information technology to create more interactive learning environments. In this context, teachers assist students in acquiring knowledge and skills through technology while ensuring that its use aligns with learning objectives and educational standards (Jufri et al., 2023). However, the implementation of technology in education continues to face several challenges, including teachers' limited skills in operating technological devices, inadequate access to technology, and insufficient support from schools and government institutions. Although many educational institutions strive to integrate technology into their curricula to create more interactive learning environments, technology utilization remains far from optimal in practice (Saripudin & Robbani, 2024). In addition, some teachers remain comfortable with conventional teaching methods and are reluctant to adopt technology-assisted approaches (Sari & Munir, 2024). In fact, the use of technology has been shown to enhance student engagement and facilitate access to information (Yuanti et al., 2024).

Students who use online learning platforms tend to be more active and enthusiastic than those who learn through traditional methods (Hirzi & Ibrahim, 2025).

Considering these challenges, innovation in learning media development is needed to bridge the gap between the abstract nature of learning materials and students' need for more meaningful learning experiences. One alternative that can be implemented is the development of an Augmented Reality (AR)-assisted e-module capable of presenting atomic model development concepts in a visual and interactive manner (Hurrahman et al., 2022; Sa'diah et al., 2022). AR technology is designed to enhance students' conceptual understanding of abstract scientific concepts (Purwanti et al., 2024). An AR-assisted e-module developed for molecular geometry learning has been shown to help visualize molecular structures, facilitate understanding of learning materials, and motivate users to learn independently (Hurrahman et al., 2022).

One application and website that can be utilized for the implementation of Augmented Reality (AR) is Assemblr Edu. This platform was selected because it is more practical, specifically designed for educational purposes, does not require programming skills, and can be accessed through smartphones. Compared with other applications such as Unity 3D, Assemblr Edu is more suitable for research emphasizing ease of use and integration into structured e-modules (Lestari et al., 2023; Rahmawati et al., 2024; Sholicha & Ratnaningrum, 2025). This platform enables the visualization of three-dimensional virtual objects within real-world environments, supports collaborative learning, and enhances the skills of both students and teachers (Robles et al., 2023). The use of Assemblr Edu allows teachers to create three-dimensional learning content that can be accessed through Android devices or smartphones (Fauzi & Saputro, 2025). The integration of AR technology and 3D content in classrooms has been proven to improve student engagement, participation, and learning achievement (Tuta et al., 2022). In addition, the application is flexible and can be accessed anytime and anywhere, thereby supporting independent learning (Sahidi et al., 2025).

Although several studies have developed Augmented Reality (AR)-based learning media for atomic model development concepts, most of them have focused primarily on the visualization of atomic models in the form of three-dimensional objects without incorporating them into a structured e-module. The resulting media generally function only as visual aids and have not been integrated into a learning system that supports students' independent learning. Furthermore, studies specifically utilizing Assemblr Edu as a platform for AR development remain limited. Based on these considerations, this study aimed to develop an Augmented Reality (AR)-assisted e-module as an interactive visualization medium for atomic model development concepts and to determine its validity, practicality, and effectiveness.

▪ **METHOD**

This study employed the Research and Development (R&D) method, which is a research approach aimed at developing new products or improving existing ones. The development model used in this study was the 4D model (Define, Design, Develop, and Disseminate) developed by Thiagarajan et al., (1974). However, this study was limited to the Develop stage. The selection of the 4D model was based on the consideration that it provides systematic procedures and is grounded in educational product design theory, including learning materials, instructional models, learning media, and educational applications. In addition, this model facilitates researchers in designing and developing

learning products, either as new innovations or as improvements to existing products, to make them more practical, comprehensive, and effective (Maydiantoro, 2021).

This research was conducted at SMA Negeri 1 Abung Semuli during the 2025/2026 academic year. The participants consisted of 35 tenth-grade students and two chemistry teachers who were involved in a limited trial to evaluate the practicality and effectiveness of the developed Augmented Reality (AR)-assisted e-module on atomic model development concepts.

The development procedures of the Augmented Reality (AR)-assisted e-module in this study followed the 4D model, which consisted of the following stages:

The define stage was the initial phase of the research and development process, aimed at identifying and defining learning needs as the basis for product development. At this stage, a preliminary analysis was conducted through interviews and observations to identify learning problems related to atomic model development concepts. In addition, analyses of student characteristics, learning materials, learning tasks, and learning objectives were carried out. The results of the define stage served as the foundation for designing an Augmented Reality (AR)-assisted e-module that was aligned with students' needs and instructional objectives.

The design stage involved developing the product based on the findings obtained during the define stage. Activities conducted at this stage included designing the Augmented Reality (AR)-assisted e-module, developing criterion-referenced tests, selecting appropriate media and formats, and creating the initial product design. Furthermore, research instruments were developed to assess the validity, practicality, and effectiveness of the e-module.

The develop stage focused on the development and refinement of the designed product. During this stage, the e-module was validated by material experts and media experts to determine its validity. The product was subsequently revised based on suggestions and feedback provided by the validators. After revision, the product was implemented in a limited trial involving students to determine the practicality and effectiveness of the Augmented Reality (AR)-assisted e-module on atomic model development concepts. The research data collected in this study consisted of several types, as presented in Table 1.

Table 1. Data Collection Techniques

Research Data	Data Sources	Instruments	Implementation Stage in the 4D Model
Validity	Material experts, media experts, and chemistry teachers	Validation questionnaire	Develop
Practicality	Students and chemistry teachers	Observation sheet and practicality questionnaire	Develop
Effectiveness	Students	Pretest and posttest sheets	Develop

Teacher Needs Analysis Interview Data

Teacher needs data were collected through structured interviews with three chemistry teachers at SMA Negeri 1 Abung Semuli. The interviews were conducted to

identify the need for developing an Augmented Reality (AR)-assisted e-module on atomic model development concepts. The obtained data were analyzed descriptively and used as the basis for product development.

Student Needs Analysis Questionnaire Data

Student needs data were collected through questionnaires administered to 35 tenth-grade students at SMA Negeri 1 Abung Semuli. The data were analyzed using percentages adapted from Sudjana (2005) to identify the need for developing an Augmented Reality (AR)-assisted e-module on atomic model development concepts.

$$\%J_{in} = \frac{\sum J_{in}}{N} \times 100\%$$

Description: $\%J_{in}$ = percentage of respondents selecting the *i-th* response option
 $\sum J_{in}$ = number of respondents selecting the *i-th* response option
 N = total number of respondents

The percentage results were subsequently interpreted using respondent index categories and presented descriptively.

Product Validity Data

Validity data were obtained through evaluations conducted by material experts and media experts involving three lecturers from Universitas Lampung and two chemistry teachers from SMA Negeri 1 Abung Semuli as validators. The assessment was carried out using a validation questionnaire based on a 1-4 Likert scale adapted from Arikunto (2018). The validation data were analyzed using percentages to determine the validity level of the developed Augmented Reality (AR)-assisted e-module.

Table 2. Likert Scale for Product Validity Assessment

Response Option	Score
Very Valid	4
Valid	3
Less Valid	2
Invalid	1

The questionnaire data were analyzed using the percentage formula adapted from Sudjana (2005). This calculation was used to determine the validity percentage score and assess the feasibility of the developed product.

$$P = \frac{\sum \text{obtained Score}}{\sum \text{maximum Score}} \times 100\%$$

The resulting percentages were then interpreted to determine the quality category of the product. The interpretation was based on the score conversion criteria adapted from Arikunto (2016) as presented in Table 3.

Table 3. Validity Score Conversion Criteria

Percentage Score	Category
0%–20%	Very Low / Poor Validity
20.1%–40%	Low Validity
40.1%–60%	Moderate Validity
60.1%–80%	High Validity
80.1%–100%	Very High Validity

Product Practicality Data

Practicality data were collected through teacher perception questionnaires, student response questionnaires, and learning implementation observation sheets. The questionnaire instruments employed a 1-4 Likert scale adapted from Arikunto (2018), as shown in Table 4. The questionnaire results were analyzed using percentages to determine the practicality level of the Augmented Reality (AR)-assisted e-module.

Tabel 4. Skala Likert Angket Uji Kepraktisan

Assessment Aspect	Score			
	1	2	3	4
Teacher Perception	Very Poor	Poor	Good	Very Good
Student Response	Very Poor	Poor	Good	Very Good

The practicality questionnaire data were analyzed using the percentage formula adapted from Sudjana (2005), to determine the extent to which the product could be effectively used in learning activities.

$$P = \frac{\sum \text{obtained Score}}{\sum \text{maximum Score}} \times 100\%$$

The resulting percentages were then interpreted to determine the practicality category of the product. The interpretation was based on the score conversion criteria adapted from Arikunto (2016).

Table 5. Practicality Score Conversion Criteria

Percentage Score	Category
0%–20%	Very Low / Impractical
20.1%–40%	Low Practicality / Less Practical
40.1%–60%	Moderate Practicality / Fairly Practical
60.1%–80%	High Practicality / Practical
80.1%–100%	Very High Practicality / Very Practical

Data on learning implementation were collected using an observation sheet with a score of 1 assigned to the response “Yes” and a score of 0 assigned to the response

“No”. The percentage of learning implementation was calculated using the formula adapted from Sudjana (2005).

$$k = \frac{\text{score of each aspect}}{\text{maximum score of each aspect}} \times 100\%$$

The learning implementation score (k) was then converted to determine the quality level of the developed product. The score conversion referred to the categories adapted from Widoyoko (2009), as presented in Table 6.

Table 6. Learning Implementation Categories

Percentage	Category
> 80	Very Good
> 60–80	Good
> 40–60	Fair
> 20–40	Poor
≤ 20	Very Poor

Product Effectiveness Data

Effectiveness data were obtained through learning achievement tests administered before and after the implementation of the Augmented Reality (AR)-assisted e-module. The test scores obtained by students were converted into achievement scores using the formula adapted from Akbar (2013).

$$\text{Student Score} = \frac{\text{total score obtained}}{\text{maximum possible score}} \times 100$$

The improvement in students' learning outcomes was analyzed using the N-gain score adapted from Hake (1999). The obtained N-gain values were subsequently interpreted according to predetermined categories to determine the effectiveness level of the developed e-module.

$$N - \text{Gain} = \frac{\text{Posttest} - \text{Pretest}}{\text{Maximum Score} - \text{Pretest Score}} \times 100\%$$

The resulting N-gain values were then converted into effectiveness categories to standardize the level of learning improvement. The interpretation categories were adapted from Hake (1999), as presented in Table 7.

Table 7. N-Gain Categories

N-Gain Value	Category
$N\text{-Gain} \geq 0.7$	High
$0.3 \leq N\text{-Gain} < 0.7$	Moderate
$N\text{-Gain} < 0.3$	Low

▪ RESULT AND DISCUSSION

This development research produced an Augmented Reality (AR)-assisted e-module as a learning medium for Atomic Model Development concepts for tenth-grade

senior high school students. The development process employed the 4D model (Define, Design, Develop, and Disseminate); however, the study was limited to the Develop stage.

Define Stage

The define stage was conducted to identify learning needs and problems encountered in schools. Activities carried out at this stage included preliminary analysis, learner analysis, task analysis, concept analysis, and the formulation of learning objectives.

Based on interviews with chemistry teachers at SMA Negeri 1 Abung Semuli, it was found that Atomic Model Development concepts were still difficult for students to understand because of their abstract nature. The learning media used in classrooms were primarily textbooks and two-dimensional illustrations, which were insufficient to help students visualize atomic models concretely.

The learner analysis indicated that 77.1% of students experienced difficulties in understanding Atomic Model Development concepts, while 71.4% stated that learning media consisting only of text and two-dimensional images were insufficient for understanding atomic concepts. Furthermore, all students expressed interest in using interactive learning media and three-dimensional visualizations. As many as 97.2% of students were interested in learning materials presented through Augmented Reality (AR) technology. These findings indicate that students require innovative and interactive learning media capable of providing more concrete visualizations of abstract concepts.

Task analysis was conducted by identifying the learning activities commonly assigned by teachers. These activities generally consisted of reading learning materials, taking notes, and completing practice exercises. Based on the findings, learning activities within the e-module were designed by integrating the Discovery Learning model to encourage students to actively construct concepts independently.

Design Stage

The design stage involved preparing the initial design of the Augmented Reality (AR)-assisted e-module. The e-module was designed using Canva and presented as a digital flipbook through the Heyzine platform. AR integration was developed using Assemblr Edu with marker-based AR technology, allowing three-dimensional objects to be displayed through QR code scanning using smartphones.

The e-module was organized according to the Discovery Learning syntax, consisting of stimulation, problem statement, data collection, data processing, verification, and generalization. The learning materials covered atomic model development, experiments related to the discovery of fundamental atomic particles, atomic notation, isotopes, isobars, and isotones. In addition to the content materials, the e-module was equipped with practice exercises, interactive quizzes, and three-dimensional atomic model visualizations to facilitate students' understanding of abstract concepts.

At this stage, research instruments were also developed, including material expert validation sheets, media expert validation sheets, student response questionnaires, teacher perception questionnaires, learning implementation observation sheets, and pretest-posttest instruments.

The practicality of the e-module was evaluated through teacher perception questionnaires, student response questionnaires, and learning implementation observation sheets. The practicality test results are presented in Figure 2.

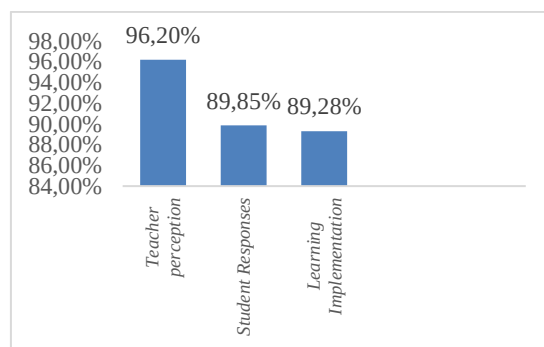


Figure 2. E-Module Practicality

Based on the teacher perception questionnaire, the Augmented Reality (AR)-assisted e-module obtained a percentage score of 96.2%, categorized as very practical. Teachers reported that the e-module was easy to use and effectively supported content delivery. This ease of use was facilitated by the systematic organization of learning materials, clear navigation, and integration of various learning media that assisted teachers in explaining Atomic Model Development concepts. These findings are in line with Wulandari and Darmana (2026), who reported that AR-based interactive e-modules are practical for classroom implementation and effectively support the visualization of abstract chemistry concepts.

Student responses yielded a percentage score of 89.85%, which was categorized as very practical. Students provided positive feedback regarding the appearance of the e-module, ease of use, and AR features that made learning more engaging and interactive. The three-dimensional visualizations presented through AR technology helped students understand abstract concepts more effectively, resulting in more meaningful learning experiences. This finding is supported by Laila and Atun (2026), who stated that AR implementation in learning can enhance learning motivation, cognitive engagement, and visualization skills.

Furthermore, the learning implementation observation results achieved a percentage score of 89.28%, categorized as very good. This result indicates that learning activities utilizing the AR-assisted e-module were successfully implemented according to the planned instructional procedures. The high level of implementation suggests that students were able to participate actively and systematically in each learning activity, enabling the learning objectives to be achieved effectively.

Based on the results of teacher perceptions, student responses, and learning implementation observations, the developed Augmented Reality (AR)-assisted e-module fulfilled the criteria of being very practical and was therefore suitable for use in chemistry learning on Atomic Model Development concepts.

The effectiveness of the e-module was measured using students' pretest and posttest scores, which were subsequently analyzed using the N-gain score adapted from Hake (1999).

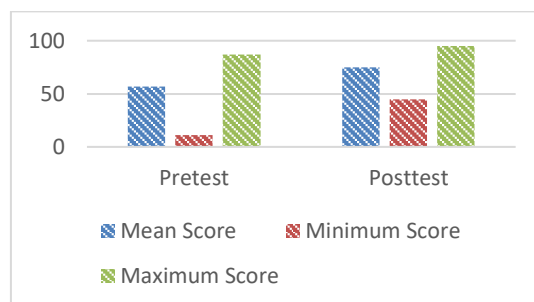


Figure 3. Students' Pretest and Posttest Results

The results showed an improvement in students' learning outcomes after using the Augmented Reality (AR)-assisted e-module, with an N-gain score of 0.43, which falls within the moderate category. This improvement indicates that the developed e-module effectively assisted students in understanding Atomic Model Development concepts, which are inherently abstract. The three-dimensional visualizations provided through AR technology enabled students to observe atomic model representations more concretely, thereby facilitating conceptual understanding. In addition, the systematic presentation of learning materials and the integrated learning activities within the e-module contributed to more meaningful learning experiences.

These findings are consistent with Rita and Guspatni (2024), who reported that AR utilization in chemistry learning helps visualize abstract concepts, making them easier for students to understand. The findings are further supported by Ramadani et al. (2020), Fadhilah and Nasution (2025), and Amriani et al. (2026), who found that the implementation of AR in chemistry learning can improve conceptual understanding and student learning outcomes. Therefore, the developed Augmented Reality (AR)-assisted e-module has the potential to serve as an effective alternative learning medium for Atomic Model Development concepts.

▪ CONCLUSION

Based on the findings of this study, the developed Augmented Reality (AR)-assisted e-module was categorized as very valid, achieving validity percentages of 90.75% from material experts and 90.00% from media experts. In addition, the e-module was categorized as very practical, obtaining percentage scores of 96.2% from teacher perception questionnaires, 89.85% from student response questionnaires, and 89.28% from learning implementation observations. The effectiveness test revealed an improvement in students' average scores from 56.71 on the pretest to 75.09 on the posttest, with an N-gain score of 0.43 in the moderate category. These findings indicate that the AR-assisted e-module is feasible for use as a chemistry learning medium on Atomic Model Development concepts and has the potential to enhance students' conceptual understanding.

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