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Development of Augmented Reality-Based Learning Media on Atomic Absorption Spectrophotometer (AAS) Material

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ABSTRACT

Atomic absorption spectrophotometer (AAS) instruments are seldom available in universities or schools due to their high cost and complex maintenance. To address this issue, innovative learning media are required to simplify and visualize AAS concepts. This study aimed to design an augmented reality (AR)-based learning medium, validate its quality, and assess its feasibility. The research employed a Design-Based Research (DBR) method using the ADDIE model. The final product consists of a homepage, main menu (learning objectives, user guide, materials, AR scans, quizzes, and developer profiles), and interactive materials such as images, videos, simulations, and data interpretation. The validation obtained an average score of 0.83, categorizing it as highly valid. The feasibility test reached 92.16%, indicating that the media is highly practical and ready for classroom use.

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Introduction

The current learning process is inseparable from rapid technological advancements, which demand innovations to make learning more dynamic (Fahreza et al., 2023). In chemistry education, practical activities are crucial for bridging theory and application (Rusdi et al., 2023). However, many students encounter challenges due to limited facilities, infrastructure, and materials (Noviani et al., 2021; Rusdi et al., 2023). To address this, technology-based learning media can offer an alternative solution (Sukasih et al., 2023).

Among various laboratory instruments, spectrophotometers are widely used in analytical, pharmaceutical, and organic chemistry to measure absorbance at specific wavelengths and provide meaningful hands-on experiences (Gandhi et al., 2022; Salsabiila et al., 2024). One key instrument is the atomic absorption spectrophotometer (AAS), which detects metal concentrations based on atomic absorption principles (Ahluwalia, 2023). However, AAS is a complex and expensive instrument, often unavailable in schools or universities due to high procurement and maintenance costs (Shidiq et al., 2022). As a result, many students struggle to understand its concepts, working principles, and components, which creates a barrier to effective laboratory learning (Naese et al., 2019; Lestari et al., 2023).

Learning media helps students deeply understand abstract concepts, facilitates practical work, and overcomes existing limitations (Rusdi et al., 2023). The learning media used must align with the rapid development of technology, information, and science to improve the quality of learning outcomes (Yudha et al., 2023) and enhance the ability to think critically with technology to solve problems (Murniatiningtyas et al., 2024). A technology that is increasingly useful in learning media is smartphones (Abidin et al., 2023). One such technology is AR (Glasby et al., 2023).

AR is a smartphone technology that combines three-dimensional (3D) digital data with the real world (Fombona-Pascual et al., 2022). In learning, AR functions to enhance student engagement through interactive simulations, directly presenting visuals of theoretical concepts (Mohamad et al., 2024), improving critical thinking skills, and problem-solving (Indahsari & Sumirat, 2023). AR can also simulate training processes and the maintenance of chemical instruments (Alatawi et al., 2023). It is used to understand abstract chemical concepts (Irwansyah et al., 2019), visualize chemical molecules (Lau et al., 2022), and increase interest and motivation in learning (Wulandari et al., 2019). Previous research has shown that AR improves learning quality, particularly in acid-base labs (Rusdi et al., 2023), alkanes and cycloalkanes concepts (Kodiyah et al., 2020), NanoDrop spectrophotometer industrial training (Alatawi et al., 2023), and analytical instrumentation design (Naese et al., 2019). This research thus focuses on developing AR-based learning media for AAS material.

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Recent studies highlight AR as an effective medium for visualizing abstract concepts and laboratory equipment (Restyayulita et al., 2023). AR allows learners to interact with virtual objects in real-world contexts, improving both comprehension and engagement. While AR has been applied in various science education areas, its use for teaching AAS instrumentation remains limited. This gap demonstrates the need for innovative AR-based media to visualize AAS design, components, and working principles. Therefore, this study aims to design AR-based learning media for AAS concepts, validate its quality, and evaluate its feasibility as an alternative learning resource in chemistry education.

Methods

The research method used is Design-Based Research (DBR). This method is a pedagogical innovation approach that begins with identifying a problem, then analyzing the appropriate technology or approach to solve it (Cochrane et al., 2023). The ADDIE model, consisting of analysis, design, development, implementation, and evaluation (Anafi et al., 2021), was employed for the research. However, this study was limited to the development stage, as the focus was on developing the media, measuring its validity, and assessing its feasibility. Thus, it has not yet been fully implemented in the learning process, and evaluation results could not be determined at this stage.study employed a meta-analysis approach, which involves summarizing, reviewing, and analyzing data from previous research. In simple terms, meta-analysis can be understood as a quantitative review of published studies with similar characteristics. This method allows researchers to systematically synthesize findings and assess the overall magnitude of an intervention’s effect.

The main sources of data in this study were articles published in scientific journals. Data collection was conducted through electronic searches using platforms such as Google Scholar and other journal databases. The keywords applied included: learning media, e-modules for students, e-modules and learning outcomes, high school biology materials, problem-based learning, learning motivation, and elementary schools. From the initial search results, 30 articles relevant to the research topic were identified, of which 25 were deemed the most suitable for further analysis (Wahyuningtyas & Kristin, 2021).

Analysis Stage

The analysis stage aims to gather information and collect data through analysis from various sources, including relevant journals, textbook analyses, course documents (CPMK 3 and sub-CPMK 4 from the chemical instrumentation course), concept maps, concept analysis, learning indicator compilation, and the selection of software tools for AR media development.

Design Stage

The design stage starts with conceptualizing the learning media. This initial design outlines the media development process and includes a basic overview of the learning media using flowcharts and storyboards. The next step involved obtaining feedback from the supervising lecturer on the design, which was revised before creating the initial product.

Development Stage

In this stage, the initial AR-based learning media product for AAS material was developed. Once the product was created, it underwent a validation test by media experts and material experts. This validation involved two chemistry education lecturers and one informatics engineering lecturer from UIN Sunan Gunung Djati Bandung. The purpose was to assess the validity of the media, after which the media was revised according to the feedback and suggestions from the validators. Afterward, a feasibility test was conducted with 15 chemistry education students from UIN Sunan Gunung Djati Bandung. The data obtained from the validation and feasibility tests were analyzed and processed, followed by the preparation of a final report.

Validation Stage

The validation test data was gathered using a validation test questionnaire that used a 1-5 Likert scale (1 = Poor, 2 = Bad, 3 = Moderate, 4 = Good, and 5 = Excellent). The data collected were then calculated and compared with the critical value (rcritical) using the following formula:

$$r = \frac{x}{N.n}$$

Description:

r = Validity value

x = The number of each answer

n = Maximum score

N = Number of validators

After the data is calculated, the results are compared. The data analysis results can be considered valid if the validity value ® is greater than the rcritical, which is more than 0,30 (Sugiyono, 2023). The interpretation of the validity value ® can be seen in Table 1.

Table 1. Interpretation of The Validity Value

No.	Validity Value	Interpretation
1.	$0.81 \le r \le 1.00$	High
2.	$0.61 \le r \le 0.80$	Moderately High
3.	$0.41 \le r \le 0.60$	Moderate
4.	$0.21 \le r \le 0.40$	Low
5.	$0.00 \le r \le 0.20$	Very Low

Feasibility Test

The feasibility test data were collected by using a Likert scale of 1-5 (1 = Poor, 2 = Bad, 3 = Moderate, 4 = Good, and 5 = Excellent). The data were then analyzed following Ernawati & Sukardiyono (2017) using quantitative calculations and adjusted according to the weight score. The feasibility percentage can be calculated as follows:

$$P = \frac{\sum n}{N} \times 100\%$$

Description:

P = Percentage (%)

$\sum n$ = Total score obtained

N = Total ideal score

Table 2. Interpretation of The Percentage Value of Egibility

No	Percentage (%)	Category	Conclusion
1	90-100	Excellent Feasibility	Learning media is ready for use
2	80-89	Feasible	Learning media is ready for use
3	70-79	Fairly Feasible	Learning media can be used after revisions
4	60-69	Low Feasibility	Revisions are needed before use
5	<60	Poor Feasibility	Major revisions are needed before use.

Results and Discussions

This study aimed to describe the design of the AR-based learning media for AAS material, analyze the results of validation tests, and assess the feasibility of the media. The display design of the initial AR-based learning media product for AAS material includes the cover page, main menu, learning objectives, media usage instructions, materials, AR scans, quizzes, and developer profiles. After the initial product was developed, a validation test was conducted to assess the validity of the learning media (Saputri et al., 2023). The validation was carried out by presenting the initial version of the media and providing a validation test questionnaire to media and material expert validators.

The average validation result, or rcount for all aspects was 0.83, which is higher than the rcritical value of 0.30. This indicates that the AR-based learning media for AAS material is highly valid, meeting the threshold for high validity. Table 3 provides a detailed summary of the average validation test results for each aspect.

Table 3. The Average Results of The Validation Test For All Aspects

No.	Rated Aspect	r_{count}	$r_{critical}$	Conclusion	Interpretation
1.	Display of learning media	0.82	0.30	Valid	High
2.	Linguistic	0.87	0.30	Valid	High
3.	Visibility	0.80	0.30	Valid	Moderately High
4.	Graphic elements	0.80	0.30	Valid	Moderately High
5.	Software engineering	0.83	0.30	Valid	High
6.	AAS material	0.86	0.30	Valid	High
7.	Comprehension	0.83	0.30	Valid	High
8.	Quiz	0.89	0.30	Valid	High
9.	Linguistic	0.80	0.30	Valid	Moderately High
	Average	0.83	030	Valid	High

Based on Table 3, the display aspect of the learning media obtained an average rcount of 0.82, which was categorized as highly valid. This suggests that the design successfully enhances learning appeal and interest, aligning with Rahmi et al. (2022), who reported that attractive displays boost student motivation. Similarly, Sa'adah et al. (2023) highlighted that user-friendly interfaces are essential for effective media adoption, which is also reflected in this study's findings.

The linguistic aspect achieved an rcount of 0.87, placing it in the highly valid category. Clear and precise language use minimizes misinterpretation, reinforcing Restyayulita et al. (2023), who emphasized that linguistic clarity is crucial in educational media to avoid confusion. The visibility aspect, with an rcount of 0.80, indicates that the media is accessible and visually engaging, consistent with Haryanto et al. (2024), who noted that visibility is a key factor in enhancing user engagement.

The graphic element aspect (rcount = 0.80) further demonstrates that visual design contributes significantly to student engagement, which aligns with Purnama et al. (2024). Likewise, the software engineering aspect (rcount = 0.83) indicates that the media is technically reliable and user-friendly, supporting Sa'adah et al. (2023), who emphasized that usability is a determining factor for the effectiveness of learning media.

The AAS material aspect obtained an rcount of 0.86, which is categorized as highly valid. This reflects the effectiveness of AR in enhancing conceptual understanding, corroborating Amanda (2024), who found that AR-based materials improve learning outcomes in analytical chemistry. The integration of images, videos, and 3D AR objects aligns with Dany et al. (2024), who argued that multimodal representations strengthen memory retention.

In terms of comprehension, the aspect achieved an rcount of 0.83 (highly valid), demonstrating that AR can significantly improve conceptual understanding of AAS material. This is consistent with Indahsari & Sumirat (2023), who reported that AR enhanced learners' ability to grasp abstract chemistry concepts. Furthermore, the quiz aspect (rcountr_{\text{count}}rcount = 0.89) indicates strong validity, showing that the AR media effectively assesses student mastery, supporting Kuswanto & Radiansah (2018), who emphasized the role of interactive assessments in reinforcing learning. Finally, the linguistic aspect of the material (rcountr_{\text{count}}rcount = 0.80) confirms that the text is communicative and easily understood, once again supporting Sa'adah et al. (2023).

After analyzing the quantitative data, the media was revised based on validator feedback. The final AR-based learning media product is shown in Figure 1.

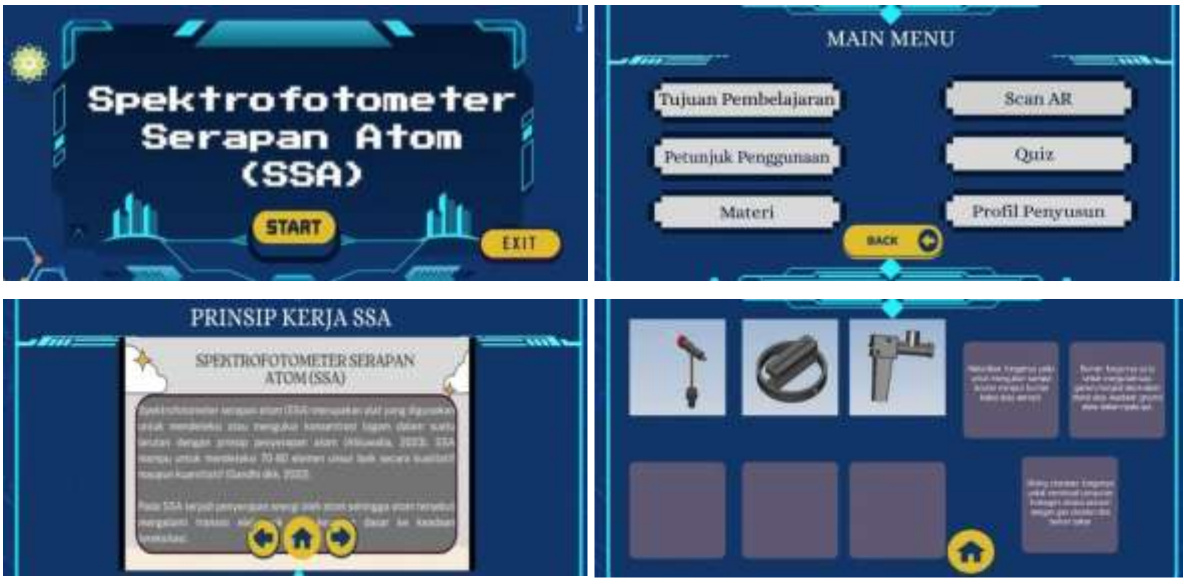
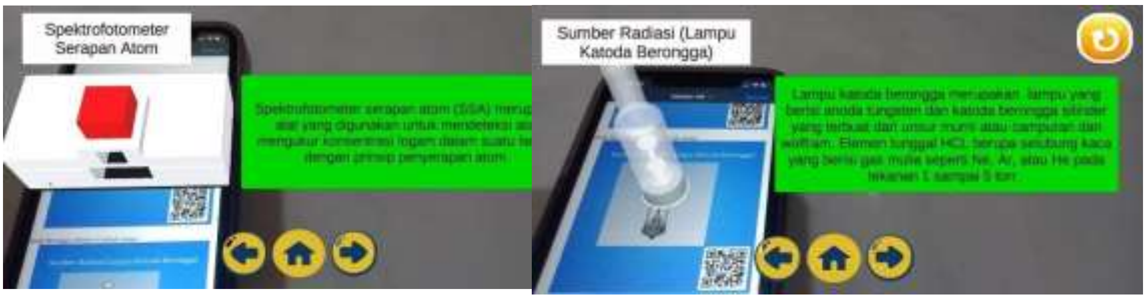


Figure 1. AR Learning Media Display

The 3D AR objects are designed to help visualize the components of the AAS (Dany et al., 2024). The AR scan display includes an AR camera that detects markers for AAS components (Usmaedi et al., 2020). Figure 2 displays examples of AR markers and 3D object representations.



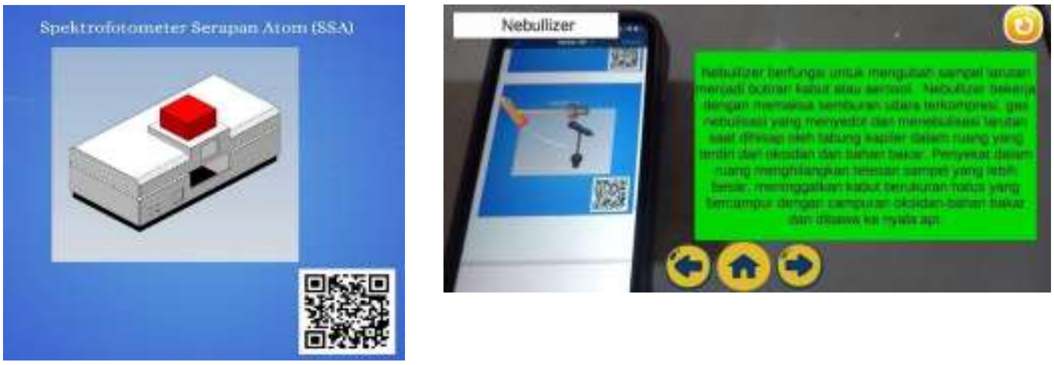


Figure 2. AR 3D Object Display and Marker AR Display

After confirming the validity and making necessary revisions, a feasibility test was conducted to evaluate the suitability of the media and gather feedback from students (Helsy & Andriyani, 2017). The feasibility test was conducted with 15 chemistry education students. The test began with providing instructions on how to install the learning media application, offering guidance on how to use it, and having the students complete a questionnaire. The results of the feasibility test for each aspect are shown in Table 4.

Table 4. Feasibility Test Results for Each Aspect

No.	Rated Aspect	Percentage (%)	Information
1.	Visual communication	91.33	Excellent Feasibility
2.	Software engineering	87.33	Feasible
3.	Material substance	94.67	Excellent Feasibility
4.	Linguistic	95.33	Excellent Feasibility
	Average	92.16	Excellent Feasibility

Based on Table 4, the visual communication aspect scored 91.33%, categorized as excellent feasibility. This suggests that the AR media design is appealing, which helps increase interest and learning motivation (Rahmi et al., 2022). The combination of visual and audio media also facilitates deeper understanding (Dany et al., 2024). The software engineering aspect scored 87.33%, falling under the feasible category, indicating that the AR media is easy to use (Sa'adah et al., 2023), with buttons functioning according to their intended roles (Kuswanto & Radiansah, 2018).

The material substance aspect received 94.67%, indicating excellent feasibility. This demonstrates that the AAS material within the AR media was appropriately analyzed and clearly presented, enhancing student motivation (Rahmi et al., 2022). The use of visual media like images, videos, and 3D AR objects (accompanied by text and audio descriptions) further aids in visualizing complex information, offering an engaging learning experience regarding AAS material (Dany et al., 2024). The quizzes (true/false, multiple choice, and drag-and-drop) allow students to assess their understanding of the material (Lestari et al., 2023).

The linguistic aspect scored 95.33%, categorized as excellent feasibility, indicating that the language used in the AR media was clear, correct, and communicative (Restyayulita et al., 2023). The use of communicative language enhances the delivery of information and simplifies the comprehension of complex concepts (Amanda, 2024).

Overall, the AR-based learning media for AAS material received an average feasibility score of 92.16%, confirming that it is very suitable for use in learning. Despite being valid and highly feasible, the media still has some limitations, such as compatibility issues with certain iOS and Android devices and a large file size, requiring further improvements to ensure broader accessibility.

Conclusions

This study successfully developed augmented reality (AR)-based learning media to support the understanding of atomic absorption spectrophotometer (AAS) concepts. The validation results (rcount = 0.83) indicate that the media is highly valid, while the feasibility test, with a score of 92.16%, demonstrates that the media is highly practical and suitable for classroom use. These findings confirm that AR technology can effectively visualize complex instrumentation and enhance student engagement in chemistry learning.

The main contribution of this study lies in addressing the limited availability of AAS instruments in educational settings by offering an innovative, interactive alternative through AR. This provides more accessible and meaningful learning experiences in analytical chemistry, particularly for students who lack access to the actual equipment. By integrating AR, this learning medium supports better visualization of AAS components, working principles, and applications, making abstract concepts easier to comprehend.

However, the media still has several limitations, such as compatibility issues with some versions of iOS and Android devices, and the large file size, which affects accessibility. Future research is recommended to develop markerless AR systems, increase interactivity, integrate direct assessment features, and optimize the file size for better compatibility across devices. These improvements will help make AR-based learning media more universally accessible and enhance its effectiveness in diverse learning environments.

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