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Developing Interactive Augmented Reality Learning Media to Introduce Chemistry Laboratory Equipment in Senior High School

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Abstract

This research aimed to describe the validity or feasibility value of developing a game-based augmented reality learning application to introduce chemical laboratory equipment. The application developed was AR-LAB (Augmented Reality Laboratory), combining augmented reality technology with quizzes. This research employed development research using Richey and Klein's theory, which contains three steps: planning, production, and evaluation. The results show that the product's validity by material and media experts was 91.67% and 91.67%, respectively, in the very good category. The teacher assessment provided an average score of 112.4 from the ideal maximum score of 120, with an ideal level reaching 93.60% in the very good category. Meanwhile, testing by ten students obtained the maximum score in the very good category. The successfully developed media has the advantage of introducing laboratory equipment in three dimensions that are affordable and easy for students to learn about chemical laboratory equipment.

Keywords: augmented reality; instructional media; laboratory equipment

Abstrak

Penelitian ini bertujuan untuk mengevaluasi validitas dan kelayakan pengembangan aplikasi pembelajaran berbasis permainan dengan teknologi augmented reality guna memperkenalkan peralatan laboratorium kimia. Aplikasi yang dikembangkan, AR-LAB (Augmented Reality Laboratory), mengintegrasikan teknologi augmented reality dengan kuis interaktif. Metode yang digunakan dalam penelitian ini adalah penelitian pengembangan berdasarkan teori Richey dan Klein, yang terdiri dari tiga tahap utama: perencanaan, produksi, dan evaluasi. Hasil penelitian ahli materi dan ahli media masing-masing mencapai 91,67% yang tergolong dalam kategori sangat baik. Selain itu, hasil penilaian guru menunjukkan skor rata-rata 112,4 dari skor maksimum ideal 120, dengan tingkat kelayakan 93,60% yang juga termasuk dalam kategori sangat baik. Uji coba terhadap sepuluh siswa menghasilkan skor maksimal, yang menegaskan bahwa aplikasi ini sangat layak digunakan sebagai media pembelajaran untuk memperkenalkan peralatan laboratorium kimia. Media yang berhasil dikembangkan memiliki keuntungan untuk mengenalkan peralatan lab kimia dalam wujud tiga dimensi murah dan mudah bagi siswa untuk mempelajari peralatan laboratorium kimia.

Keywords: fun_colloid; koloid; pendidikan; inovasi; pembelajaran multimedia

Introduction

The development and utilization of information technology are now inevitable (Hanifah et al., 2021). Information technology plays a crucial role in enhancing various aspects of life, thereby influencing improvements in quality of life. One significant impact of information technology lies in its application to enhance the quality of education. It is impossible to overlook the interaction between educators and learners when discussing education. Educators are tasked with creating a conducive and enjoyable learning environment. Aiming to achieve the three main objectives of education: acquiring knowledge, shaping attitudes, and developing skills Top of Form (Lubis et al., 2020).

Alongside the advancements in Information Technology (IT), numerous instructional media are engaged in materializing the achievement of learning objectives. One such medium is through the utilization of augmented reality-based media (Suciliyana et al., 2020). Augmented reality visualizes abstract concepts to introduce or enhance understanding of a targeted object. They are designed to facilitate detailed information delivery on a tangible object (Ma'ruf et al., 2024). Augmented reality provides an alternative way to stimulate students' imagination towards the intended object.

The operational principle of AR involves a calibrated camera that detects provided markers (Andrian et al., 2020). Subsequently, upon recognizing the marker pattern, the webcam compares it with its database. It will not be processed if the marker does not match the database. However, if it matches, the marker information will render and display pre-designed 3D objects or animations (Krisnandry et al., 2020a).

Augmented reality (AR) represents a variation of virtual reality (VR), where VR immerses users into a virtual environment. Unlike VR, which entirely replaces the user's view with a virtual environment, AR allows users to perceive both the real and virtual worlds simultaneously. AR exhibits three key characteristics: integration of real and virtual worlds, real-time interaction, and the presentation of objects as three-dimensional models (Ramadhan et al., 2021).

Currently, augmented reality finds utility across various domains, including educational media. Besides being more interactive, the implementation of augmented reality is also cost-effective. Another advantage inherent in augmented reality is its ease of operation. Nevertheless, augmented reality also exhibits some drawbacks, including requiring substantial storage memory for operating devices (Sandi 2021).

Several studies investigated the use of augmented reality in learning media. For instance, Rizti Yovan & Kholiq (2021) explored the development of augmented reality media to train high school students in abstract thinking about magnetic field materials. This research implies the potential to enhance educators' knowledge regarding developing physics learning materials based on augmented reality. Also, Krisnandry & Bahri (2020b) conducted a study entitled Implementation of Augmented Reality Technology (AR) in Redox Reaction and Electrochemistry Smart Book Application Using Marker-Based Tracking Desktop-Based Method. This research aimed to create redox reaction and electrochemistry books supplemented with smart book features as teaching aids. It displays 3D animations more realistically and interactively using augmented reality technology to keep students engaged in learning redox reactions and electrochemistry.

Additionally, instructional materials are utilized to introduce experimental equipment, such as the study by Yana et al. (2021), which investigated the development of laboratory equipment introduction videos and the implementation of tools in the Google Classroom application. The aim was to assess the feasibility and students' response to the instructional videos introducing laboratory equipment in the 10th-grade science class at State Senior High School 8, Bengkulu. The research findings indicate that the developed instructional aids are highly suitable as instructional tools for

introducing experimental apparatus. However, better improvement and interactive media were needed to enhance students' understanding of chemical apparatus.

Based on an interview with one of the chemistry teachers at Kolombo High School, several issues have been identified as the basis for the lack of implementation of laboratory equipment introduction materials in the school's laboratory. The laboratory is used jointly with other subjects, such as physics and biology. Additionally, some students lack seriousness during laboratory sessions. It might be because they do not understand the laboratory regulations. Consequently, laboratory equipment becomes vulnerable to being knocked over and falling, leading to damage or breakage. While the teacher introduced laboratory equipment in class, the illustrations were limited to those available on the website.

Implementing augmented reality in laboratory equipment recognition will help students learn laboratory apparatus independently (Widayanti and Nur'aini 2020). It will avoid passive learning, which tends to inhibit students from expressing opinions or asking about unfamiliar topics. The chemistry learning process should be predominantly practical rather than theoretical, enhancing students' understanding of the material (Saputra and Kurniawati 2021a). Therefore, chemistry as both a process and practice must be supported synchronously with various methods, ensuring a balanced learning approach. Another factor influencing the introduction of experimental devices is the limited availability of meetings to explain laboratory tools and the scarcity of literature sources for learners.

Therefore, this research aims to develop an augmented reality-based learning media integrated with flashcards containing barcodes to facilitate student interaction with various objects. It streamlines the process for teachers to introduce laboratory equipment to students and enables students to quickly identify the equipment within the laboratory. Considering the rapid advancement of technological knowledge, it is regrettable that such opportunities have not been fully utilized.

Method

Research methodology encompasses the steps involved in acquiring scientific knowledge or expertise and becoming a scientific approach to obtaining data for specific purposes and utilities. This study employed the Research and Development (R&D) method. Research and development represent the methodology used to enhance a product to improve one of the rights developed by researchers.

The developmental model applied in this research was the PPE (Planning, Production, and Evaluation) model, developed by Richey and Klein (Husniah et al, 2022). Richey and Klein mentioned that the focus of research and development design can be on front-end analysis planning, production, and evaluation (Shahnaz et al, 2021), emphasizing primarily the focus and design development through planning, production, and evaluation analysis. This PPE developmental model entails a comprehensive analysis from inception to conclusion, encompassing design, production, and evaluation. The steps in utilizing the PPE model for this research are as follows:

a. The Planning Stage involves creating a product plan tailored to specific objectives.
b. The production stage involves the actual creation of products based on pre-established designs. Production entails the manufacturing process according to predetermined plans.
c. The evaluation stage involves assessing the products that experts have utilized. It serves to identify product weaknesses and gather feedback from experts. This phase is crucial for understanding the product's effectiveness and receiving expert recommendations.

Data Analysis Techniques

Analysis is utilized to examine how existing data from research is processed to ascertain the quality of a product, which

material and media experts validated, assessed by teachers, and responded to by students. Once all data is gathered, the outcome of the data analysis is the culmination of their assessment.

The analysis technique of product assessment in the development of augmented reality learning media based on gaming for laboratory equipment recognition is carried out through the following steps:

1) Converting qualitative product quality assessment outcomes employing the Likert scale, as in Table 1.

Table 1.
Conversion Guideline from Category Into Score

Information	Score
Very Good	5
Good	4
Moderate	3
Poor	2
Very Poor	1

2) Calculating the average score from the evaluations of one subject matter expert, one media expert, and five reviewers (chemistry teachers) for all aspects of assessment and each evaluation, using the following formula.

$$x = \frac{\sum x}{n}$$

X = Average Score
∑x = Total Score
n = Number

3) Transforming the average scores across all assessment aspects into qualitative values in alignment with the ideal assessment criteria as in Table 2.

Table 2.
Average Score Conversion Guideline

Quantitative Score Range	Qualitative Category
Xi + 1,80 SBi < X	Very Good
Xi + 0,60 SBi < X ≤ Xi + 1,80 SBi	Good
Xi - 0,60 SBi < X ≤ Xi + 0,60 SBi	Moderate
Xi – 1,80 SBi < X ≤ Xi – 0,60 SBi	Poor
X ≤ Xi – 1,80 SBi	Very Poor

X as Actual Score
Xi as the Average number of ideal scores
= ½ x (ideal maximum score + ideal minimum score)
SBi as standard deviation
= 1/6 x (ideal maximum score – ideal minimum score), maximum ideal score as ∑ criteria items x highest score

4) Calculating the overall percentage of augmented reality learning media quality adequacy.
5) Calculating the percentage of ideal quality of augmented reality learning media across each aspect is crucial.
6) Converting student responses from letter format to scores was achieved by employing the Guttman scale, containing yes and no as the scores of 1 and 0, respectively.

Results and Discussion

The research on the Development of an Augmented Reality Game-Based Application for Laboratory Equipment Recognition employed the PPE development model. The selection of this model was

justified by its focus on comprehensive analysis-driven development and design, covering planning, production, and evaluation stages. The PPE model development technique is one of the approaches for developing new products or refining existing ones, ensuring accountable outcomes. Employing the PPE model facilitated the evaluation of development activities at each stage.

Planning Stage

The planning stage aims to design the development of an augmented reality game-based learning media for introducing high school chemistry laboratory tools. The requirements necessary for this design process covered:

1) Needs Analysis

The analysis of needs, conducted on April 5, 2023, was a crucial step in gathering information for product development. This activity involved observing the process of introducing chemical laboratory equipment and interviewing relevant teachers. The observations indicated that despite the presence of an integrated laboratory, practical sessions were often not conducted optimally. One of the reasons was the lack of laboratory assistants available to help supervise students during the practical sessions, coupled with students' limited understanding of laboratory equipment names, resulting in only a tiny portion of them being actively engaged, while others merely observed.

2) Curriculum Analysis

Analyzing the curriculum became an essential need to establish the competencies to be achieved in teaching the introduction to chemical laboratory equipment with an independent curriculum approach. In its implementation, classroom teaching is strengthened by an independent curriculum, supported by teaching materials in the form of Student Worksheets. In this context, the independent curriculum approach, which integrates worksheets as a learning instrument, facilitates more effective adaptation to individual student needs in achieving the desired competencies.

3) Literature Review

A literature review was conducted to refer to theories and concepts found in various sources such as books, journals, theses, and dissertations. The literature review affirmed that the use of instructional media, particularly in the form of augmented reality applications, has the potential to enhance students' understanding of introductory concepts. Furthermore, the literature analysis conducted by the researcher provides a basis for designing product assessment instruments, which encompass the evaluation of product feasibility aspects and students' conceptual understanding achievements. Therefore, the synthesis of information from various literature sources has formed a solid foundation for this research.

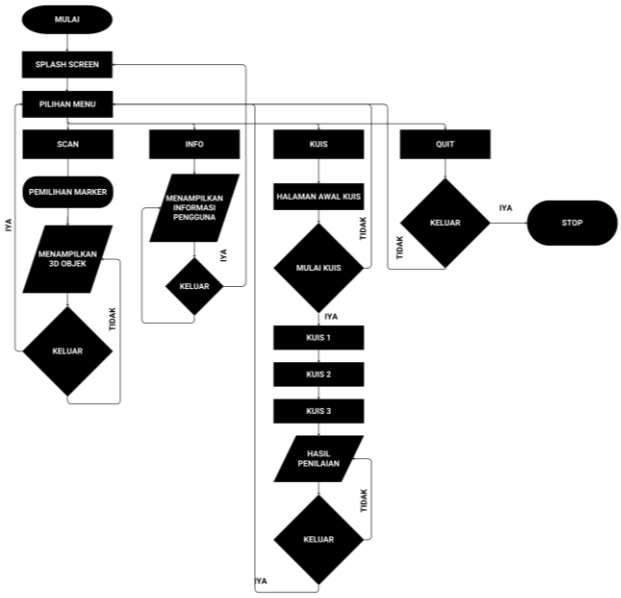
Production Stage

This stage constituted a crucial step in the product design process to optimize it for educational material purposes. During product development, various aspects were considered based on previous analyses. The ongoing application development involved augmented reality, aiming to showcase 16 types of tools in a 3D format while providing 20 different questions to introduce some commonly used tools in high school chemistry lab sessions.

1) Flowchart Design

A flowchart is a visual tool that illustrates the flow of a program from one step to the next. Moreover, its primary function is to systematically detail processes, facilitating readers' comprehension of the presented information. In other words, flowcharts aid in simplifying procedural sequences and facilitating information interpretation. Consequently, the utilization of flowcharts not only aids in presenting information more clearly but also enhances efficiency in understanding and following the described in Figure 1.

Figure 1.
Flowchart of AR Development Guideline



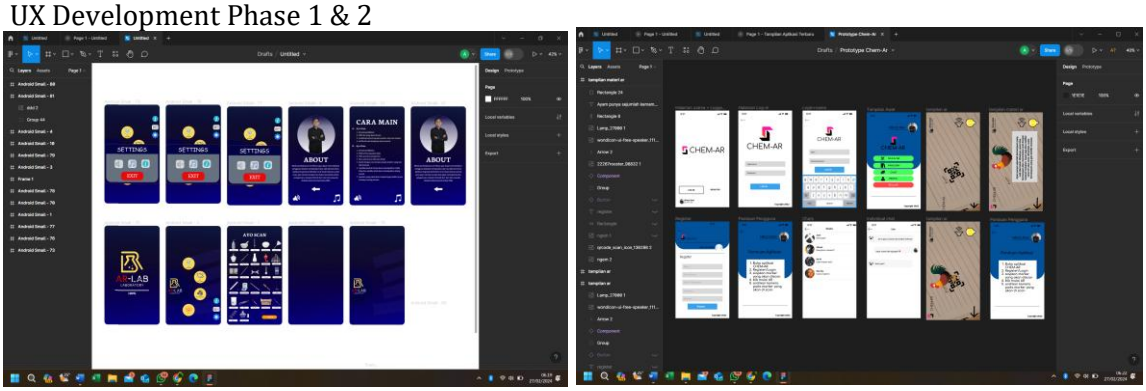
2) Storyboard design

According to Iwan Binanto (2010:275) as cited in Rustamana et al. (2023), the description of scenes, visual design elements, audio elements, duration, annotations, and voice narration was conceptualized in creating a storyboard. It was suggested that the storyboard's scope be first outlined as a detailed script, which was then filled with graphic and visual details to strengthen and elucidate the intended theme. The final production constraints would be delineated to align with the intended type of production. For instance, the storyboard will be tailored to the needs of augmented reality.

3) UX Design (User Experience)

The experiences users encounter when interacting with this augmented reality development media were encapsulated within the UX. The primary objective of UX design is to craft satisfying, efficient, and effective experiences for users, thereby enhancing satisfaction with game-based augmented reality learning media development. Figma is the software utilized for UX design. It is remarkably user-friendly for novices yet boasts diverse features (Figure 2).

Figure 2.
UX Development Phase 1 & 2



4) User Interface (UI) Design

The user interface encompasses elements that facilitate interaction between users and systems, such as buttons, icons, menus, and other interactive components. Its primary goal was to enhance the user experience in utilizing augmented reality development applications. Canva is the software commonly utilized in UI development, renowned for its abundant features and user-friendly interface (Figure 3 and 4).

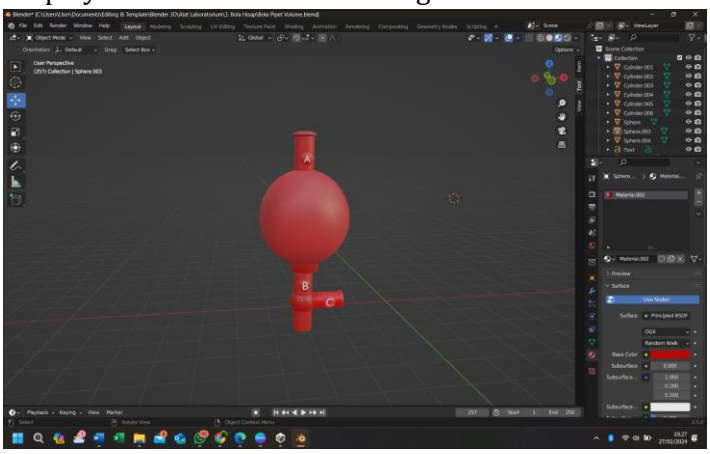
Figure 3.
Display of Start Menu, Marker Selection and Information

Figure 4.
Display of Quiz

5) Create 3D model designs

The 3D design software used in developing augmented reality learning media was Blender (Figure 5). This software allowed users to export 3D model results into various formats that could be used in Unity development software. There were sixteen forms of 3D models developed, namely consisting of a Bunsen burner, a micropipette, a microscope, a fume cupboard, a mortar and pestle, a measuring flask, a GC-MS, an FT-IR, a spray bottle, a suction ball, an SPU, a UV-VIS, a tube rack reaction, a dropper pipette, glassware, and tweezers.

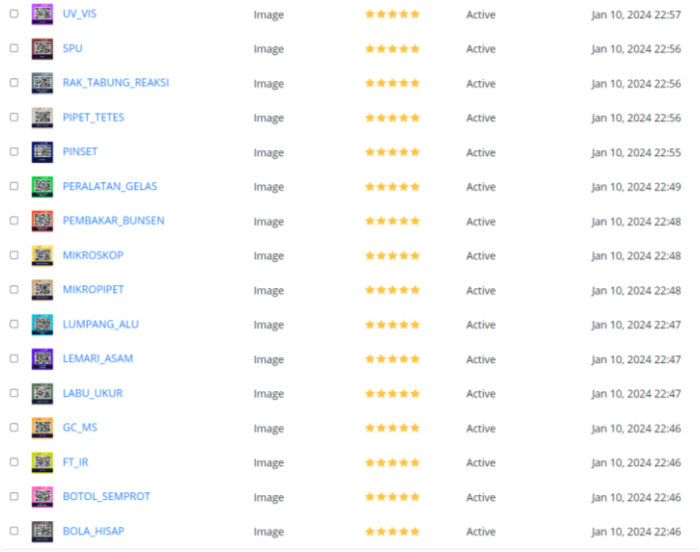
Figure 5.
Display of The Process of Creating a 3D Model



6) Connecting marker to the Vuforia SDK

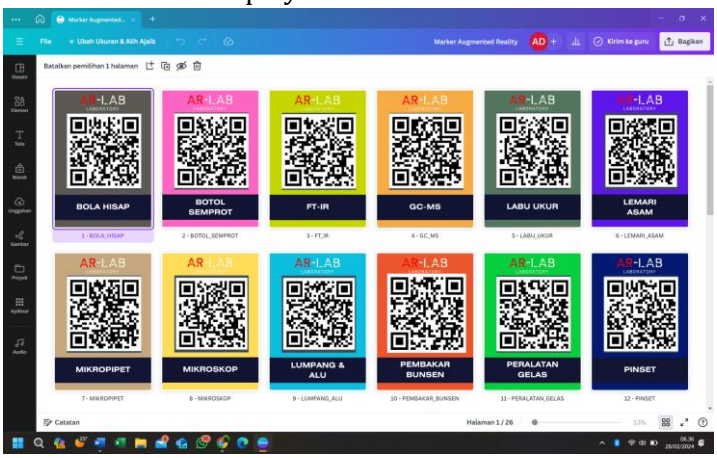
Vuforia SDK Engine is a software platform or plugin for creating augmented reality applications, especially those used in Unity 3D applications. Developers could easily add advanced computer vision functionality to any application, enabling it to recognize images and objects, and interact with real-world spaces (Figure 6).

Figure 6.
Vuvoria SDK Engine Platform View



The marker-making process itself was done using Canva software in a quantity that corresponded to the number of 3D objects, namely sixteen (Figure 7).

Figure 7.
AR-LAB Marker Display



7) Reassembling all builds

In the process of developing augmented reality applications using Unity, one of the crucial stages was reassembling separate builds into a single unit. After all the components have been arranged properly, the developer can then compile and test to ensure that the application being developed runs smoothly.

After the compilation process was complete, the build results will produce a program that could be run on various platforms, one of which is Android mobile devices. The next stage was to conduct a thorough testing process to ensure the

application ran smoothly without bugs or other issues.

Evaluation Stage

At this stage, an analysis of the feasibility of game-based augmented reality learning media for the introduction of SMA chemistry laboratory equipment was described based on the assessments of expert validators, teachers and students.

1) Media expert validation

Data on the quality of the media being developed, specifically a game-based augmented reality application for introducing chemical laboratory equipment, was obtained through an assessment by the owner of Cikara Studio, who is a media expert. The validation was carried out by filling in a quality assessment sheet. Then, the results were converted into quantitative data, which were tabulated and analyzed to evaluate the quality of the product being developed. The assessment of the quality of this media focused on three aspects: application display, flashcards, and augmented reality, each of which is divided into 12 indicators. The results of the assessment data by media experts can be seen in Table 3.

The results of evaluating the quality of game-based augmented reality learning media for the introduction of chemistry laboratory equipment by media experts show an overall average score of 55, which is close to the ideal maximum score of 60, reaching an ideal percentage of 91.67%. Meanwhile, the results of the overall score calculation by media experts placed the product in the very good category.

2) Material expert validation

Data on the quality of game-based augmented reality development media for introducing laboratory equipment was obtained through assessments by a material expert, who was a chemistry education lecturer. The validation was carried out by filling out a quality assessment sheet, which was then converted into quantitative data, tabulated and analyzed to assess the quality of the product being developed. The assessment of the quality of the augmented reality development media in the introduction of chemistry laboratory apparatus was divided into three aspects: material aspect, content aspect, and language aspect. The results of the quality assessment by material expert lecturers are presented in Table 3.

Table 3.
Material Expert Validation Result

Assessment Aspect	∑ Score	∑ Ideal Max Score	Ideal Percentage (%)	Category
Material aspect	8	10	80%	Very Good
Content aspect	25	25	100%	Very Good
Language aspect	22	25	88%	Very Good
Total	55	60	91,67%	Very Good

The results of the quality assessment of game-based augmented reality learning materials for introducing chemistry laboratory equipment, evaluated by material experts, obtained an average score of 55. This score is close to the ideal maximum of 60, achieving an perfect percentage of 91.67%. The calculation results show that the overall score by material experts indicated that the game-based augmented reality development media was considered a very good category.

3) Teacher assessment

Data regarding the quality of game-based augmented reality learning media products for introducing chemistry laboratory equipment was obtained through assessments from five reviewers, who were chemistry teachers. Qualitative data were collected by filling out a quality assessment questionnaire, which was then converted into quantitative data. Furthermore, it was calculated and analyzed to assess the quality of the product that had been developed.

Aspects of assessing the quality of game-based augmented reality learning media for introducing chemistry laboratory

equipment include six elements: material, content, language, application display, flashcards, and augmented reality. Data from quality assessments from reviewers are presented in Table 4.

Table 4.
Media Expert Validation Result

Assessment Aspect	∑ Score	∑ Ideal Max Score	Ideal Percentage (%)	Category
Material aspect	8	10	80%	Very Good
Content aspect	25	25	100%	Very Good
Language aspect	22	25	88%	Very Good
Total	55	60	91,67%	Very Good

The results of the evaluation of the quality of game-based augmented reality learning media for introducing chemistry laboratory equipment by the reviewer, who is a chemistry teacher, overall reached an average score of 112.4 from the ideal maximum score of 120, with an ideal level of 93.60%. The calculation results conclude that the overall score given by the reviewer is in the range 100.8 < X. Therefore, it can be concluded that augmented reality-based learning media for laboratory equipment is categorized as very good.

4) Student response

After the product has passed a series of trials by material experts and media experts and is declared feasible or valid after several revisions with the guidance of the thesis supervisor, the next step is to test student responses. The aim was to evaluate user responses to the ARLAB application.

This test was carried out on class X students who had received lessons on introducing chemical laboratory equipment. Testing involved 10 randomly selected students and was carried out outside the learning environment and school.

The questionnaire instrument applied uses the Guttman scale with "Yes" or "No" statements. Qualitative data is converted into quantitative data through the use of the Guttman scale, which was then arranged in tables and analyzed based on the desired category criteria. The results of student responses are summarized in Table 5.

Table 5.
Data on Assessment Aspects by Chemistry Teachers

Assessment Aspect	∑ Score	∑ Ideal Max Score	Ideal Percentage (%)	Category
Material aspect	9	10	90%	Very Good
Content aspect	23,2	25	92,80%	Very Good
Language aspect	23	25	92%	Very Good
Application display aspect	25	25	100%	Very Good
Flashcard display aspect	14,4	15	96%	Very Good
Augmented reality aspect	17,8	20	89%	Very Good
Total	112,4	120	93,60%	Very Good

From the data obtained, it can be seen that all statement indicators in the questionnaire were categorized as very good, with percentage results reaching 100%. These results indicate that the developed product has met the learning standards expected by students. Apart from that, the applications that have been developed are also considered interesting and practical.

This media has advantages compared to previous studies that developed learning media to introduce chemical instruments. (Saputra and Kurniawati

(2021a) developed an Android-based medium for practical material to introduce chemical laboratory equipment for high school. However, the media developed is still two-dimensional. The media developed by Zamhari et al. (2022) as a puzzle cannot be used online and must be conducted offline. Meanwhile, Pradana et al. (2022) successfully developed augmented reality media to introduce laboratory equipment. However, the media developed for science laboratories still lacks the introduction of chemical lab equipment. Therefore, the media developed successfully in this study has the advantage of introducing laboratory equipment in three dimensions, which is easy to access and learn anytime and anywhere.

Conclusion

The conclusion from this study indicates that developing game-based learning media with augmented reality to introduce chemical laboratory equipment follows the PPE (Planning, Production, and Evaluation) model. This media is designed with an augmented reality feature that allows users to see three-dimensional objects and access interactive quizzes to improve understanding. In addition, the validation results by media experts and material experts show that the developed learning media meet very good quality standards. Assessments from chemistry teachers and student responses also show positive results, where this media is considered very good and worthy of being used as a learning tool to help students understand chemical laboratory equipment more interactively and interestingly.

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