Developing an Augmented Reality-Based Laboratory Manual for Chemistry Education in Low-Resource Schools

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ABSTRACT

Hands-on chemistry experiments are vital for high school education but are often hindered by resource limitations in schools, particularly the lack of laboratory facilities and materials. This research and development (R&D) study aimed to design, develop, and evaluate an Augmented Reality (AR)-based practicum guide as a practical solution to these challenges. Employing the ADDIE development model, the study produced an AR application and a companion laboratory manual for acid-base chemistry. The product's validity was assessed by experts using Aiken's V, while its practicality was evaluated through questionnaires administered to 31 high school students and a chemistry teacher. The results demonstrated high quality, with an expert validation score of 0.87 ('Very Valid'). The practicality assessment was also highly positive, yielding average scores of 86.85% ('Very Good') from students and 98.21% ('Very Good') from the teacher. The study concludes that the AR-based practicum guide is a valid and highly practical tool that effectively overcomes resource barriers in science education. It enhances student engagement and offers a viable solution for conducting laboratory activities in schools with limited facilities, thereby helping to democratize access to hands-on scientific learning.

Keywords: Augmented Reality, Chemistry Education, Laboratory Manual, Low-Resource Schools, Educational Technology

INTRODUCTION

Experiment is essential for chemistry learning in high school (Shana & Abulibdeh, 2020). By participating in hands-on experiments, students can apply their theoretical knowledge to real-world settings and comprehensively comprehend the subject (Kotsis, 2024). In addition, experiment improve students critical thinking abilities, formulate hypotheses, and evaluate data, fostering a sense of independence and ownership in their learning (Fahmi et al., 2019). Students also involve in actively during the lesson, in which will promote higher motivation among the classroom atmosphere (Sharaabi-Naor et al., 2014).

The implementation of laboratory activities in schools is often hindered by a lack of facilities, infrastructure, or limited resources for effectively managing such activities (Nesti et al., 2025). A lack of necessary chemicals prevents the implementation of certain laboratory modules (Kisdiono et al., 2023). Furthermore, even when chemicals are available, their safety measures often fail to meet required standards, which significantly elevates the risk of accidents (Ranza et al., 2024; Ridasta, 2020). These constraints are particularly acute in low-resource school A significant challenge is that many schools lack dedicated chemistry laboratories for conducting practical work settings, where dedicated chemistry laboratories may be absent altogether (Junaidi et al., 2017; Sari, 2024).

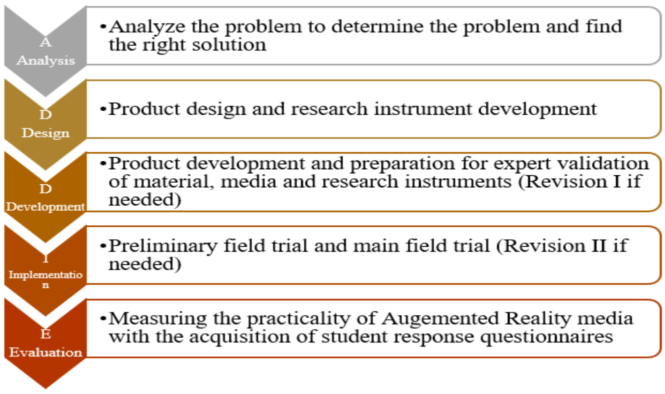
Recent developments in educational technology offer promising alternatives to address these challenges. Augmented Reality (AR) has emerged as an effective tool for enhancing science learning experiences (Elmqaddem, 2019; Rusdi et al., 2023). AR functions by combining the real world with a virtual one, using a camera to capture a live view and overlaying computer-generated models to enrich the learning process (Makhasin & Utami, 2023). The underlying principle involves the real-time integration of immersive, 3D virtual objects that coexist in the same physical space as the user (Harahap et al., 2020; Sylvia et al., 2021). Furthermore, the relatively low cost and increasing accessibility of AR tools make them a viable option for under-resourced educational contexts (Mustaqim, 2017). In the context of chemistry practicals, AR-based instructional guides can offer pedagogical advantages by visualizing abstract phenomena, increasing student motivation, and supporting safer, more effective preparation for laboratory work (Mahendra et al., 2021). A key advantage of AR is its ability to generate a 3D object instantly when a marker is scanned, a feature that significantly boosts student interest. This allows students to explore a tangible, virtual representation of an experiment, fostering a comprehensive understanding of the procedures before they conduct them in a physical laboratory (Rizal & Yermiandhoko, 2018).

However, while the potential of AR in science education has been widely recognized, there is a notable gap in the literature concerning the design, development, and evaluation of AR-based laboratory manuals specifically tailored for low-resource high school environments. This research and development study seeks to fill this gap by creating and evaluating an AR-enhanced chemistry practicum guide designed for schools with limited laboratory access and resources.

METHOD

This study employs a Research and Development (R&D) design using the ADDIE model, which includes five sequential stages: Analysis, Design, Development, Implementation, and Evaluation (Figure 1) (Setiadi & Yuwita, 2020). The ADDIE model is recognized for its systematic approach and its capacity to address cognitive, affective, and psychomotor domains throughout the instructional design process (Pranata et al., 2021)(Pranata et al., 2021; Harefa et al., 2023). Previous work have demonstrated the effectiveness of the ADDIE model in educational media development, supporting its use in this context (Cahyadi, 2019; Harefa et al., 2023).

Figure 1: ADDIE Model to Develop Instructional Media



1. Data Collection

The study utilized both qualitative and quantitative data. Qualitative data were obtained from interviews, observations, and expert feedback. Quantitative data included expert validation scores and questionnaire responses from students and teachers. Qualitative responses were analyzed thematically based on their relevance to the development objectives.

2. Validity Analysis

Content validity was assessed using Aiken's V index (Equation 1-2), which measures the agreement among expert raters regarding the relevance of items to the intended indicators (Kania et al., 2024)

$$V = n(c-1)\sum s \text{ ... (Eq. 1)}$$

$$s = r - lo \text{ ... (Eq. 2)}$$

Where r is score given by the rater, Io is lowest possible rating (1), c is the highest possible rating (4), and n is number of raters. Interpretation of Aiken's V follows the criteria in Table 1.

Table 1:
Interpretation of Aiken's V (Febriandi et al., 2020)

V Score	Category
> 0.80	Very Valid
0.60–0.80	Valid
0.40–0.60	Moderate
< 0.40	Low Validity

3. Practicality Analysis

The practicality of the AR-based guide was assessed through descriptive analysis of questionnaire responses (Equation 3) (Candrawaty et al., 2022). The average percentage score was interpreted using the criteria in Table 2:

$$PracticalityIndex = \frac{(totalscoreobtained)}{(maximumpossiblescore)} \times 100\% \text{ ... (Eq. 3)}$$

Table 2:
Interpretation of Practicality Index (Candrawaty et al., 2022)

Practicality Index	Category
86–100%	Very Good
76–85%	Good
66–75%	Moderate
56–65%	Low
≤ 55%	Very Low

FINDINGS AND DISCUSSION

1. Analysis

The analysis phase identified the necessity of AR-based practicum media by aligning chemistry curricula with national education standards. Document reviews (syllabus, RPP, LKS/LKPD) and interviews with educators revealed a lack of interactive, visually engaging instructional resources aligned with Kompetensi Inti (KI) and Kompetensi Dasar (KD). Moreover, observations indicated a strong preference among students for visual-spatial learning, supporting the integration of image- and video-based AR experiences.

2. Design Phase

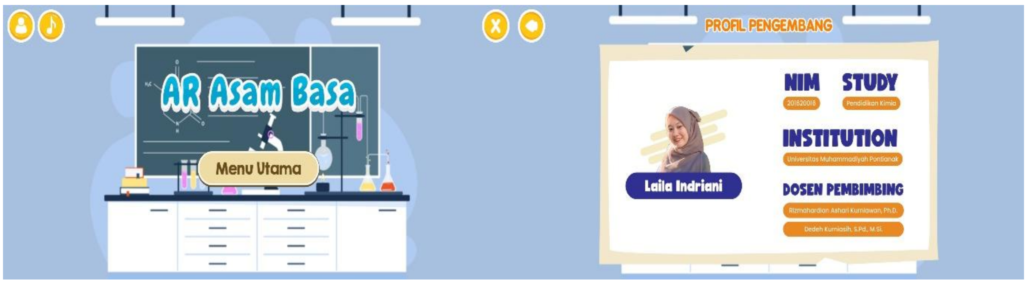
Based on the analysis, the AR-based practicum guide was designed with the following components: media design, instructional design, and research instrumentation. Media were designed using dual-format delivery, comprising a printed practicum guidebook and a mobile AR application focused on acid-base concepts. For instructional design, activities were structured using inquiry-based and scientific approaches, emphasizing conceptual understanding through hands-on AR simulations. Research instrumentation were developed, including validation sheets and response questionnaires, to evaluate both the content validity and practical usability of the media.

3. Development Phase

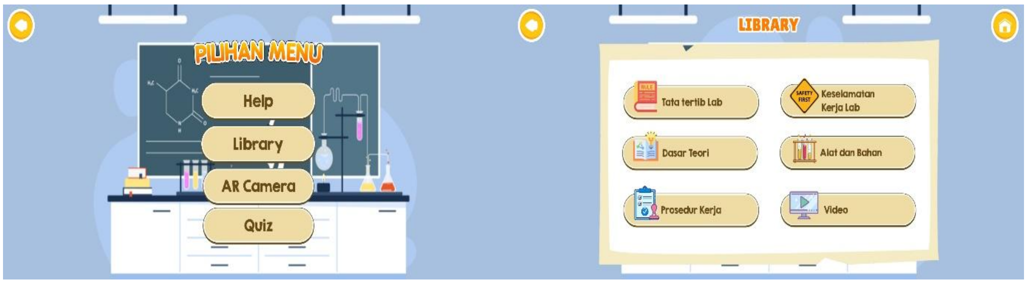
a. AR Application

The development phase yielded two major outputs including AR application and accompanied with a physical laboratory manual. AR app was developed for android-base device The .apk version can be downloaded from https://tinyurl.com/ARLabManual. Upon launching, the application first displays a splash screen presenting the developer's credentials, including name, student number, program of study, and supervisor (Figure 2a). This screen leads to a main menu that serves as the central navigation hub (Figure 2b). The menu features four primary components: (1) a Help Menu, providing instructions on the application's features and proper usage; (2) a Library, containing essential resources such as experimental procedures, laboratory safety protocols, and a list of materials; (3) the AR Camera, which is the core interactive tool; and (4) a Quiz for assessment. The Help and Library resources are designed to be reviewed by the student before initiating the AR simulation.

Figure 2:
(a) Splashscreen and Menu Display Pratical Guide Application, (b) Developer Profiles, (c) Menu Display, (d) Library Menu Display



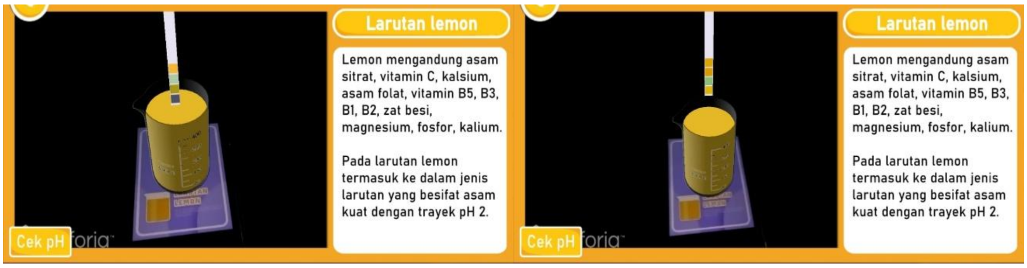
(a) (b)



(c) (d)

The AR Camera module activates the device's camera to scan markers embedded within the physical practicum guidebook. Once the application recognizes a marker, it automatically renders a pre-designed three-dimensional (3D) object or simulation that corresponds to the specific experiment (Figure 3). For example, in the acid-base experiment, scanning the marker displays a 3D simulation of a solution with a universal indicator. The simulation is interactive; when the user immerses the virtual indicator into the solution, it changes color to reflect the solution's pH level. An accompanying "pH analysis" menu appears, which provides the precise pH value and identifies the chemical compounds present in the virtual solution.

Figure3:
Augmented Reality Display, (a) First Look, (b) The Second Look, (c) Final View AR



(a) (b)

(c)

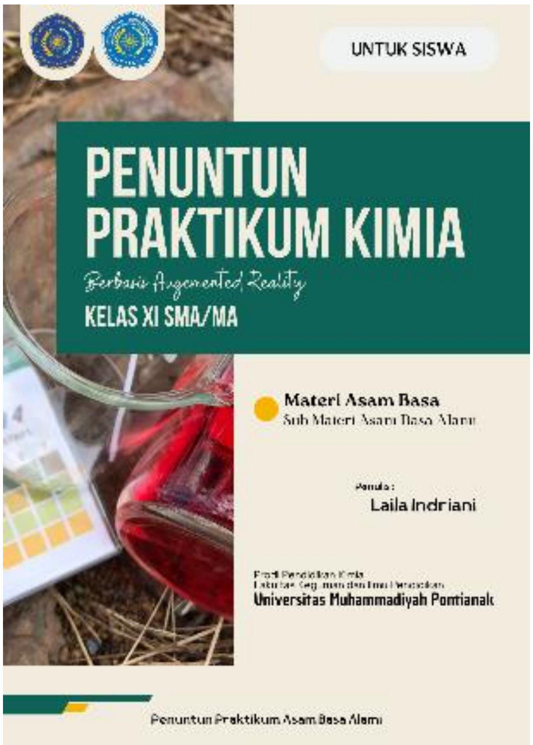
The final component of the application is the quiz module, designed to evaluate the student's comprehension of the experimental procedures (Figure 4). This module consists of five questions, with each question worth a maximum of 20 points, totaling a maximum score of 100.

Figure 4:
The user interface of the integrated quiz module.

b. Laboratory Manual

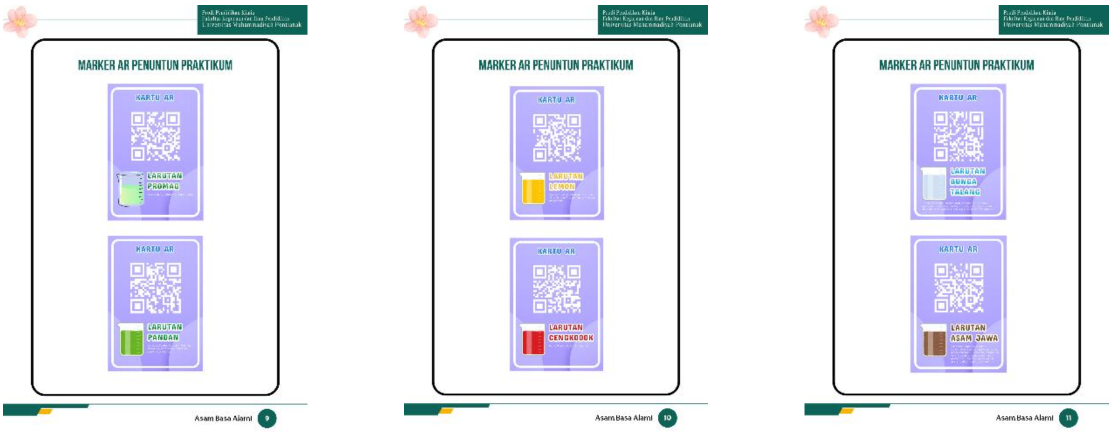
The laboratory manual is a physical book as a companion to AR media. The appearance of the printed book of the practicum guide can be seen in Figure 5.

Figure 5:
Laboratory Manual Cover



Embedded within the pages of this guidebook are a series of custom-designed AR markers (Figure 6). These markers function as visual, spatial anchors for the AR software. When a marker is scanned by a device's camera, it is recognized by the application, which then triggers the rendering of a specific, corresponding 3D model onto the live camera view. The technical workflow began with designing the target images for the AR markers. These images were then imported into the Unity development environment to be recognized by the software. Separately, the 3D assets for the experiments, such as the model for the acid-base solution, were created using 3D modeling software. This completed 3D object was subsequently imported into the Unity project and linked to its corresponding AR marker, establishing the connection required for the interactive simulation to function.

Figure 6:
Example designs for the Augmented Reality (AR) markers embedded in the practicum guidebook.



c. Expert Validition

Table 3:
Validition Results

Number	Aspect	Intervals	Category
1	Language	0,78	Valid
2	Material	0,90	Very Valid
3	Media	0,93	Very Valid
	Average	**0,87**	**Very Valid**

Based on the assessment criteria table evaluating expert validation results for AR-based acid-base laboratory experimental guidance across three dimensions language, material, and media the findings reveal significant validity. Linguistic validation yielded an interval of 0.78, placing language within the valid category. Material expert validation achieved an interval of 0.90, indicating a high level of validity for the materials utilized. Furthermore, media expert validation resulted in an interval of 0.93, affirming the robust validity of the augmented reality-based acid-base laboratory experimental guidance media. The average outcome across three validations was 0.87, signifying that the AR-based acid-base laboratory manual falls within the highly valid category.

4. Implementation Phase

Following the expert validation, the product was evaluated in a two-phase trial process conducted with students from Class XI IPA at SMA Taman Mulia Sungai Raya. The initial small-scale trial involved a focused group of 10 students. This was followed by a large-scale trial to gather data from a broader cohort of 31 students from the same class. In both trial phases, a student response questionnaire was administered immediately after the intervention to assess the product's practicality and gather user feedback.

5. Evaluation Phase

Data was collected in two phases. The initial small-scale trial, involving 10 students, yielded an average practicality score of 84.75%, corresponding to a 'Good' rating. In the subsequent large-scale trial with 31 students, the average score increased to 86.85%, achieving a 'Very Good' rating. The response from the participating chemistry teacher was highly positive, resulting in an average score of 98.21%. This falls within the 'Very Good' category according to the assessment criteria.

The high practicality scores from both students and teachers indicate that the AR-based guide is an effective and well-received educational tool. The positive reception suggests that the application successfully facilitates the execution of practicum sessions, particularly in educational contexts where there are constraints on school facilities and laboratory infrastructure. The content of the guide, which focuses on natural acid-base indicators and pH analysis, provides a viable method for students to achieve key learning objectives without requiring a fully equipped physical laboratory. These findings align with previous studies that underscore the effectiveness of technology-enhanced learning media, such as AR, in educational contexts (Rahayu et al., 2022). The viability of such products as suitable learning aids is further corroborated by similar research, which has also reported exceptionally high user acceptance rates (Rahmawati & Kamaludin, 2024).

CONCLUSION

This research successfully developed and evaluated an AR-based practicum guide, confirming its high levels of validity and practicality. The findings particularly highlight the guide's value as a practical solution for schools operating with low laboratory resources, effectively overcoming common challenges like limited access to tools, materials, and dedicated lab space. Moreover, quantitative feedback from student trials confirmed that the guide's interactive design significantly boosts learning engagement and enthusiasm.

Beyond these immediate outcomes, this study underscores the broader potential of integrating AR to democratize science education. By providing accessible and engaging virtual experiments, such technology can bridge resource gaps and enhance the quality of learning, especially in under-equipped environments. It is therefore recommended that educators consider adopting similar technologies to ensure that hands-on scientific inquiry remains a central and effective part of the student experience, regardless of physical or financial constraints.

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