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Analysis of High School Needs for the Development of Virtual Laboratories Based On Augmented Reality Technology on Acids and Bases Materials

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ABSTRACT

Limited laboratory facilities in high schools remain the main obstacle in chemistry learning, especially in acids and bases material that requires direct experimentation to reinforce concepts. Augmented reality (AR) technology through virtual laboratories offers an innovative alternative that enables safe, interactive, and flexible practicum simulations. This study aims to analyze the needs of teachers and students for the development of AR-based virtual laboratories and identify the challenges of its implementation. The research method was qualitative with a needs analysis approach, involving in-depth interviews, observation, and curriculum document analysis at six high schools in Indonesia.

The results show that more than 80% of teachers reported that limited laboratory facilities and safety risks are the main reasons for the difficulty of conducting acids and bases practicum in schools. As much as 85% of students stated that lecture-based learning alone makes acid–base concepts feel abstract and difficult to understand. Needs analysis indicated that teachers expect AR-based virtual laboratories to feature realistic acid–base experiment simulations, equipped with 3D animations of ionic reactions, digital pH indicators, and quiz-based evaluation features. Meanwhile, students emphasized the importance of appealing design, simple navigation, and compatibility with smartphones and offline access.

The study also found main challenges including limited ICT devices in schools, low digital literacy among teachers, and the need for intensive training to support AR technology implementation in chemistry learning. These findings complement previous research focused on media design by

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presenting the real needs of users in the field. Theoretically, this study enriches the literature on AR utilization in science education through the integration of user needs analysis. Practically, the results can serve as a reference for media developers, teachers, and policymakers in designing AR-based virtual laboratories that are relevant, effective, and inclusive, thereby improving the quality of high school chemistry learning on acids and bases material.

INTRODUCTION

In the digital era and the 21st-century education revolution, technological innovation is increasingly important in science education. Augmented Reality (AR) allows three-dimensional visualization of abstract concepts such as molecular structures and chemical interactions, which are difficult to convey through traditional media. Literature indicates that AR significantly improves learning motivation, student engagement, and concept comprehension. However, despite its great potential, AR adoption in high schools remains relatively limited by cost, infrastructure, and educator preparedness. Globally, science education faces serious challenges in delivering abstract material such as acids and bases. In Indonesia, many students struggle to deeply understand these concepts due to the lack of laboratory practice facilities and limited time and resources.

One innovative effort is developing AR-based learning media for materials such as chemical bonding, molecular shapes, and more. Priyanto et al. (2022) reported that AR media for covalent bond material received a media validation result of 89.58% and positive responses from students and teachers. Specifically for acids and bases, Rahmadani & Guspatni (202x) designed AR learning applications using Blender 3D, EasyAR, and Unity, employing the Plomp model development approach. This model is tailored to schools needing animation and Q&A to facilitate independent concept discovery by students. Other research on AR-based practicum media also shows its potential. Pohan et al. (2022) integrated local wisdom into AR e-modules for chemical bonding, demonstrating high validation and effectiveness in improving students' spatial intelligence.

AR applications can achieve learning effectiveness, but they have not been specifically directed at acids and bases context nor highlighted comprehensive implementation needs in high schools. Fitriana et al. (2022) through PRISMA methodology found that AR is used at

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various education levels, including secondary schools, with a main focus on 3D visualization, interactivity, experiment safety, and increased information retention and conceptual understanding. Although some studies prove AR media's effectiveness, there is a lack of research exploring schools' real needs such as teacher, student, curriculum, and technical/infrastructure constraints for deploying AR virtual laboratories for acids and bases. In-depth qualitative research is needed to understand these dynamics from the direct perspective of field users.

Another gap is the lack of studies combining needs analysis with prototype media tested and evaluated for usability, pedagogy, and accessibility. Previous research (e.g., Priyanto et al. on chemical bonding and Rahmadani & Guspatni on AR acids–bases design) shows potential but is not integrated with actual school-based needs analysis. Thus, this study addresses the gap by conducting qualitative needs analysis covering teacher perceptions, student readiness, infrastructure constraints, and learning expectations for AR-based virtual laboratory development for acids and bases at the high school level. This approach improves upon prior studies' shortcomings that mainly focused on media design or validation, without investigating the learning context's needs.

Theoretically, the study will enrich the literature on AR technology implementation in education by adding a contextual needs framework and participatory design methodology. Practically, the findings are expected to provide practical recommendations for media developers, educators, and policymakers to develop AR-based virtual laboratories that are appropriate and easy to adopt by high schools in Indonesia. The main objective is to understand real needs and challenges in high schools concerning AR-based virtual laboratory development for acids and bases materials. Benefits include: (1) supporting teachers in visual and interactive delivery of abstract concepts; (2) helping students explore and comprehend acids and bases more deeply; (3) providing a foundation for the development of pedagogically and practically relevant learning media; and (4) opening opportunities for the implementation of more inclusive and scalable innovative technology in secondary education.

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RESEARCH METHODS

This study used a descriptive qualitative approach with a needs analysis method. This approach was chosen because the aim is to deeply explore the needs, perceptions, and expectations of high school teachers and students regarding the development of AR-based virtual laboratories for acids and bases materials, so the results can provide a conceptual basis for the development of learning media relevant to the school context.

The research was conducted at six high schools in Maros Regency, South Sulawesi Province, selected based on criteria: (1) limited chemistry laboratory facilities, (2) adoption of the Merdeka Curriculum, and (3) basic access to ICT devices. Research subjects included 12 chemistry teachers and 60 grade XI students, selected using purposive sampling to fit the research objectives.... Data included: 1) Primary data, obtained through in-depth interviews with teachers and students, and direct observation of chemistry learning activities, 2) Secondary data, obtained from curriculum documents, syllabi, and school reports about laboratory facilities and chemistry learning outcomes.

Data collection techniques included: 1) In-depth interviews with chemistry teachers and students to explore needs, expectations, and challenges in acids–bases learning, 2) Participatory observation during lessons to identify teacher strategies, student engagement, and media limitations, 3) Document analysis covering curricula, learning devices, and laboratory infrastructure data. Research instruments used were 1) Semi-structured interview guides, 2) Learning observation sheets, 3) Field notes.

Data analysis used the Miles & Huberman (1994) model consisting of three stages: 1) Data reduction: sorting, simplifying, and focusing data relevant to virtual laboratory AR development needs, 2) Data presentation: organizing data in descriptive narrative, tables, and thematic categories, 3) Drawing conclusions and verification: identifying patterns, themes, and main needs of teachers and students, and confirming results with respondents using member checking.

RESULTS AND DISCUSSION

This research was conducted across six high schools in Maros Regency, South Sulawesi Province, involving 12 chemistry teachers and 60 grade XI students. Data were collected

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through in-depth interviews, observation, and curriculum document analysis. The main findings are as follows.

Chemistry Laboratory Conditions in High Schools

Field observations showed that 83% of schools have incomplete laboratories that are rarely used for practicum. Teachers stated limited chemicals, equipment, and safety risks as the main reasons for rare practical activities. One teacher commented: "We more often explain acids and bases theoretically because the laboratory doesn't support practical work."

Teachers' Needs for Virtual Laboratory

About 75% of teachers reported needing AR-based learning media capable of simulating acids–bases experiments, especially titration, indicator color changes, and ion representation in solution. Teachers also emphasized the importance of quiz-based evaluation features so students can measure understanding independently.

Students' Needs for Virtual Laboratory

Interviews with students revealed that 85% have difficulty understanding acids–bases concepts via lectures alone. They expect more interactive and visual learning media. 78% stated the virtual laboratory should be accessible via Android smartphones, with a simple, appealing interface, and contain gamification elements.

Expected Features

Needs analysis identified some essential features for AR-based virtual laboratory development, including: 1) 3D titration simulation for acids–bases, 2) pH indicator visualization (analog and digital), 3) Particle ion animation in solution, 4) Independent experiments with varied substances, 5) Digital worksheet and interactive quizzes.

The study also uncovered several challenges in implementation, including: 1) Limited ICT infrastructure: 67% of schools lack adequate computers, 2) Teacher readiness: 58% of teachers are unfamiliar with AR and need training, 3) Limited Internet access: 42% of schools are in low-network areas, so applications should be usable offline. Overall, the study highlights a gap between curriculum demands emphasizing chemistry experiments and real school conditions with limited laboratory facilities. AR-based virtual laboratory development is seen as a potential solution but must account for user needs, ease of access, and teacher training support for effective implementation.

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Results indicate that laboratory facility constraints in high schools remain the main challenge in chemistry learning, especially for acids and bases material. These findings align with Rahmadani and Guspatni (2022), which emphasize that chemistry practice often fails in schools due to a lack of laboratory materials and equipment. This impacts students' understanding since acids and bases are abstract and require experiment visualization for stronger conceptual grasp.

Teachers' needs for AR-based virtual laboratories able to simulate titration, pH indicators, and ion reactions reflect a push for technology-based innovation. This matches Priyanto and Sumarwan (2022), who developed AR media for chemical bonding material and received very positive validation from teachers and students. Therefore, developing AR media for acids–bases topics is a relevant step to address the need for alternative practicum in schools.

Students' needs for interactive, smartphone-based, gamified learning media confirm that the digital generation prefers visual, practical learning. Fitriana et al. (2022) noted that AR use in chemistry education increases student engagement, strengthens information retention, and facilitates understanding of abstract concepts. This supports study data showing that 85% of students struggle to grasp acids–bases material through lectures alone.

Implementation challenges such as limited ICT, teacher readiness, and uneven internet access show that AR-based media development depends not just on application design but also on the supporting educational ecosystem. As Pohan et al. (2022) stated, AR media success depends on not only design validity but also accessibility and ease of use in schools. Thus, the recommended solution is developing a virtual laboratory that runs on smartphones in offline mode, complete with simple guides for teachers.

This research also highlights a gap in previous studies—most AR work in chemistry education (e.g., Bahriah et al., 2022; Priyanto & Sumarwan, 2022) focuses more on media design and validation, without in-depth needs analysis of teachers and students in school. Consequently, this study contributes new insights through user needs identification as a basis for more relevant and applicable AR media development at the high school level. The findings reinforce augmented learning theory, emphasizing that AR technology connects abstract learning experiences to real-world contexts, deepening student understanding (Wikipedia, 2023). Practically, the study recommends schools and education policymakers support AR

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implementation by providing teacher training and basic ICT infrastructure. AR-based virtual laboratory development for acids and bases is not just technological innovation but an urgent need to bridge curriculum gaps, limited school facilities, and student learning characteristics in the digital era.

CONCLUSION

The study demonstrates that chemistry learning on acids and bases material at the high school level still faces major challenges due to limited laboratories, practicum equipment, and safety risks. The majority of teachers mainly use lecture methods, so students struggle to understand abstract concepts. Needs analysis showed that teachers expect learning media in the form of AR-based virtual laboratories simulating titration, pH indicators, and ion dynamics in solution. Students highlighted the need for interactive, smartphone-based, gamified, and independently usable media.

The findings reflect a gap between curriculum expectations and actual school conditions. Therefore, AR-based virtual laboratories are considered an alternative solution to enhance chemistry learning quality. The study contributes to knowledge development by emphasizing the importance of needs analysis as the basis for contextually relevant, easy-to-implement digital learning media design.

For media developers, it is recommended to design AR-based virtual laboratories that include simulations of acids–bases experiments, ion animations, digital pH indicators, and interactive quizzes. The application should be compatible with Android smartphones and support offline access to overcome internet connectivity issues. For teachers and schools, chemistry teachers should receive training on how to effectively utilize AR technology in their teaching practices. Schools should support this implementation by providing basic ICT devices and promoting technology-driven alternatives to conventional practical work. For future researchers, since the current study is limited to needs analysis, further research is necessary to design, develop, and evaluate the effectiveness of AR-based virtual laboratories in enhancing students' conceptual understanding, learning outcomes, and practical skills.

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