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Development of Augmented Reality-Based Interactive Multimedia for Pre-Laboratory Assistance on Factors Affecting Reaction Rates

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ABSTRACT

This study developed augmented reality (AR)-based interactive multimedia as a pre-laboratory companion for the practicum on factors affecting reaction rates at the Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya. A Research and Development approach using the 4D model was employed and limited to the define, design, and development stages. Product quality was evaluated through expert validation, student practicality responses, and a One-Group Pretest-Posttest design. Three chemistry lecturers validated the product, while the user trial involved 50 students. The developed Android application, FARR Chemlab, integrates theoretical content, safety information, three-level chemical representations, three-dimensional objects, and AR-based practicum visualization. Content validity achieved a mean score of 4.44 with a mode of 5, construct validity achieved 4.87 with a mode of 5, and overall validity reached 4.74 with a mode and median of 5. Practicality reached 98.44% based on 443 supportive responses out of 450. Mean test scores increased from 6.12 to 13.22 out of 15. Because score differences were non-normal, the Wilcoxon Signed-Rank Test was applied and showed a significant difference ($W = 19$, $p < 0.001$); the class N-Gain was 0.800. The novelty lies in positioning AR as a structured pre-laboratory companion that integrates procedural preparation, laboratory safety, and multiple chemical representations in one mobile application.

INTRODUCTION

Laboratory learning is a central component of chemistry education because it connects conceptual knowledge with observable phenomena, practical skills, and safe experimental practice. Its value, however, depends partly on how well students are prepared before entering the laboratory. Pre-laboratory activities can provide the conceptual, procedural, and safety information needed to complete laboratory tasks more efficiently and with fewer errors, and they are most useful when they are integrated into the overall laboratory learning process (Agustian & Seery, 2017). For this reason, pre-laboratory preparation is not merely an administrative requirement but an important stage for helping students understand what they will do, why they will do it, and how to work safely.

This preparation is particularly important for the topic of factors affecting reaction rates, which requires students to connect macroscopic observations with submicroscopic explanations based on particles and collisions and with symbolic representations such as equations, graphs, and quantitative relationships. Difficulties in moving among these representation levels have been documented in reaction-rate learning. Safitri et al. (2019), for example, reported that only 21.92% of students in their study were able to

interconnect all three representation levels, whereas 37.56% were unable to understand or connect the three levels. Alternative conceptions in chemical kinetics can also persist from secondary school to undergraduate study, including difficulties related to concentration, temperature, catalysts, and activation energy (Cakmakci, 2010). Consistent with these findings, a reaction-rate module integrating macroscopic, submicroscopic, and symbolic representations was reported to support students' mental models and learning outcomes (Murni et al., 2022). These findings indicate that pre-laboratory support for reaction-rate experiments should prepare students not only for procedural steps but also for the conceptual connections underlying the observed phenomena.

At the Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya, a preliminary needs analysis was conducted using a questionnaire involving six laboratory assistants (n = 6). All six laboratory assistants (100%) reported that practicum participants generally did not read the practicum guide before entering the laboratory. The questionnaire focused on students' preparation before laboratory work and the forms of support needed before the practical session. The responses indicated that students often entered the laboratory without first reading the practicum guide and therefore had limited preparation regarding procedures, observation techniques, and laboratory safety. The needs analysis also indicated a demand for supplementary mobile learning support that could provide procedural simulation, equipment visualization, and occupational safety information. These findings establish the pre-laboratory preparation problem; the choice of AR was subsequently considered as a design response to the need for more contextual and interactive visualization.

Previous studies provide evidence for this design choice. In chemistry laboratories, AR has been used to give students contextual information about scientific instruments and to improve the accessibility of instrument-related information (An et al., 2020). AR has also been implemented as a pre-laboratory learning aid for molecular-modeling activities, allowing students to inspect three-dimensional structures before the laboratory session (Lau et al., 2022). More recently, Bullock et al. (2024) integrated macroscopic video, symbolic two-dimensional animation, and particulate three-dimensional AR in a chemistry learning environment and reported significant learning gains. Compared with static written guidance, these applications illustrate an important affordance of AR: procedural or otherwise invisible information can be superimposed on a physical or camera-based learning context and explored interactively. Nevertheless, the studies above mainly addressed laboratory instrumentation, molecular stereochemistry, or organic reaction mechanisms. For reaction-rate learning, multiple-representation interventions have been developed using structured learning modules (Murni et al., 2022), However, the studies reviewed in this work have not addressed an integrated mobile pre-laboratory application that combines procedural preparation, MSDS and safety information, three-level chemical representations, three-dimensional objects, and AR-based practicum visualization specifically for factors affecting reaction rates. FARR Chemlab was therefore developed to address this gap.

Accordingly, this study had four objectives: (1) to develop AR-based interactive multimedia as a pre-laboratory companion for the practicum on factors affecting reaction rates; (2) to determine its feasibility through expert assessment of content and construct validity; (3) to examine its practicality based on student responses; and (4) to examine changes in students' conceptual understanding before and after using the application in a One-Group Pretest-Posttest trial. Because the trial did not include a comparison group, the pretest-post-test analysis was interpreted as evidence of within-group change after the intervention rather than as a definitive causal estimate of the application's effect.

RESEARCH METHOD

This study used a Research and Development approach to produce and evaluate an educational product. The development framework followed the 4D model consisting of define, design, development, and disseminate, but the study was limited to the development stage and a limited user trial (Fauzi & Maksum, 2020). The research was conducted from January to November 2026 at Chemistry, FMIPA UNESA, with the limited trial conducted in the Basic Chemistry Laboratory.

During the define stage, the research team conducted initial analysis, user analysis, task analysis, concept analysis, and learning-objective analysis. The initial needs analysis included a pre-research questionnaire administered to six laboratory assistants (n = 6) involved in the practicum, focusing on students' pre-laboratory preparation and the forms of procedural, visualization, and safety support needed before practical work. Learning objectives were formulated using the ABCD components (Audience, Behavior, Condition, and Degree). During the design stage, the team prepared pretest-posttest instruments, selected AR as the medium, created the storyboard and application-page format, and developed the first draft using Blender 3D, Vuforia SDK, and Unity. The application structure included the opening page, developer profile, user guide, learning outcomes, theoretical material, Material Safety Data Sheet (MSDS) information, AR practicum, and evaluation.

During the development stage, the first draft was reviewed and validated by three chemistry lecturers. Validation covered content validity and construct validity using a five-point Likert scale, with a minimum mode of 4 used as the validity criterion (Sugiyono, 2021). After revision, the product was tested with 50 students. Practicality was measured using a nine-item response questionnaire scored with the Guttman scale; a practicality percentage of at least 61% was defined as practical (Riduwan, 2015).

Changes in conceptual understanding were examined using a One-Group Pretest-Posttest design. Students completed a 15-item pretest before using the AR multimedia and a post-test afterward. Descriptive statistics were calculated for both tests. Normality was tested using Shapiro-Wilk. Because the score differences were not normally distributed, the Wilcoxon Signed-Rank Test was used to compare pretest and post-test scores. N-Gain was also calculated as supplementary descriptive information; however, the primary inference was based on the pretest-post-test difference within the tested group.

RESULTS AND DISCUSSION

Development of FARR Chemlab

The developed multimedia was named FARR Chemlab (Factor that Affecting Reaction Rate Chemlab). It was designed as a vertically oriented Android application with a red-maroon visual identity, consistent menu icons, and relatively large buttons. The main menu provides access to application and developer information, guidance, course learning outcomes, theoretical content, MSDS information, and the AR practicum. The guidance page contains numbered usage steps, including marker download and the recommended sequence of menus to study before the practicum.

The MSDS section provides safety information for chemicals used in the practicum, including HCl, CaCO3, Na2S2O3, KMnO4, H2C2O4, and H2SO4. The AR practicum page combines a camera view with virtual practicum objects, a timer, and an information button. This arrangement was designed to allow students to inspect equipment layout and procedural stages in a contextual form before entering the real laboratory.



Figure 1. FARR Chemlab interface: opening page, main menu, guidance, MSDS, and AR practicum view.

Content validity covered material presentation, illustrations and representations, the presence of three levels of chemical representation, and the accuracy of facts, concepts, and theory. Construct validity covered alignment with course learning outcomes, student characteristics, language, user guidance, decision-making elements, application display, feature placement, and visual communication. The combined assessment comprised 57 ratings from three validators across 19 indicators. Forty-three ratings (75.44%) were scored 5, thirteen (22.81%) were scored 4, and one (1.75%) was scored 3. No scores of 1 or 2 were recorded.

Table 1. Summary of Expert Validation

Component	Mean	Mode	Maximum-score achievement	Interpretation
Content validity	4.44	5	88.89%	Highly valid
Construct validity	4.87	5	97.44%	Highly valid
Overall	**4.74**	**5**	**94.74%**	**Highly valid**

The content-validity component with the highest score was material presentation (mean 4.83; mode 5; 96.67%). The lowest component was the accuracy of facts, concepts, and theory (mean 3.67; mode 4; 73.33%), indicating that conceptual substance remained the main area requiring careful final checking. Construct validity was stronger overall, with student characteristics and language, user guidance, decision-making elements, and visual communication each reaching a mean of 5.00 and 100% of the maximum score. Minor improvements were indicated for color use, 3D objects, readability, and feature placement.

Practicality

The practicality questionnaire consisted of nine statements, including two negative statements that were reverse-scored. A total of 443 supportive responses were obtained from 450 possible responses, producing a practicality level of 98.44%, categorized as very good. Forty-three students provided supportive responses on all nine items, while seven students supported eight of nine items. The result indicates that the application was perceived as easy to install and use, visually clear, and supportive of practicum visualization.

Table 2. Student Practicality Responses

Indicator	Supportive responses	Percentage
Easy to open/install	50/50	100%
Simple and non-confusing display/features	49/50	98%
Quick to open	49/50	98%
Not too heavy for the device (negative item)	48/50	96%
Improves understanding of the practicum	50/50	100%
Increases curiosity	49/50	98%
Clear macro-submicro-symbolic illustrations	50/50	100%
Features support practicum visualization (negative item)	49/50	98%
Clear and complete 3D AR objects	49/50	98%

Pretest-Posttest Outcomes

The user trial involved 50 students. The mean pretest score was 6.12 out of 15 (40.80%), with a standard deviation of 3.33 and a median of 6.00. The mean post-test score was 13.22 (88.13%), with a standard deviation of 1.46 and a median of 14.00. The mean increase was 7.10 points. Forty-four students improved, two remained unchanged, and four showed lower post-test scores. At the item level, pretest accuracy ranged from 22% to 60%, whereas post-test accuracy ranged from 84% to 100%, showing that improvement occurred across the tested content rather than only in the total score.

Table 3. Pretest-Post-test Statistics and Inferential Analysis

Measure	Pretest	Post-test / Result
N	50	50
Mean score (max. 15)	6.12	13.22
Mean percentage	40.80%	88.13%
Standard deviation	3.33	1.46
Median	6.00	14.00
Range	2-15	10-15
Shapiro-Wilk, score difference	-	$W = 0.899$; $p < 0.001$
Wilcoxon Signed-Rank Test	-	$W = 19$; $p < 0.001$
Class N-Gain	-	0.800

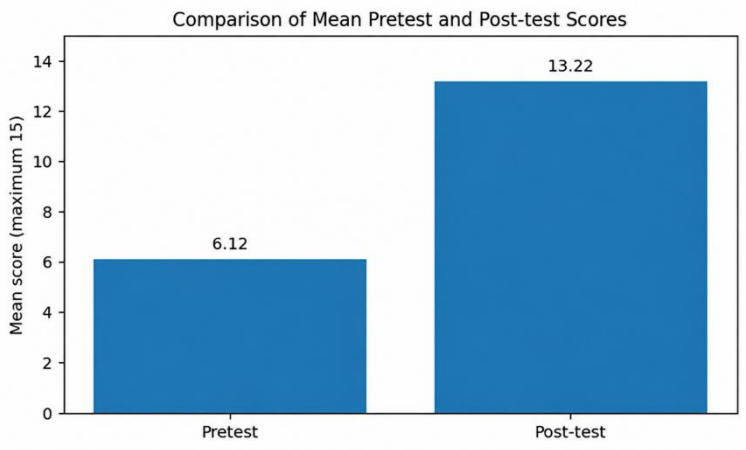


Figure 2. Comparison of mean pretest and post-test scores.

The Shapiro-Wilk test showed that the pretest, post-test, and score-difference data were not normally distributed (all $p < 0.001$). Consequently, the planned paired-sample t-test was not used, and the Wilcoxon Signed-Rank Test was selected as the nonparametric alternative. The Wilcoxon result ($W = 19$; $p < 0.001$) showed a significant difference between pretest and post-test scores. Because the post-test mean and median were higher and most students improved, the difference indicates increased conceptual understanding after using FARR Chemlab in the tested group. The class N-Gain of 0.800 provided additional descriptive evidence of a large relative increase, although N-Gain was not the primary effectiveness criterion in the study.

The three quality indicators were mutually consistent: expert validation established feasibility, student responses showed very high practicality, and pretest-post-test data showed significant improvement in conceptual understanding. The high user responses to three-level representations and 3D objects are especially relevant to the design purpose of AR in this product, namely helping students connect visible practicum phenomena with concepts that cannot always be observed directly.

The findings should nevertheless be interpreted within the study design. The One-Group Pretest-Posttest design did not include a control group. Therefore, the supported conclusion is that a significant increase occurred after the intervention in the tested group, not that all improvement can be attributed exclusively to the multimedia. In

addition, although the research questions included student readiness before laboratory work, the final dataset reported conceptual understanding and practicality responses but did not contain a separate readiness instrument or scientific-behavior observation measure. Direct conclusions about laboratory readiness therefore require additional data.

CONCLUSION

FARR Chemlab, an Android-based interactive multimedia application using augmented reality, was successfully developed as a pre-laboratory companion for the practicum on factors affecting reaction rates. The product integrates theoretical content, learning outcomes, user guidance, MSDS information, three-level chemical representations, 3D objects, and an AR practicum interface. Expert assessment categorized the product as highly valid, with overall mean validity of 4.74, a mode of 5, a median of 5, and 94.74% of the maximum score. Student responses indicated very high practicality at 98.44%. In the 50-student trial, the mean score increased from 6.12 to 13.22 out of 15, and the Wilcoxon Signed-Rank Test showed a significant pretest-post-test difference ($W = 19$; $p < 0.001$), supported descriptively by an N-Gain of 0.800. These findings support FARR Chemlab as a valid and highly practical pre-laboratory medium and show improved conceptual understanding after its use in the tested group. Future evaluation should use a comparison group and a dedicated measure of pre-laboratory readiness to strengthen causal interpretation and directly assess readiness outcomes.

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