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Research Article

User-Centered Design Approach in Mobile AR: Application for Hydrocarbon Visualization in Chemistry Course

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Abstract: Students often struggle to understand the chemical concepts, particularly in visualizing hydrocarbon compounds. Since it was difficult to see the hydrocarbon at submicroscopic and symbolic levels with human eyes. Meanwhile, Augmented Reality (AR) technology offers potential solutions to visualize the hydrocarbon compounds with three dimensional objects, which provide an effective and accessible pedagogical framework for understanding hydrocarbon principles. Therefore, this research focuses on enhancing the visualization of symbolic aspects of chemistry through iterative design involving both teachers and students. Initially, this study implements User-Centered Design (UCD) methodology, engaging users throughout the entire development lifecycle of a Mobile AR application to ensure alignment with user requirements and characteristics. Furthermore, the evaluation was conducted using the User Experience Questionnaire (UEQ), which is effective in assessing both pragmatic (practicality) and hedonic (pleasure and enjoyment) aspects of user experience across six dimensions: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. The results showed significant improvements across all evaluation criteria, with five out of six dimensions achieving 'Excellent' ratings. We found that by involving students and teachers throughout the design process, the application successfully improved user experience in terms of interactivity, understandability, effectiveness, and efficiency. Hence, this study demonstrates that the AR application—developed in alignment with users' needs—could significantly enhance the chemistry learning experience for high school students.

Keywords: chemistry learning, hydrocarbon compounds, mobile augmented reality, user-centered design, user experience questionnaire

1 Introduction

Several high school students rate a chemistry course as a complicated subject [1]. The possible reasons were the complexity or abstraction of the chemistry content and the participation of many students in the process of learning chemistry, which puts teachers in a dilemma about the effective delivery of chemistry material [1–3]. Furthermore, a study conducted at MAN 2 Bantul with a sample size of 24 students from class XI IPA 2 showed that there were significant misconceptions about the learning of hydrocarbon materials. High-category misconceptions were found in the reaction sub-material of hydrocarbon compounds as many as 66.7%. Several sub-materials had medium-category misconceptions, namely understanding of hydrocarbon compounds (31.3%), structure and nomenclature (56.3%), type of carbon atoms (37.5%), physical and chemical properties of hydrocarbon compounds (45.8%) and isomers (47.9%). Low-category misconceptions were found in the uniqueness of the carbon atom sub-material (16.7%) [4, 5]. This is in line with our preliminary research in this study conducted on 34 high school students in grades 11 and 12 with respect to hydrocarbon materials, which resulted in an average of 3.57 (somewhat difficult) on a scale of 1 (easy) to 5 (difficult).

In addition, the chemistry course syllabus in high schools is applied at three levels of chemical representation: macroscopic, submicroscopic, and symbolic. Specifically, macroscopic representation involves directly observable phenomena. Submicroscopic representation focuses on abstract aspects, such as atoms, molecules, and ions, that cannot be seen directly. Meanwhile, symbolic representation uses symbols, formulas, and chemical equations to explain these phenomena [3]. Furthermore, submicroscopic and symbolic levels have been identified as complex tasks for students, particularly in naming and writing structure formulae of hydrocarbons [6].

In addition, less effective teaching methods, such as the lecture method without visual learning media and abstract material, lead to students having a low level of understanding [4].To resolve similar issues and promote students to higher levels of performance in naming and writing hydrocarbon formulas, earlier work using physical ball-and-stick models was sufficient to improve student performance [6].

In the last decade, AR has emerged as a new solution for learning [7]. AR allows users to view the natural world enriched with digital information, increasing thereby the interaction and understanding of objects or concepts. In chemistry learning, AR supports the 3D visualization of molecular structures, their spatial dynamics and interactions, and the possibility of molecular formation from individual fragments [8]. In addition, AR can enhance students' motivation to learn, as it is more interactive and engaging [9].

Mobile Augmented Reality brings AR technology to mobile devices, allowing for broader and more flexible access [10]. Several studies have proven the potential for using MAR in chemistry learning to improve students' understanding [11, 12]. It also showed that MAR increased student engagement and motivation during the learning process [13]. However, to ensure that the AR applications developed are effective and easy to use, a user-centric approach is needed. This is where a good User Experience (UX) design comes in. User-Centered Design (UCD) involves engaging users in the development process from the very start to the end, thus delivering an application that meets the requirements and characteristics of users [14, 15].

The evaluation of the applications will be performed based on the User Experience Questionnaire (UEQ) methodology. The UEQ was selected due to its famousness in eval-

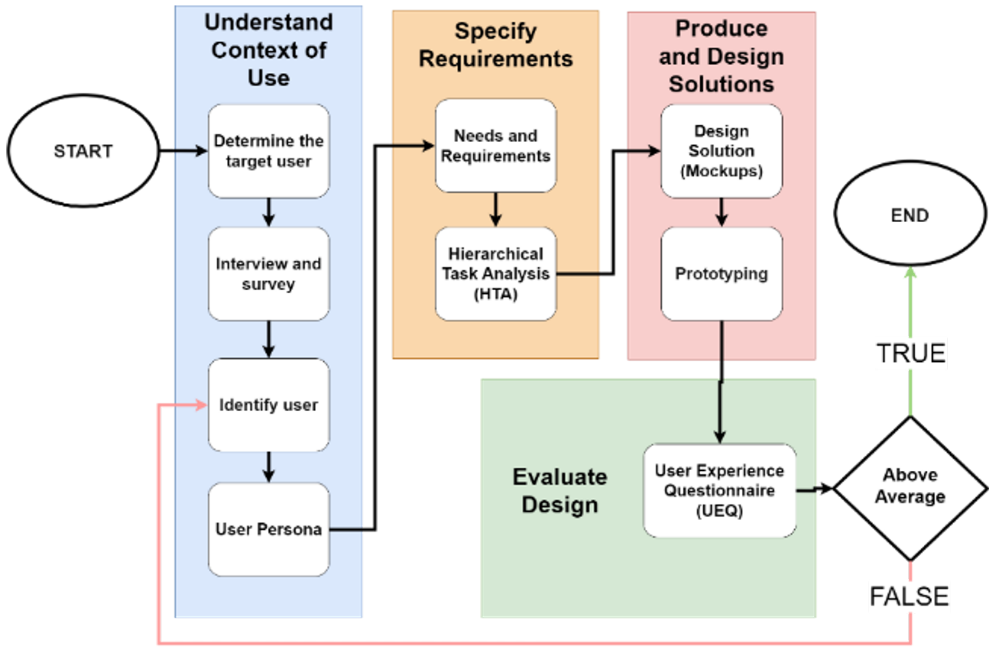

Figure 1: UCD research method.

uating pragmatic—related to practicality —and hedonic—related to pleasure and enjoyment—activities of User Experience [16]. UEQ has 26 statement items, grouped into six dimensions, such as attractiveness, efficiency, perspicuity, dependability, stimulation, and novelty [16–18]. By involving students and teachers in the design process from the early stages with UCD, our developed application is expected to improve the user experience, both in terms of interactive, easy to understand, effective, and efficient, and interesting from the problems and solutions assessed in previous research according to the user's subjectivity.

2 Research Method

In the quest for an interactive design, UCD enables research to identify user needs and expectations as a basis for developing user experience design [19]. This UCD method is iterative in studying user behavior and needs. It focuses on certain characteristics of probable users such as gender, habits, and age groups [20]. The steps that go into UCD have four phases [21]. Figure 1 illustrates the UCD method applied in this investigation.

2.1 Understand the Context of Use

This section discusses the determined target user, the interview and survey, and the user persona.

2.1.1 Determined the target user

The first step in identifying the user context (specify the context of use) is to determine the target users. At this stage, the determination is aligned with the needs of the problem to be solved. The application's target users or potential users have been identified and can be seen in Table 1, which will be used for subsequent interviews and surveys.

Table 1: Potential users

No.	Users	Descriptions
1	High School Grade XI Students	Students in grade XI are chosen as the primary users of the application because the topic it covers, which is the visualization of hydrocarbons, aligns with the chemistry curriculum taught at this level.

2.1.2 Interview and survey

After identifying the target users shown in Table 1, interviews and surveys were conducted to establish the characteristics and needs of the users. Interviews, based on the questions listed in Table 2, were conducted with chemistry teachers in high schools. The purpose of these interviews was to gather information about teachers' experiences, challenges, and needs related to chemistry teaching. A semi-structured interview was conducted with a teacher via the Zoom platform, using a set of prepared questions. The interview and survey questions were adopted and adapted from relevant research journals to align with the study objectives [22]. At the same time, questionnaires or surveys, as presented in Table 3, were distributed to students who were learning from these chemistry teachers. Most of the responses from the chemistry teachers interviewed highlighted several issues, including the lack of laboratory facilities and inadequate media for explaining theoretical concepts in teaching and learning activities. Furthermore, it was observed that atomic theory required a deeper understanding as it is an abstract concept.

Table 2: Interviewed questions

No.	Asked Questions	Respondents
1	What is the current chemistry teaching and learning process like?	Teacher
2	How does the learning process take place during chemistry teaching and learning activities? Is it more theory-based or practical-based?	Teacher
3	What challenges are faced when implementing theory/practical work?	Teacher
4	Has a digital teaching method previously been capable of fully addressing these issues (practical/non-practical)?	Teacher

The survey in Table 3 was developed in collaboration with the suggestions from chemistry teachers, which aligned with the curriculum and user needs. The validation of the survey questions is carried out by material experts, namely the chemistry teacher concerned. Results from 34 respondents of Grade XI and XII students indicate difficulties in thermochemistry, hydrocarbon compounds, chemical bonding, and molecular shapes. Potential users showed a high interest in AR. After analysis and discussions with high school chemistry teachers, hydrocarbon compounds were selected as the most challenging topic, considering their relationship with chemical bonding and molecular shapes, which are also problematic for students.

Table 3: Surveyed questions

No.	Asked Questions	Respondents	Type
1	How difficult is it for you to understand chemistry material in class?	Students	Scale
2	Do you feel anxious or stressed when studying chemistry? Explain.	Students	Description
3	In your opinion, what makes chemistry a complex subject to learn?	Students	Description
4	Do you feel your teacher explains chemistry material in an easy-to-understand way? Explain.	Students	Description
5	Do you have enough time and resources to study chemistry outside of class hours? Explain.	Students	Description
6	Do you find the current chemistry learning methods used in class (e.g., discussions and practical work) helpful? Explain.	Students	Description
7	Rate the following chemistry topics from most difficult to easiest for you to learn: 1. Atomic structure, 2. Chemical bonding and molecular shape, 3. Thermochemistry, 4. Stoichiometry, 5. Hydrocarbon compounds.	Students	Scale
8	Choose three chemistry topics that are most difficult for you to learn and explain why.	Students	Description
9	Have you ever used augmented reality (AR) technology before?	Students	Description
10	Please explain what you used it for.	Students	Description
11	Are you interested in using a mobile AR application to learn chemistry? Explain.	Students	Description
12	In your opinion, what features should a mobile AR application have to help you learn chemistry? How necessary is it for you to use AR in chemistry teaching and learning activities in the classroom?	Students	Scale

2.1.3 User persona

Next, a user persona of students that would represent the potential of this category would have to be developed, as depicted in Figure 2. The development of user personas is based on an analysis conducted from students survey results and discussed with the relevant chemistry teacher for validation. It should treat basic demographics—biography, personality—an identification of the person's interests, influences, goals, needs, and expectations, his or her motivations, pain points, and frustrations.

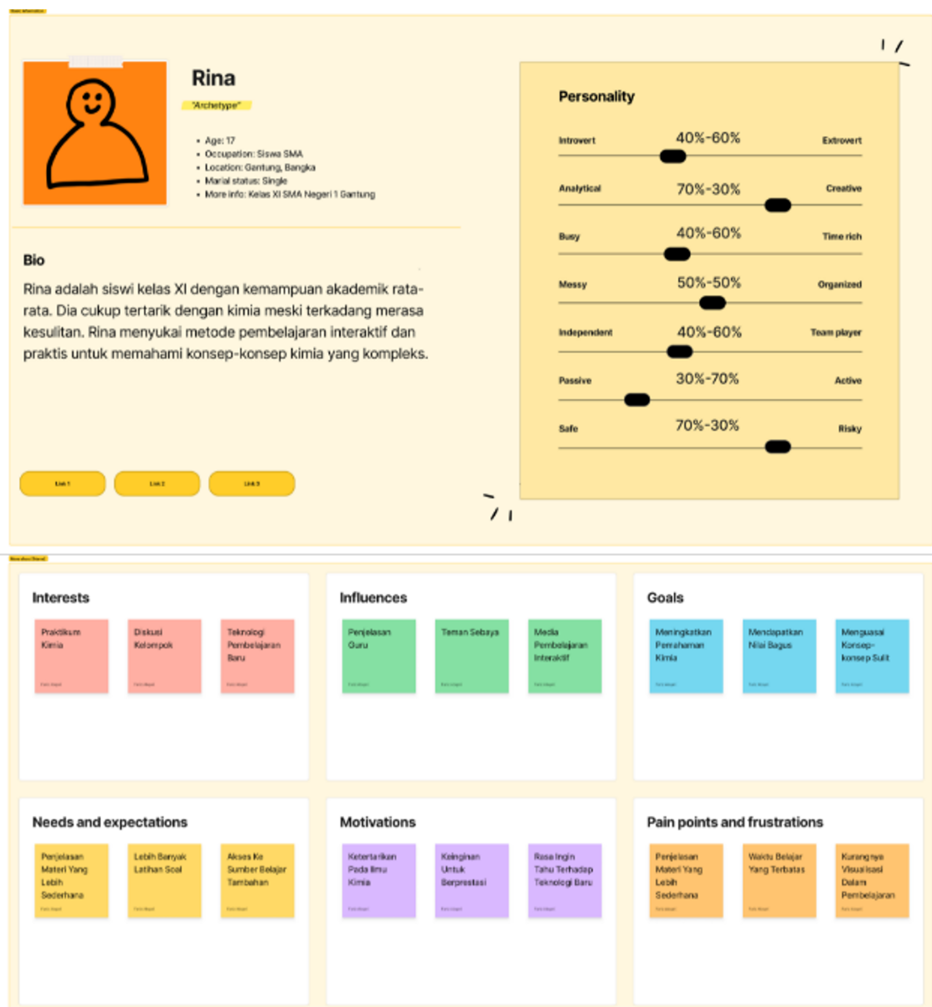

Figure 2: Student user persona.

2.2 Specify Requirements

This section discusses the requirement table, and hierarchical task analysis (HTA).

2.2.1 Requirements table

The requirements table, derived from survey and interview analyses conducted in the specific context of the use phase, aims to understand and explore user needs and requirements. Table 4 shows the requirements table.

Table 4: Requirements table

Needs	Requirements	Frequency
Better visualization of chemical concepts	The AR application must be able to display interactive 3D atomic models of carbon compounds.	7
Simplified explanation of materials	Learning content should be presented in easily understandable language and use everyday life analogies.	7
More practice exercises	The application must provide a comprehensive question bank with varying levels of difficulty.	5
Access to additional learning resources	The application must have features that link to external learning resources such as videos, articles, and online simulations.	3
Virtual laboratory experiments	The application must provide chemical experiment simulations that can be conducted virtually.	4
More interactive learning	The application must use gamification elements and interactive quizzes to increase student engagement	6

2.2.2 Hierarchical task analysis (HTA)

Once the filtered features have been filled into the requirements table, a Hierarchical Task Analysis can be developed. HTA is a method intended to break down difficult tasks into simpler, manageable subtasks in hierarchical form. This method was formulated based on prior user research and then filtered according to the frequency analysis of user needs. First, the HTA process emphasizes the proceedings on how to use the application; these then get elaborated in terms of user requirements. The next step is an enhancement of the required actions needed in order to satisfy these user needs in a rather detailed and structured way. Each stage in HTA reflects those necessary ingredients linked to user interactions as they work towards completing their tasks. Figure 3 is the main components of this HTA.

2.3 Produce and Design Solutions

The solution design will provide an interactive prototype development framework based on the hierarchical task analysis of the specified requirements. Figure 4: Augmented reality architecture and Figure 5: Design Mock-up of the Application's Main Features. The broad structure of AR begins with the acquisition of real-world data by different cameras

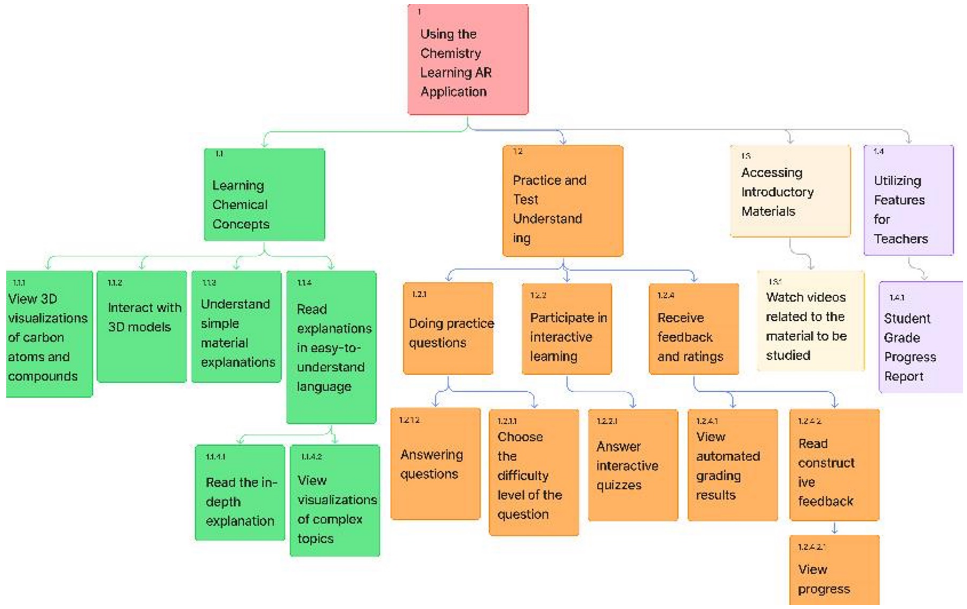

Figure 3: Hierarchical task analysis.

and sensors of the mobile device. The input received is then sent for processing through an image processor and tracker, which acts as an input for a Simultaneous Localization and Mapping (SLAM) system that maps the environment and localizes the device. The system software performs 3D reconstruction in such a way that virtual object rendering can be enabled. 3D models of hydrocarbons are retrieved from the database and integrated into the reconstructed environment. The user input is handled to manipulate the AR content, and a quiz system manages the educational components. The resulting augmented view, including real and virtual elements of the educational content, is projected on the device screen, allowing for an interactive learning experience in exploring molecular structures in AR. This mockup design was prepared using Figma, which is a professional software design tool.

2.4 Evaluation Result

The UEQ instrument in Figure 6 collected responses from 34 participants: 47.1% were experienced but non-technical, 35.3% were highly experienced and technical, 14.7% could operate most software well, and 2.9% found most software challenging. In this case, UEQ analysis tools were used to calculate the UEQ instrument responses.

In this analysis phase, the collected data undergoes a transformation process. The original 1-7 scale is converted from -3 to +3, encompassing negative and positive values. Following this conversion, the items are categorized into six distinct dimensions: Attractiveness (6 items), perspicuity (4 items), efficiency (4 items), dependability (4 items), stimulation (4 items), and novelty (4 items). For each of these categories, mean scores are calculated and assigned. These scores are then benchmarked against the UEQ database for comparison, with the results presented in Table 6 as the first iteration and Table 7 as the last iteration.

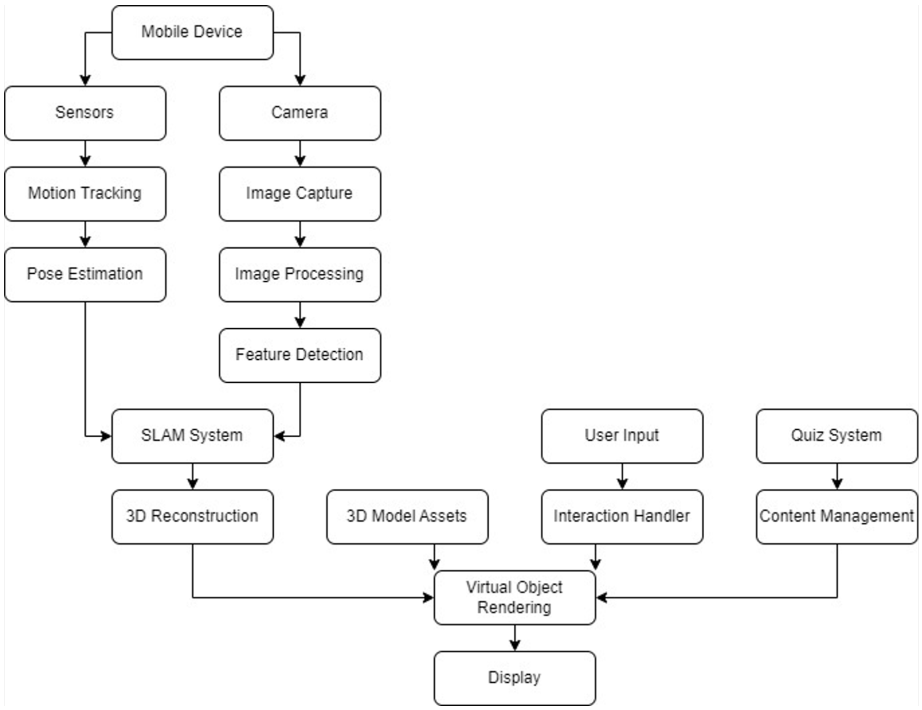

Figure 4: AR architecture.

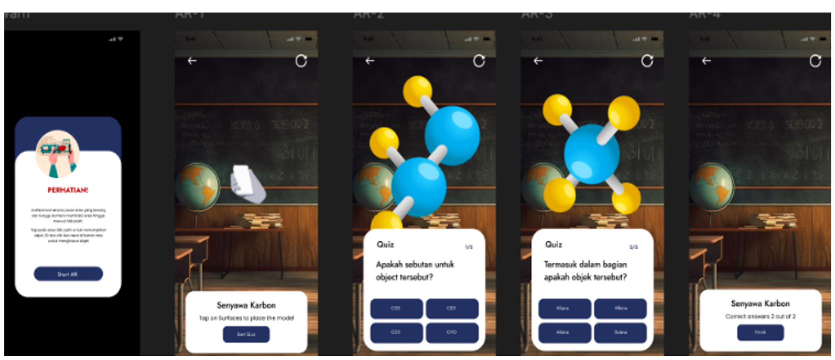

Figure 5: Prototype.

Based on this solution design, an interactive prototype was prepared for the users to get a feel of using the key features of the application. It went through two iterations that were tested for UI and interaction design. Feedback from these tests was inducted into the refinement of the application so that it caters to the needs of the user. Table 5. shows the software specifications required in the development of this prototype.

Table 5: Requirements table

Needs	Requirements
1	Android SDK version 35.0.0
2	VS Code (version 1.92.0)
3	Flutter 3.7.12
4	Dart 2.19.6
5	ar_flutter_plugin : ^0.7.3

The minimum Android version required for the prototype to function was Android 7.0 Nougat (Android SDK 24), with AR features included as a requirement.

2.5 Evaluate Against Requirements

The UEQ represents six aspects of the user experience: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty [15]. It has been designed as 26 questions rated on a scale of 1-7 as shown in Figure 6 [17]. Once the data have been collected, UEQ data is then evaluated with an official tool which generates graphs of ranking scores Below Average, Above Average, Good or Excellent.

3 Results

Teachers and students collaborated closely to create the user experience for a chemistry learning app. The teachers played a role in grasping student behaviors from an educators viewpoint addressing concerns and validating student issues before delving into the students own viewpoints. This method provided insight into the learning environment. Guaranteed that the app met the genuine educational requirements.

3.1 Implementation Result

The UCD approach was extremely helpful in creating a user experience that met the needs of the users, leading to a functional user app, for its target users. The app was subjected to some changes based on user input and testing. This application uses Markerless Tracking to display 3D models for easier use anywhere without carrying anything except a mobile phone. A significant improvement was seen in the way 3D models were presented during quizzes. The app was adjusted to show the models in a manner that matches the questions shown in Figure 7.

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

Figure 6: UEQ instrument.

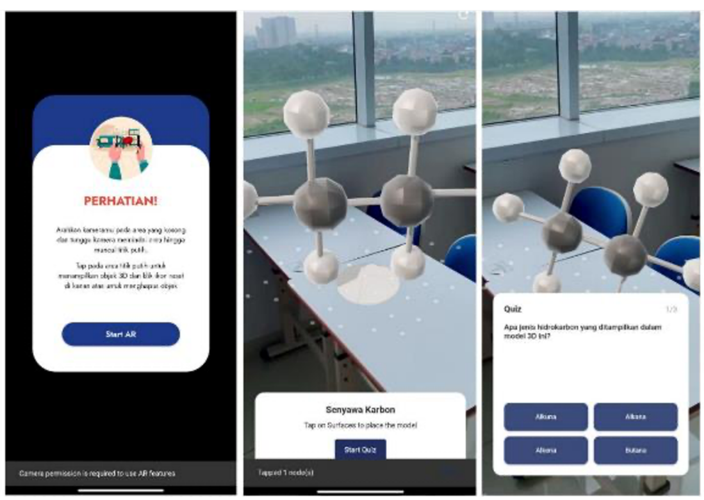

Figure 7: UEQ instrument.

3.2 Evaluation Result

The UEQ instrument in Figure 6 collected responses from 34 participants: 47.1% were experienced but non-technical, 35.3% were highly experienced and technical, 14.7% could operate most of the software well, and 2.9% found most of the software challenging. In this case, UEQ analysis tools were used to calculate the responses of the UEQ instrument.

Table 6: UEQ first iteration

Scale	Mean	Comparison to Benchmark	Interpretation
Attractiveness	1.71	Good	10% of results better, 75% of results worse
Perspicuity	1.25	Above Average	25% of results better, 50% of results worse
Efficiency	1.53	Good	10% of results better, 75% of results worse
Dependability	1.14	Above Average	25% of results better, 50% of results worse
Stimulation	1.72	Excellent	In the range of the 10% best results
Novelty	0.91	Above Average	25% of results better, 50% of results worse

Table 7: UEQ last iteration

Scale	Mean	Comparison to Benchmark	Interpretation
Attractiveness	2.28	Excellent	In the range of the 10% best results
Perspicuity	1.65	Above Average	25% of results better, 50% of results worse
Efficiency	2.09	Excellent	In the range of the 10% best results
Dependability	2.04	Excellent	In the range of the 10% best results
Stimulation	2.26	Excellent	In the range of the 10% best results
Novelty	1.73	Excellent	In the range of the 10% best results

Now, when comparing the first and final iterations, significant improvements were observed across all dimensions of user experience, as presented in Table 6 and Table 7. These improvements include:

- Attractiveness: The mean improves from 1.71 to 2.28, thus moving the product from the top 25% to the top 10% of benchmark results.
- Effectiveness: The efficiency of the product has literally soared from 1.53, which is Good, to 2.09, which is Excellent, hence hitting the top 10% of benchmark results.
- Dependability: From an initial rating of 1.14, which stands for Above Average, to 2.04, which is Excellent, there was a high rise in how users build trust and perceive its reliability.
- Stimulation: From an initial strong score of 1.72, representing Excellent, to 2.26, it is strongly seated within the top 10% of benchmark results.
- Novelty: Move from 0.91 (Above Average) to 1.73 shows a huge improvement in the way innovation and creativeness of the product come across.

The product has gone from generally being above average to really excel in almost all respects, with five of its six dimensions now in the top 10% of benchmark results. Part of the reason it has come this far is due to the iterative design process and the dedication of the team in enhancing the user experience.

4 Discussion

The results of the research demonstrate the effectiveness of utilizing UCD principles in developing a Mobile AR (MAR) app, for chemistry education. By following a UCD approach that involves input from educators and students throughout the design process, a user-friendly experience tailored to meet the audience's needs and expectations was successfully created. Initial analysis of user needs revealed a demand for enhanced visualization of concepts related to hydrocarbon compounds.

The identified need for better visualization tools aligns with studies that highlight the challenge faced by students to understand submicroscopic representations in chemistry [3, 6] . For solving this problem of visualization, AR technology was used to present three-dimensional models of carbon compounds to students so that they can conceptualize abstract ideas.

The benefits of the design approach embedded in UCD are underscored by enhancements observed in different facets of the UEQ from the initial to the last iteration. The key areas that exhibited progress were Reliability, Appeal and Effectiveness all achieving "evaluations", by the conclusion. This suggests that the software provides engaging experience while meeting user's practical requirements effectively.

The significant increase in the Novelty rating moving from "Above Average" to "Excellent " implies that consumers perceive the integration of AR technology in chemistry education, as innovative. This result is in line with earlier research that has demonstrated how AR can boost students' enthusiasm and involvement during the learning process [9, 13].

Perspicuity improved significantly but stayed in the "Above Average" group, all other dimensions experienced gains as well. This implies that although the program is generally simple to use and comprehend, learnability and clarity may still need to be improved. Future improvements to onboarding procedures or the implementation of user interfaces with greater intuitiveness could improve this area.

A stimulating and attractive learning environment is produced when attractiveness and stimulation levels are high. These findings imply that the application effectively satisfies the necessity for more interactive learning techniques, which was noted as a crucial need in the preliminary user analysis.

The UCD method is adaptable and receptive as shown by how the prototype has evolved based on user input, in improving the 3D model display during quizzes. The final product is practical. Tailored to meet the needs and preferences of users due to this refining process.

While the outcomes are promising, it's essential to acknowledge the constraints of the research. The sample size of 34 individuals may not be fully representative of all high school chemistry students even though it sufficed for the UEQ investigation. To validate these findings future studies may require more diverse samples.

5 Conclusion

This project therefore demonstrated how UCD could successfully be applied for the development of a mobile AR application in chemistry education. A collective design by teachers and students resulted in a powerful application that vested an effective way of overcoming obstacles in visualizing complex chemical concepts, especially hydrocarbon compounds. All the aspects studied in the UEQ presented very important improvements. The last iteration obtained an excellent rating in five out of six categories, which evidence high user satisfaction and effectiveness. This again points to the importance of users throughout a design process, as the student-friendly tool produced showcases the potential of MAR technology in meeting the challenges in chemistry education. Further research is recommended on the effect that this application may have on academic achievement and possible integration into existing curricula. The findings of the study consequently mean an addition to evidence to support that an AR application with its development putting careful consideration into user needs enhances chemistry education effectively.

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