ISSN: 1985-5826 AJTLHE Vol. 16, No. 1, June 2024, 141-156

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

EFFECTIVENESS OF IMOCHEM (AUGMENTED REALITY MOBILE APPLICATION FOR ORGANIC CHEMICAL MECHANISMS): A PRELIMINARY STUDY

Salmiah Jamal Mat Rosid[1]*, Nurul Najidah Mohamed[1], Ismahafezi Ismail[2], Norsyafikah Asyilla Nordin[3], Nurulhuda Mohammad Yusoff[1], Siti Noor Syuhada Mohd Amin[1], Sarina Mat Rosid[4]

[1]Unisza Science and Medicine Foundation Centre, Universiti Sultan Zainal Abidin, Gong Badak Campus, 21300 Kuala Nerus, Terengganu, Malaysia

[2]Faculty of Informatic & Computing, Universiti Sultan Zainal Abidin, Besut Campus, 22200 Besut, Terengganu, Malaysia

[3]Faculty of Pharmacy, Universiti Sultan Zainal Abidin, Besut Campus, 22200 Besut, Terengganu, Malaysia

[4]Advanced Membrane Technology Research Centre (AMTEC), Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia

(Corresponding author: salmiahjamal@unisza.edu.my)

Abstract

Organic chemistry is considered a complicated science subject in chemistry, especially when it involves the mechanism. The importance of this topic in the foundation study is to understand the basics of reaction and how chemical reactions react through mechanism. It has long been a belief in science education that the laboratory has the potential to be a place where theory and practice can coalesce for students. However, from the previous observation during the class, it was found that most foundation students can not relate the theory they learned during the lecture to the laboratory experiment. Therefore, this study aims to develop an inquiry-based Augmented Reality (AR) learning tool for foundation chemistry courses, examine its effect on students' cognitive performance, compare its effects on high-achieving and low-achieving students, and investigate students' attitudes toward the software. The effectiveness of this AR mobile apps was investigated using question and the students need to answer that question before and after the use of AR mobile apps. A qualitative data was collected among

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

the students after the completion of use AR mobile apps using questionnaire. A statistical analysis has been done using paired t-test and it shows that the t-test yielded a Pearson correlation of -0.15 with variances of 17.24 and 3.67 for low achievers and high achievers, respectively. Therefore, this study is anticipated to reinforce students' knowledge, facilitate better learning, and improve test scores in organic chemistry courses, particularly in the mechanism section.
Keywords: Augmented reality; chemistry; organic chemistry; mechanism

Abstrak

Kimia organik dianggap sebagai subjek sains yang rumit dalam kimia, terutamanya apabila ia melibatkan mekanisma. Kepentingan topik ini dalam kajian dasar adalah untuk memahami asas tindak balas dan cara tindak balas kimia bertindak balas melalui mekanisma. Telah lama menjadi kepercayaan dalam pendidikan sains bahawa makmal berpotensi untuk menjadi tempat teori dan amalan boleh bergabung untuk pelajar. Namun, daripada pemerhatian sebelum ini semasa kelas, didapati kebanyakan pelajar asasi tidak dapat mengaitkan teori yang dipelajari semasa kuliah dengan eksperimen di makmal. Oleh itu, kajian ini bertujuan untuk membangunkan alat pembelajaran Realiti Terimbuh (RT) berasaskan inkuiri untuk kursus kimia asas, mengkaji kesannya terhadap prestasi kognitif pelajar, membandingkan kesannya terhadap pelajar berpencapaian tinggi dan berpencapaian rendah, dan menyiasat sikap pelajar ke arah perisian. Keberkesanan aplikasi mudah alih RT ini telah disiasat menggunakan soalan dan pelajar perlu menjawab soalan tersebut sebelum dan selepas penggunaan aplikasi mudah alih RT. Data kualitatif telah dikumpul dalam kalangan pelajar selepas selesai menggunakan aplikasi mudah alih RT menggunakan kaedah soal selidik. Analisis statistik telah dilakukan menggunakan ujian-t berpasangan dan ia menunjukkan bahawa ujian-t masing-masing menghasilkan korelasi Pearson sebanyak -0.15 dengan varians 17.24 dan 3.67 untuk pencapaian rendah dan pencapaian tinggi. Oleh itu, kajian ini dijangka dapat mengukuhkan pengetahuan pelajar, memudahkan pembelajaran yang lebih baik, dan meningkatkan markah ujian dalam kursus kimia organik, khususnya dalam bahagian mekanisma.
Kata kunci: Realiti terimbuh; kimia; kimia organik; mekanisma

1.0 INTRODUCTION

The study of organic chemistry is a fundamental component of A-levels, foundation studies, and undergraduate chemistry courses, requiring students to gain a deep understanding of the intricate processes involved in organic reactions, a fundamental aspect of this branch of

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

chemistry (Ferguson & Bodner, 2008). In addition to theoretical knowledge, students engage in laboratory experiments to observe and comprehend how these reactions occur, providing a practical dimension to their learning and reinforcing their understanding of reaction mechanisms. The ability to interpret and apply these mechanisms is vital for a comprehensive understanding of organic reactions. However, mastering organic reactions demands strong cognitive abilities, particularly in terms of recalling reaction outcomes (O'Dwyer & Childs, 2017). The teaching and learning process within the domain of organic chemistry heavily relies on the cognitive domain, which spans the acquisition and application of knowledge from the foundational ability of simple recall to the higher-order skill of critically evaluating complex learning materials (Taber, 2019; Blackie, 2022).

Despite its significance, organic chemistry is often perceived as a challenging subject, contributing to student apprehension and, in some cases, suboptimal performance. This difficulty becomes particularly relevant for students facing the Semester II final examination at UniSZA Science and Medicine Foundation Centre, where organic chemistry is a mandatory subtopic. Addressing these challenges is imperative for enhancing overall student performance in the final exams and fostering a deeper and more confident understanding of organic chemistry concepts. One of the essential mechanisms that students must grasp in organic chemistry revolves around halogenation in alkane and alkyl halide reactions, which encompass SN1, SN2, E1, and E2 mechanisms. The halogenation of alkanes is a type of substitution reaction where one or more hydrogen atoms in an alkane molecule are replaced by halogen atoms. Understanding these key steps is essential for predicting the products of halogenation reactions, considering factors such as regioselectivity (which hydrogen is replaced) and the formation of different halogenated products. Additionally, being aware of the radical nature of this reaction helps in anticipating the potential for side reactions and the importance of radical stability in product formation. Overall, the halogenation of alkanes is a significant process for introducing halogen atoms into organic molecules, and mastery of its mechanism is fundamental in organic chemistry. Meanwhile, understanding the mechanisms of SN1, SN2, E1, and E2 reactions is crucial in organic chemistry, as these reactions represent fundamental processes that dictate how molecules undergo transformations. Understanding these mechanisms is essential for predicting reaction outcomes, designing synthetic pathways, and interpreting experimental results in organic chemistry. Students and practitioners alike benefit from mastering these key aspects to navigate the intricacies of organic reactions effectively.

ISSN: 1985-5826 AJTLHE Vol. 16, No. 1, June 2024, 141-156

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

Consequently, there is a need for interactive learning tools, especially in this organic chemistry topic, to facilitate a better comprehension of the movement of intermediate species throughout the mechanism process. To address this educational challenge, the development and application of instructional learning tools have garnered increased attention. These tools are gaining popularity as they present an engaging approach to active learning, incorporating augmented reality to enhance knowledge acquisition (Wojciechowski & Cellary, 2013). This innovative method aims to make the learning process more dynamic and accessible, allowing students to interact with and visualize the intricacies of organic chemistry mechanisms, particularly in halogenation reactions. Augmented Reality (AR) is an expansion of Virtual Reality (VR). In contrast to conventional VR, AR offers a seamless user interface that merges the real and virtual worlds. Users have the ability to engage with virtual elements overlaid on actual environments and experience a genuine and natural human-computer interaction (Yogesh et al. 2022). The establishment of a local AR environment only requires a computer and a camera. The camera identifies markers within its field of view and subsequently displays the captured scene along with the virtual objects represented by the markers simultaneously on the computer screen. Users can manipulate the markers to interact with the overlaid virtual elements (Carlos et al. 2019). The rapid advancement of Augmented Reality has led to the significant emergence of incorporating AR into educational practices (Dickey, 2011). According to Harle and Towns (2011), research that has been dedicated to examining visuospatial abilities within the realm of chemistry has revealed particular challenges that students face when it comes to understanding, interpreting, and converting molecular depictions. The research conducted by Tuckey et al. (1991) highlighted that a significant number of students, even at the tertiary level, encounter obstacles in engaging with three-dimensional visualization. These obstacles stem from a misconception surrounding a small set of relatively straightforward principles and competencies.

Wojciechowski and Cellary (2013) developed an augmented reality (AR) setting to facilitate chemistry experiments, such as the reaction between hydrochloric acid (HCl) and sodium hydroxide (NaOH) yielding table salt (NaCl) and water. The findings indicate that the active engagement of students in practical tasks significantly enhances their perceived enjoyment, consequently boosting their motivation towards learning. Seamless AR environments seamlessly integrate educational resources with the physical surroundings of students, enabling them to interact with objects independently (Plunkett, 2019). Fonseca et al. (2014) provided a platform for visualizing various stages of a construction process using AR on mobile gadgets, aiming to boost comprehension and investigate the link between tool

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

usability, student engagement, and academic performance following AR implementation. The outcomes underscored a strong relationship between the integration of mobile devices in educational settings, student motivation, and academic success.

Therefore, this project aims creating an augmented reality mobile application designed to display organic chemical reactions and mechanisms. IMOCHEM provides a mobile learning experience that goes beyond typical classroom limits by utilising the widespread use of mobile devices. Students will be drawn to learn more about this subtopic due to the interactive use of mechanisms. They can assess the effectiveness of teaching and learning using the application of Augmented Reality on high-achieving and low-achieving students. User feedback involves collecting input through surveys or interviews to pinpoint the strengths, flaws, and opportunities for enhancement in the programme. This study is a pioneering attempt to utilise Augmented Reality technology to improve comprehension of Organic Chemical Mechanisms. It is supported by thorough statistical analysis and design principles focused on user experience.

2.0 MATERIALS AND METHODS

2.1 Requirement Study

During the preliminary analysis of the Augmented Reality (AR) environment user interface (UI), the research will prioritize an in-depth examination of real-time interaction data, emphasizing the principles of Human-Computer Interaction (HCI). This phase aims to delve into the intricacies of user engagement within the AR environment, exploring how users interact with the interface in real-time to inform the development and refinement of an intuitive and user-friendly AR UI. The focus on HCI principles underscores the commitment to understanding the dynamic interplay between users and the AR system, ensuring that the UI not only meets technical requirements but also aligns seamlessly with user expectations and enhances the overall interactive experience.

2.2 Design

The design process for the virtual button framework and Augmented Reality (AR) interfaces is intricately tailored to the specific needs and preferences of the target user, achieved through the application of a standardized Graphic User Interface (GUI) within the virtual realm. This approach ensures that the virtual buttons and AR interfaces are not only technically robust but also align seamlessly with the user's expectations, providing a familiar and intuitive interaction

ISSN: 1985-5826 AJTLHE Vol. 16, No. 1, June 2024, 141-156

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

environment. By incorporating a standard GUI into the virtual world, the design strives to enhance user accessibility, optimize functionality, and create a cohesive and user-friendly experience within the AR interface, thus contributing to a more immersive and effective interaction for the intended user demographic.

2.3 Development

In the developmental phase of creating a dynamic and immersive user experience, the integration of real-time interaction methods and Augmented Reality (AR) hardware within the Unity 3D framework is essential. This process involves translating the meticulously designed 3-dimensional environment into robust programming code, implementing advanced programming techniques to address the intricate requirements of the educational application.

An immersive experience lies in the utilization of a powerful QR code generator method. This method ensures the generation of distinct AR Markers for Organic Chemistry AR notecards, where even subtle variations such as a single letter or capitalization produce significantly different patterns. This approach enhances the accuracy of AR Marker recognition, enabling the app to precisely identify and augment the associated AR notecards in real-time.

The integration of augmented reality hardware, particularly through smartphone devices, serves as a conduit for students to engage with the educational content in an unprecedented manner. Upon scanning the AR Marker, the smartphone seamlessly projects a real-time AR video, providing students with an interactive visualization of organic chemistry reactions. This immersive experience goes beyond traditional learning methods, allowing students to witness reaction mechanisms first-hand and fostering a deeper understanding of the subject matter.

As the video unfolds, students can actively participate in the learning process by manipulating the AR environment, exploring molecular structures, and gaining insights into the intricacies of organic chemistry reactions. The synergy of Unity 3D's versatile programming capabilities and augmented reality hardware integration ensures a seamless and engaging educational experience for students, transforming the study of organic chemistry into an interactive journey that transcends the boundaries of traditional learning methods.

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

2.4 Assessment and Statistical analysis

Statistical analysis encompasses the process of collecting, organising, interpreting, and presenting data. Statistical analysis in this project most likely involves analysing data concerning the utilisation of the IMOCHEM application. This analysis may encompass user feedback involves collecting input through surveys or interviews to pinpoint the strengths, flaws, and opportunities for enhancement in the programme. The quantitative methods to analyse the data obtained from the final examination and the questionnaire using Likert scale. A paired t-test on the low achieving student and high achieving student and a descriptive statistical on the scores of high-achieving and low-achieving students to determine the differences between them were conducted. Furthermore, evaluating learning results through tests before and after application clarifies the educational effectiveness of the programme. The descriptive statistics (average score) for each item on the questionnaire was calculated.

3.0 RESULTS AND DISCUSSION

3.1 IMOCHEM Application

Two specific topics within organic chemistry, namely hydrocarbons involving halogenation and alkyl halides with SN1, SN2, E1, and E2 mechanisms, have been selected for in-depth study. To facilitate this learning process, students have been provided with a comprehensive booklet containing distinct markers corresponding to each mechanism. These markers serve as visual aids, enabling students to identify and understand the nuances of the reaction mechanisms associated with hydrocarbon halogenation and alkyl halide reactions. Figure 1 shows the image of the marker in the AR application.

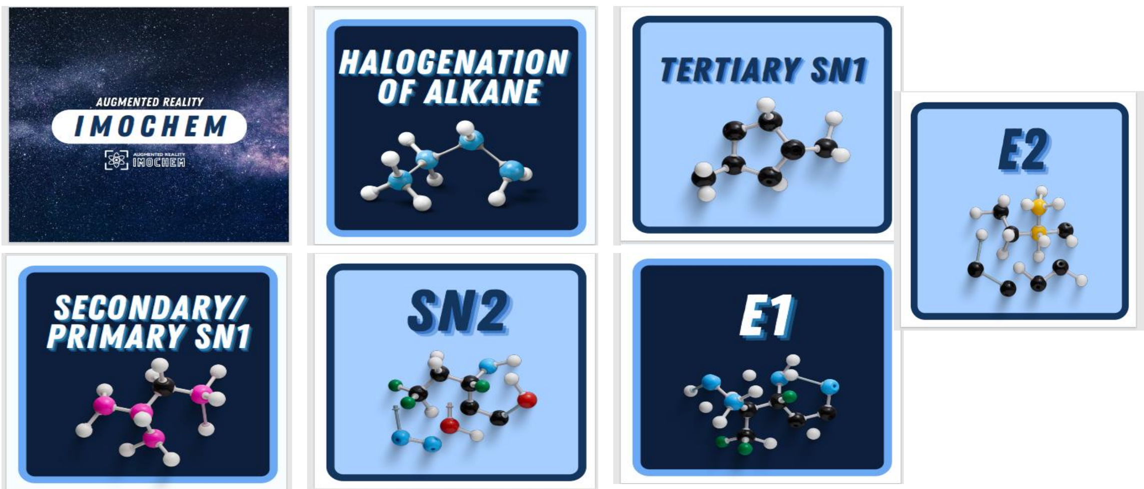


Figure 1. Image of marker on IMOCHEM booklet in AR application

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

Upon successfully downloading the IMOCHEM app from the Google Play store, students gain the valuable opportunity to enhance their learning experience by accessing mechanic content for free. This content is readily available through the simple yet effective process of scanning the IMOCHEM booklet. Figure 2 provides a visual representation, illustrating the sequential steps students can follow to seamlessly access and leverage the educational resources within the IMOCHEM app, thereby enriching their understanding of mechanics-related concepts.

Figure 2. Step of access of IMOCHEM apps

3.2 Method of Implementation

The study involved the active participation of 16 students enrolled at UniSZA Science and Medicine Foundation Centre, who actively engaged in the implementation of the IMOCHEM application. This research aims to systematically assess the efficacy of the developed IMOCHEM application by closely examining its impact on the learning outcomes of the participating students. The investigation encompasses a detailed analysis of the characteristics and educational achievements of the study cohort, focusing specifically on their engagement with the IMOCHEM app as a tool for learning reaction mechanisms.

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

The collected data, as presented in Table 1, offers a comprehensive insight into the outcomes observed before and after the implementation of the IMOCHEM app. Notably, the 16 students are divided into two distinct groups, with student numbers 1-8 representing low-achieving students and student numbers 9-16 denoting high-achieving students. The subsequent analysis seeks to discern any notable differences in learning outcomes, knowledge retention, and comprehension, providing valuable insights into the overall effectiveness of the IMOCHEM app in enhancing the understanding of reaction mechanisms among students with diverse academic backgrounds.

Table 1. Marks before and after implementation of IMOCHEM apps

Student	Marks Before Implementation	Marks After Implementation
1	9.0	13.0
2	11.0	15.0
3	13.5	17.0
4	9.5	12.5
5	13.0	16.0
6	7.0	10.0
7	2.0	6.0
8	16.0	19.0
9	12.0	15.0
10	13.0	16.0
11	9.5	13.0
12	13.0	16.0
13	17.0	19.5
14	11.5	15.0
15	13.0	16.0
16	10.0	14.0

Table 2 shows the statistical analysis of IMOCHEM apps using t-test. From the table, it can be seen that the R^2 obtained is 0.9881 and the p-value from this data is 8.22×10^{-7} which is below than 0.05, then a result is statistically significant. That's means this IMOCHEM apps is significant to improve the knowledge of student in organic chemistry mechanism for both low achieving students and high achieving students.

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

Table 2. Statistical analysis of IMOCHEM apps using t-test

Regression statistical	
Mean	11.4
Variance	13.18571429
Observations	15
Multiple R	0.994056766
R Square	0.988148854
Adjusted R Square	0.987237227
Standard Error	0.410227103

The findings of the study, as detailed in the descriptive statistical analysis presented in Table 3, indicate a noteworthy improvement in both high achievers and low achievers following the implementation of the IMOCHEM apps. The discernible increase in mean grades among the participating students (n=16) post-IMOCHEM app usage establishes a statistically significant enhancement in their overall understanding of the mechanisms involved. The comprehensive analysis reveals that the introduction of IMOCHEM apps has not only contributed to a substantial increase in mean grades but has also resulted in minimal disparities between high achievers and low achievers.

These outcomes underscore a clear and positive impact on students' attitudes towards learning chemistry, suggesting that the IMOCHEM apps have effectively bolstered cognitive abilities, fostered teamwork, and encouraged the adoption of enjoyable and engaging study habits. The statistically significant improvement in mean grades across both high and low achievers underscores the universal efficacy of the IMOCHEM apps in facilitating a more comprehensive and enriched learning experience for all students involved in the study.

Table 3. Descriptive statistical analysis for high and low achievers

Students	Standard deviation	Median	Mean	Variance
High achiever	2.05	16	15.56	4.23
Low achiever	4.48	15	13.56	20.05

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

Meanwhile, the t-test analysis revealed a Pearson correlation of -0.15, with variances of 17.24 and 3.67 observed for low and high achievers, respectively. The Pearson correlation serves as a quantitative measure of the linear relationship between two sets of data, essentially representing a normalized covariance measurement. Its result ranges between -1 and 1, indicating the strength and direction of the correlation. The coefficient is a product of the standard deviations of the two variables and their covariance.

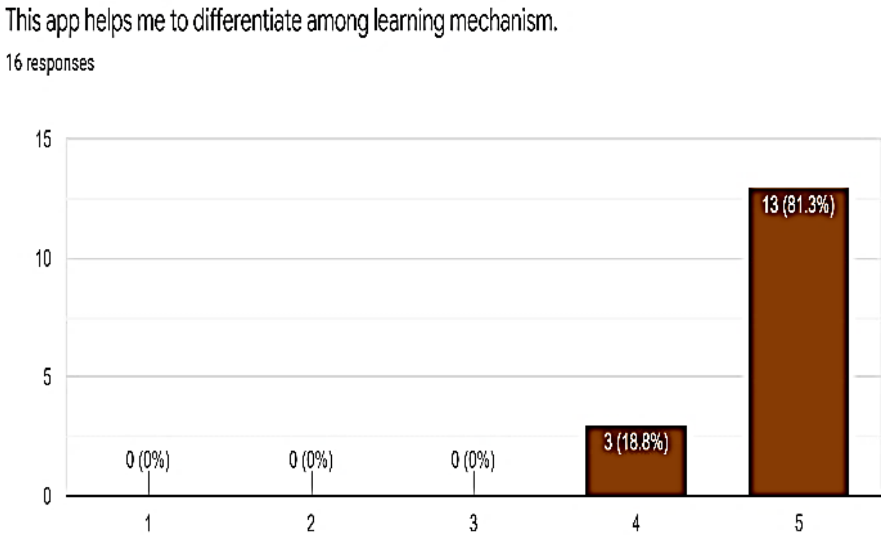
In this context, the negative Pearson correlation of -0.15 implies an anti-correlation, suggesting that the data points tend to lie on opposite sides of their respective means. The negative value indicates that there were relatively few sample students, and there was limited variation in scores between the periods before and after the implementation of the IMOCHEM apps. This may be attributed to the utilization of a small number of sample questions during the study.

3.3 Analysis Survey on Effectiveness of IMOCHEM Application

The outcomes derived from the implementation of the app will undergo a comprehensive evaluation, with a particular emphasis on nurturing students' understanding of the covered topic and gauging their perceptions of the augmented reality (AR) app's role in facilitating their learning process. The collection of data for this evaluation employed multiple methodologies, encompassing learning assessment tests (as detailed in Section 3.2) and the distribution of questionnaires designed to elicit insights into the students' learning experiences and impressions of the IMOCHEM app. A visual representation of the students' responses to the IMOCHEM app is provided in Figure 3, offering a comprehensive overview of their feedback and attitudes towards this innovative educational tool.

ISSN: 1985-5826 AJTLHE Vol. 16, No. 1, June 2024, 141-156

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09



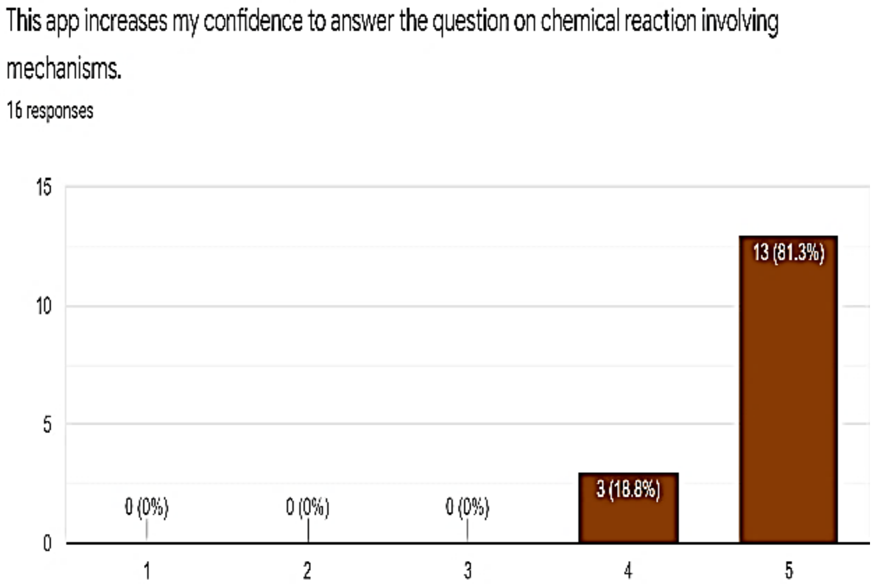


Figure 3. Some responses of the students towards IMOCHEM apps

The findings from the survey utilizing a Likert scale to assess students' perspectives on the IMOCHEM apps are summarized in Table 4, where each item is assigned a maximum score of five. Notably, the majority of students demonstrated a high level of satisfaction and positive feedback, as reflected in their scores, with nearly all respondents assigning almost the maximum of 5 points for each item. This overwhelming trend in high scores suggests a consensus among the students regarding the effectiveness and value of the IMOCHEM apps in enhancing their learning experiences and understanding of the subject matter. The

ISSN: 1985-5826 AJTLHE Vol. 16, No. 1, June 2024, 141-156

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

consistently positive ratings underscore the favourable reception of the AR app, indicating its significant impact on student engagement and comprehension in the context of organic chemistry education.

Table 4. Score for the survey using Likert scale towards IMOCHEM apps (n= 16)

No.	Question	Score (5)
1.	This app helps me to prepare before attending chemistry lectures.	4.87
2.	This app increases my knowledge and understanding on chemical reaction mechanism.	4.87
3.	This app helps me to know the nucleophile and electrophile in a chemical reaction.	4.81
4.	This app increases my confidence to answer the question on chemical reaction involving mechanisms.	4.81
5.	This app helps me to understand the pathway mechanisms of a chemical reaction independently.	4.87
6.	This app helps me to differentiate among learning mechanism.	4.81
7.	This app helps me to remember chemistry theory.	4.75
8.	This app is user-friendly.	4.81
9.	This app makes learning chemistry more fun and interesting.	4.87
10.	This technique of teaching (using IMOCHEM) suits me well compare conventional method.	4.75

Furthermore, the survey responses overwhelmingly suggested that students utilizing the IMOCHEM app exhibited statistically superior final results when compared to their counterparts in the control group, who underwent traditional teaching methods. The discernible trend in positive perceptions regarding the impact of augmented reality (AR) apps on learning outcomes underscores a shift towards recognizing the potential of these innovative educational resources. There is an emerging acknowledgment of the transformative influence of AR apps in increasing classroom participation and enhancing the overall learning experience, indicating a growing acceptance of new and dynamic approaches to education.

ISSN: 1985-5826 AJTLHE Vol. 16, No. 1, June 2024, 141-156

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

And, some comments that encourage more exploration of this apps are:

... *It is very easy to use. Furthermore, it helps me revise back all the mechanisms. So convenient*. (Student 1)

…. *The app is really interesting and it helps in focusing on the chemistry subject more easily.* (Student 2)

…. *For me, I love to use the app since it uses the AR technology. I hope that some other mechanism or other topic were added in the app.* (Student 3)

4.0 CONCLUSION

The application of augmented reality (AR) to actively engage students in the process of meaningful and interactive learning is not a novel concept. In recent years, extensive research has been conducted to integrate various AR apps into educational curricula, aiming to cultivate a dynamic and enjoyable learning environment. The outcomes of this study affirm that the IMOCHEM app has proven instrumental in facilitating a better understanding of crucial subtopics, specifically Hydrocarbon (Halogenation) and Alkyl Halide (SN1, SN2, E1, E2) mechanisms.

The consistently higher averages obtained from each survey question, all surpassing 4.75, strongly indicate that the IMOCHEM app significantly contributed to enhancing students' knowledge. These positive results underscore the app's efficacy in conveying complex concepts, fostering a more profound comprehension of organic chemistry mechanisms, and creating an engaging educational experience. Moreover, the feedback received from students regarding the IMOCHEM app was overwhelmingly positive, with a notable portion expressing a desire for more frequent incorporation of the app into their classes. This collective endorsement from students further emphasizes the potential of AR apps like IMOCHEM in transforming and enriching the traditional learning landscape.

5.0 ACKNOWLEDGEMENT

This research was supported by Universiti Sultan Zainal Abidin through Scholarship of Teaching and Learning (UniSZA/2021/SoTL/02). We also want to thank the student who participated in this research

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

STATEMENT DECLARATION

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

6.0 REFERENCES

Blackie, M.A.L. (2022). Knowledge building in chemistry education. *Foundations of Chemistry, 24*, 97–111.

Carlos F., Sergio I.-S., & Carlos O., (2019). The impact of virtual, augmented and mixed reality technologies on the customer experience. *Journal of Business Research, 100*, 547-560.

Dickey, M. D. (2011). Murder on Grimm Isle: The impact of game narrative design in an educational game-based learning environment. *British Journal of Educational Technology, 42*(3), 456-469.

Ferguson R., & Bodner G. M. (2008). Making sense of the arrow-pushing formalism among chemistry majors enrolled in organic chemistry. *Chemistry Education Research and Practice, 9*, 102-113.

Fonseca, D., Martí, N., Redondo, E., Navarro, I., & Sánchez, A. (2014). Relationship between student profile, tool use, participation, and academic performance with the use of augmented reality technology for visualized architecture models. *Computers in Human Behavior, 31*, 434–445.

Harle, M., & Towns, M. (2011). A review of spatial ability literature, its connection to chemistry, and implications for instruction. *Journal of Chemical Education, 88*(3), 351–360.

Received: 25 March 2024, Accepted: 20 June 2024, Published: 30 June 2024
https://doi.org/10.17576/ajtlhe.1601.2024.09

O 'Dwyer, A., & Childs, P. E. (2017). Who says Organic Chemistry is Difficult? Exploring Perspectives and Perceptions. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(7), 3599-3620.

Plunkett, K. (2019). A Simple and Practical Method for Incorporating Augmented Reality into the Classroom and Laboratory. *Journal of Chemical Education, 96*(11), 2628-2631.

Taber, K.S. (2019). *Foundations for teaching chemistry: Chemical knowledge for teaching* (1st ed.). Abingdon, London: Routledge.

Tuckey, H., Selvaratnam, M., & Bradley, J. (1991). Identification and rectification of student difficulties concerning three-dimensional structures, rotation, and reflection. *Journal of Chemical Education, 68*(6), 460–464.

Wojciechowski, R., & Cellary, W. (2013). Evaluation of learners' attitude toward learning in ARIES augmented reality environments. *Computers & Education, 68,* 570–585.

Yogesh K. D., Laurie H., Abdullah M. B., Samuel Ribeiro-N., Mihalis G., Mutaz M. Al-D., Denis D., Bhimaraya M., Dimitrios B., Christy M.K. C., Kieran C., Ronan D., Rameshwar D., Vincent D., Reto F. D.P. G., et al. (2022). Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy*. International Journal of Information Management, 66*, 102542.