A Comparative Study: Augmented and Virtual Reality Applications for Improving Comprehension of Abstract Programming Concepts

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Abstract: This paper presents the development of a Virtual Reality (VR) application to enhance the learning experience of Python collection data types for electrical and electronic engineering students, and the comparison of this VR application with an Augmented Reality (AR) application developed for the same field, and a paper-based content. AR and VR, as emerging technologies, hold promise for transforming educational and cognitive processes, especially in engineering education where students often struggle with abstract programming concepts. The research focuses on using VR to make abstract concepts like Python collections more accessible and understandable through immersive and interactive experiences. The VR application allows students to engage with virtual representations of Python data types, promoting a deeper comprehension. A comparative user study was conducted, involving participants using either the VR or AR application or learning through a printed booklet. The effectiveness of these methods was assessed by pre- and post-comprehension tests. The results indicated a significant improvement in understanding Python collections with the VR application, as evidenced by the substantial difference between its pre- and post-test score means. This finding suggests that VR, more effectively than AR or traditional methods, aids in grasping abstract programming concepts.

1 INTRODUCTION

AR and VR are revolutionary technologies that have the potential to reshape the landscape of education and learning. In general terms, AR allows users to perceive the actual world while overlaying or integrating virtual elements onto it and this technology encompasses three fundamental attributes: the fusion of real and virtual environments, seamless real-time interaction, and a three-dimensional aspect (Azuma, 1997). Besides, VR consists of interaction, immersion, and imagination (Burdea and Coiffet, 2003) and uses computer technology to simulate an interactive three-dimensional environment, where objects have a sense of spatial presence (Bryson, 2013).

In the realm of engineering education, these immersive technologies offer unique opportunities to enhance the understanding of complex concepts. Building upon the AR application designed to improve the comprehension of Python collection data types (Lists, Tuples, Sets, and Dictionaries) for first-year electrical and electronic engineering students in (Cinar et al., 2023), this paper introduces the development and implementation of a VR application that takes the learning experience to new heights by adding interaction using Oculus Integration SDK (Software Development Kit).

The VR application represents a natural progression from the booklet and the AR application, allowing users to delve into a fully immersive virtual environment. By integrating real-time interaction and virtual elements, the VR application provides an enhanced learning experience with added layers of interactivity.

1.1 Hypothesis

The paper posits three primary hypotheses as follows:

- **Hypothesis 1 (H1).** Both sample group 1 (users of the AR application) and sample group 2 (users of the VR application) will show a statistically significant improvement in comprehension from the pre-test to the post-test. H1 is based on the premise that both AR and VR technologies offer enhanced learning experiences compared to tra-

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ditional methods. AR and VR can provide more interactive and engaging ways to visualize and interact with complex concepts, in this case, Python collection data types. These technologies have been shown to increase motivation and engagement, which are key factors in learning.

- **Hypothesis 2 (H2).** The rate of comprehension improvement from the pre-test to the post-test will be greater in sample group 2 compared to sample group 1. H2 is based on the premise that VR technology typically offers a more immersive learning environment than AR. While AR overlays digital information in the real world, VR creates a completely virtual environment that can more fully engage the user's senses. This total immersion in VR is hypothesized to lead to a higher level of concentration and focus on the subject matter, potentially resulting in a greater comprehension improvement compared to AR.
- **Hypothesis 3 (H3).** The rate of comprehension improvement from the pre-test to the post-test will be greater in both sample group 1 and sample group 2 compared to the control group (readers of the booklet). H3 is based on the premise that the control group, using traditional paper-based learning materials, is exposed to a more passive form of learning. In contrast, AR and VR provide active learning experiences, where users can engage directly with the material. The interactive nature of these technologies caters to various learning styles (visual, kinesthetic, etc.), potentially leading to enhanced cognitive processing and retention of information.

1.2 Contribution

The addressed gaps include:

- How interaction is effectively used during the VR application development process,
- How a VR-based educational application is developed for such a specific application area as Python collection data types,
- How more robust and extensive content for this kind of VR application can be designed in this direction,
- What type of evaluation methods can be adopted to analyse the outcomes of this kind of VR application,
- How users can gain more effective learning experiences with a VR application compared to paper-based and AR content.

This VR application presents an innovative and engaging method to improve understanding of complex programming concepts, contributing to research on VR's educational use and demonstrating its effectiveness for engineering students, with implications for the design of future VR tools across various educational fields.

The research methodology involves a comparison between the effectiveness of booklet, AR, and VR applications for learning by dividing participants into three groups to use each method, and conducting pre- and post-comprehension tests to evaluate their effectiveness, with a focus on determining if the VR application surpasses the AR application in user engagement and learning outcomes.

The findings from this research hold significant implications for integrating immersive technologies into engineering education. The VR application's interactive support is a key point here. Moreover, the study contributes to the growing body of knowledge on the potential of VR in education, highlighting the benefits of interactive and adaptive learning environments.

As VR technology continues to evolve, the outcomes of this research will inform future advancements in educational applications, paving the way for more effective and inclusive learning experiences across diverse domains. By blending the realms of AR, VR, and interaction, this study represents a forward-looking endeavor that strives to empower engineering students on their educational journey.

In summary, the contributions of this work are threefold, encompassing key advancements in the development of the VR application for enhancing the comprehension of abstract and/or complex programming concepts, specifically focused on Python collection data types:

- Firstly, a cumulative design approach was adopted when the VR application was developed based on the AR application developed previously.
- Secondly, the incorporation of Oculus Integration SDK for interaction within the VR environment is a notable contribution, improving a deeper and more permanent understanding of programming concepts.
- Thirdly and finally, the research methodology employed, involving a comparative user study between the booklet, the previously developed AR application, and the new VR application, aims to provide insights into the effectiveness of VR-based learning tools.

2 BACKGROUND

2.1 Augmented and Virtual Reality in Engineering Education

The integration of AR and VR technologies into engineering education has become a subject of extensive study and exploration, each offering unique benefits and applications.

Numerous studies have explored the use of AR in engineering education. According to (Billinghurst and Duenser, 2012), AR is gaining significance in the educational realm, particularly for its positive impact on student memory retention and comprehension.

In (Luo and Mojica Cabico, 2018) an AR-based learning tool was developed for construction engineering students and it demonstrated improved learning experiences and enhanced understanding compared to traditional 2D graphics. In (Kaur et al., 2020) it was emphasised that AR is seen as a valuable tool for enhancing student motivation by providing interactive learning experiences in engineering education

According to (Tuli and Mantri, 2020), while practical labs in science and engineering education face limitations due to costs and resource constraints, AR not only effectively overcomes these issues, particularly in simplifying concepts like Fleming's rule in electromagnetism, but also surpasses web-based applications in improving student understanding and flow awareness in this field.

Additionally, it was underlined in (Jesionkowska et al., 2020) that AR technology is known to boost motivation and improve perceptions of STEAM subjects. It promotes active learning and curiosity and empowers students to take charge of their educational journey.

On the other hand, the use of VR in engineering education has been researched in many studies to date. The studies analysed in (di Lanzo et al., 2020) demonstrated that the utilisation of VR in engineering education has the potential to provide advantageous and promising outcomes concerning desired learning achievements in tertiary and industry institutions.

According to (Radianti et al., 2020), there are certain gaps in terms of immersion, application areas of VR, content, evaluation, methods, and theories in the relevant literature.

In (Laseinde et al., 2015) the researchers employed VR as a technique to effectively communicate engineering topics to first-year engineering students. The outcomes obtained through the implementation of this teaching tool make a substantial contribution to the field of VR content development and enhance students' retention of engineering concepts. In (Dinis et al., 2017) their VR interface enables participants to immerse themselves in a three-dimensional model of a building on the campus, facilitating the exploration of various disciplines within civil engineering. Users can reveal concealed components in the building systems by switching the visibility of different sets of building elements. In (Muller et al., 2017) the utilisation of consumer-grade VR equipment for immersive learning purposes within the field of Mechanical Engineering was underlined. The design of a VR immersive learning game was outlined and a methodology was proposed for evaluating the user experience, specifically examining three dimensions: usability, utility, and acceptability.

In (Kamińska et al., 2017), VR was highlighted as a new trend in mechanical and electrical engineering education, by demonstrating its effectiveness in immersive learning by reducing costs, eliminating the need for expensive equipment, and enhancing material retention and educational outcomes, with most participants effectively interacting with the VR platform and showing improved comprehension and retention.

Briefly, the dynamic synergy in AR and VR is transforming the landscape of engineering education, paving the way for more immersive, engaging, and effective learning experiences while addressing various challenges, ultimately shaping the future of engineering instruction.

2.2 Augmented and Virtual Reality in Computer Science and Programming Concepts

The use of AR and VR for engineering education has opened up new avenues for teaching Computer Science (CS) and programming concepts, as evidenced by a plethora of studies in the literature.

In the relevant literature, one can encounter studies that incorporate AR into engineering education to teach CS concepts and topics.

In (Bacca Acosta et al., 2014) it was underlined that AR techniques enhance the effectiveness of visualisations and offer multiple benefits for learning programming, including improved learning outcomes, increased motivation, interactivity, and collaboration.

In (Schez-Sobrino et al., 2021) a 2-D graphic notation within a 3-D environment was introduced. This innovative approach employed graphical representations inspired by roads and traffic signs within the realm of programming instruction, enabling the visualisation of programs through AR. CS students evaluated these visual representations, confirming the clarity and practicality of the suggested notation for conveying programming concepts.

Furthermore, (Theodoropoulos and Lepouras, 2021) highlighted the tremendous potential of AR as a tool to support CS education. Immersive and engaging AR tools are considered essential for effective CS education.

In addition, it is inevitable to find studies in the literature in which VR is employed to teach CS concepts as part of engineering education.

It was underlined in (Oktaviati and Jaharadak, 2018) that the integration of gamification and virtual environments in CS education enhances interactivity, content absorption, interest, comprehension, and efficiency, leading to a more engaging and effective learning experience.

According to (Batista et al., 2020), the utilisation of virtual environments in CS education has yielded positive outcomes in the learning process.

In conclusion, both AR and VR have emerged as powerful tools for enhancing the teaching and learning of CS within engineering education, offering immersive experiences, improved comprehension, and heightened motivation, paving the way for more effective and engaging pedagogical approaches in this dynamic field.

2.3 The Use of Gamification in Augmented and Virtual Reality

According to numerous papers, the use of gamification in AR and VR applications yields significant advantages in terms of comprehension.

According to (Lampropoulos et al., 2022), the integration of gamification into AR holds promise for fostering customised and collaborative learning experiences.

On the other hand, in (Agbo et al., 2021) the authors identified gaps in VR applications for Computer Science (CS) education, emphasising the need for contextualization of VR experiences to align with CS educational goals and integrate real-world scenarios, thereby enhancing the relevance, understanding, and engagement of CS learners and preparing them for practical applications.

In (Nicola et al., 2018) a VR application incorporating gamification principles was developed for learning the Bubble Sort algorithm, significantly improving student engagement and effectiveness in understanding the sorting technique. According to (Bromana and Mårell-Olssonb, 2018), the primary objective of gamification is to amplify students' intrinsic motivation by providing them with clues, challenges, and opportunities for progression or "levelling up."

In summary, the strategic use of gamification within AR and VR applications emerges as a pivotal approach to enhance comprehension and engagement, offering students tailored, immersive, and contextually rich learning experiences in the field of CS education.

3 MATERIALS AND METHODS

The process is meticulously orchestrated for a thorough comparative analysis between the booklet, AR, and VR applications. In the study, details are provided about the booklet and VR application, while details about the AR application used for comparison can be found in (Cinar et al., 2023).

3.1 Purpose and Development of the Booklet

Initially, a comprehensive booklet was crafted, encompassing detailed examples of Python's collection data types: lists, tuples, and dictionaries. This booklet meticulously presented the data types along with their inputs and corresponding outputs in a lucidly written format.

The inception of the booklet was driven by a strategic purpose: to establish a control group for the user study, distinct from those utilising the AR and VR applications. This booklet served as a foundational tool, offering a traditional, non-digital method for comprehending abstract programming concepts. Its role was pivotal in providing a baseline for comparison, ensuring that the study could accurately gauge the effectiveness and added value of the AR and VR applications in enhancing understanding of Python's collection data types. This comparative approach was instrumental in assessing the incremental benefits of immersive technologies in educational contexts, particularly in the realm of abstract programming concepts.

Figures 1 and 2 show some list and tuple data type examples in the booklet.

List Examples

- Adding a New Data:

  [a, b, c, d, e, a]
  0|1|2|3|4|5

  Input: list = ['a', 'b', 'c', 'd', 'e', 'a']   Output: ['a', 'b', 'c', 'd', 'e', 'a']
  print(list)

  Input: list = list + ['f']   Output: ['a', 'b', 'c', 'd', 'e', 'a', 'f']
  list

- Slicing & Indexing:

  Input: list[3:5]   Output: ['d', 'e']

Figure 1: An Example of the List Data Type in the Booklet.

Tuple Examples

(a, b, c, d, e, a)
0|1|2|3|4|5

Input: tup=('a', 'b', 'c', 'd', 'e', 'a') print(tup) — Output: ('a', 'b', 'c', 'd', 'e', 'a')

Input: tup[0] — Output: 'a'

Input: tup[0, 3] — Output: ('a', 'b', 'c')

- Error Condition:

Input: tup[0]=12312 tup — Error: 'tuple' object does not support item assignment

Figure 2: An Example of the Tuple Data Type in the Booklet.

3.2 Purpose and Development of the VR Application

The final phase of development witnessed the evolution of the AR content into a fully-fledged Virtual Reality (VR) application. Here, the essence of interaction was significantly amplified, allowing users to engage with programming concepts in a highly interactive and spatially contextualised virtual environment.

The purpose of the VR application is to facilitate users in enhancing their understanding of the subject by presenting basic commands and differences in Python collection data types through 3D objects in a virtual environment using interactive learning.

Python collection data types were categorised into four subjects: Lists, Tuples, Dictionaries, and Sets before the VR application was developed. This categorisation was applied to the development process of the application.

Unity 2021 was employed to develop this application. It is a newer version of Unity 2020 and is a game engine that provides the same functions to its users with newly added features.

Since the VR application was developed for Oculus or Meta devices with its new name such as Oculus or Meta Quest 2, Oculus Integration SDK was used as a software development kit.

The VR application features several interactive elements to boost user engagement and learning effectiveness. These include:

- Hand Interaction for the natural manipulation of objects, mirroring real-life hand movements, and enhancing the learning of abstract concepts.
- Grab Interaction allows users to physically handle virtual objects, vital for teaching programming and data structures.
- Ray Interaction uses a virtual 'laser pointer' for distant object interaction, aiding in navigating complex information.
- Poke Interaction, simulating finger poking, is ideal for pressing buttons or handling small items.

Together, these features create an immersive environment, combining natural interaction, object manipulation, distant engagement, and simple, effective interaction with smaller items, all contributing to an enhanced learning experience in programming concepts.

Accordingly, the necessary configurations were completed. Every scene includes a panel including a question about Python collection data types. In addition, buttons and pins were created to represent elements of the indexes in the questions. Thus, users can push the buttons or drag the pins with their hands in the scenes to answer the questions. Using these kinds of interactive elements, these concepts and notions were thought to be able to be more understandable and tangible for users.

In the VR application, each index element is visualised as a button or pin, as shown in the slicing & indexing example in Figure 3 with the list index ['a', 'b', 'c', 'd', 'e', 'a', 'f']. Users are instructed to list elements from the third to the fifth, meaning pressing the buttons representing 'd' and 'e'.

Figure 3: A Slicing & Indexing Example in the List Data Type.

When the 'Correct Answer' toggle is pressed, "Correct Answer" is displayed on the panel above, and the correct answer ['d', 'e'] is shown as in Figure 4, indicating the buttons 'd', and 'e' are pressed.

Figure 4: 'Correct Answer' of the Slicing & Indexing Example.

In the reverse sorting example shown in Figure 5, the user is presented with a list index [123, 12321, 312, 45435, 35, 345, 1, 1] and asked to arrange the elements, represented as pins, in reverse order.

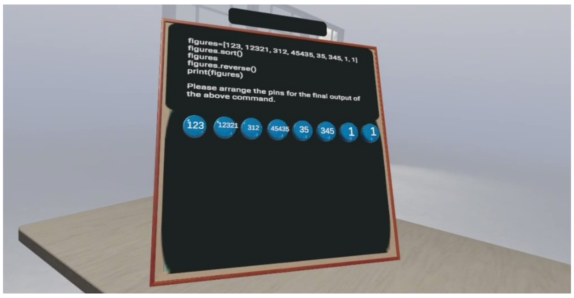

Figure 5: A Reverse Sorting Example in the List Data Type.

When the 'Correct Answer' toggle is pressed, "Correct Answer" appears on the panel above and the user views the correctly arranged index [45435, 12321, 345, 312, 123, 35, 1, 1], as depicted in Figure 6 with pins arranged in the respective order.

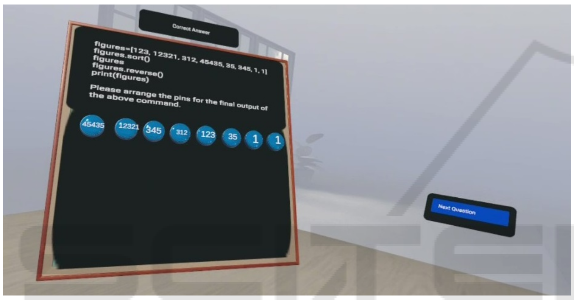

Figure 6: 'Correct Answer' of the Reverse Sorting Example.

Thanks to the before-mentioned concept design, the users can interact with the index elements with their own hands and get more familiar with how the data type commands work and what kind of functions they have.

C# programming language was used to write the scripts of the VR application through Visual Studio. The fact that the 3D objects created in the application could be interactive was ensured in this way.

4 EXPERIMENT

A user study process was carefully organised and executed to evaluate the performance and user-friendliness of the VR application developed along with the booklet and the AR application developed previously. To conduct this user study, ethical approval was received from the Engineering and Physical Sciences Faculty Research Ethics Committee at Queen's University Belfast.

4.1 Objective

The main objective of the experiment was to assess the difference in students' comprehension of Python collection data types. To achieve this, Sample Group 1 was tasked with answering a set of questions before and after using the AR application, while Sample Group 2 was given the same questions before and after using the VR application. The control group, on the other hand, answered the same questions before and after reading a printed booklet containing the content covered in the applications.

4.2 Participants

39 people participated in the user study conducted. All participants were electrical & electronic engineering students. They were divided into three groups with an equal number of participants, namely 13 participants in the control group, 13 participants in sample group 1, and 13 participants in sample group 2, and were categorised as follows:

- **Control Group.** They read the booklet and did not use the AR or VR applications.
- **Sample Group 1.** They used the AR application.
- **Sample Group 2.** They used the VR application.

4.3 Equipment

The booklet was used by the control group as paper-based content during the user study.

The AR application was used by sample group 1 on Xiaomi 11 Lite 5G NE with the Android operating system during the user study.

The VR application developed was used by sample group 2 on Meta Quest 2 as the VR headset during the user study. The Meta Quest 2 HMD (Head-Mounted Display) is a prominent device in the consumer VR market. It boasts outstanding features such as a display resolution of 1832 x 1920 per eye, a refresh rate of 90Hz, and 6 degrees of freedom (DOF) for a truly immersive experience.

4.4 Procedure

Participants who chose to take part were first required to provide their consent by approving a consent form. Subsequently, they were divided into three approximately equal groups: Sample Group 1, Sample Group 2, and the Control Group. All participants provided their consent before participating in the study.

The pre- and post-tests had 10 questions on the primary aspects of data types. It included six multiple-choice questions and four true-false questions. Furthermore, the booklet contained example commands for the AR and VR applications. The tasks of the three groups are listed as follows:

- **Control Group.** They completed the pre-test, then read the booklet, and finally completed the post-test.
- **Sample Group 1.** They completed the pre-test, then used the AR application, and finally completed the post-test.
- **Sample Group 2.** They completed the pre-test, then used the VR application, and finally completed the post-test.

5 RESULTS AND DISCUSSION

The literature analysis highlights the scarcity of research on the effects of educational VR and AR applications on users, particularly in comparison to traditional learning methods. It also highlights the growing significance of VR- and AR-enhanced educational tools.

Notably, the educational technology landscape has also seen a surge in interest in VR applications providing immersive and interactive learning experiences that can enrich educational outcomes and engagement. However, similar to AR, there remains a scarcity of research examining the effects of VR-based educational applications. This highlights the importance of further exploration into the influence of VR and AR technologies in education, given their evolving roles in shaping the future of learning.

This study introduces the development of a VR application aimed at enhancing student comprehension of Python collection data types and presents the comparison of this VR application with the booklet and the AR application developed previously. The VR application offers various options for learning and leverages the power of immersion and interaction. Additionally, it has been created specifically for the Meta Quest 2 HMD, while the booklet is used as printed and the AR application is accessible on smartphones and tablets running the Android operating system.

To contrast the pre- and post-test scores among the control group, sample group 1, and sample group 2, a paired sample t-test was employed as the statistical method. MATLAB was utilised to generate scatter plots for visualising these comparisons. Notably, when presenting the t-test results in the tables, most values were rounded to two decimal places, but the p-values were presented with greater precision, often extending to four decimal places after the decimal point.

5.1 The Control Group (Readers of the Booklet)

Figure 7 shows the pre- and post-test scores of each participant in the control group in a scatter plot. In Figures 7, 8, and 9, if a participant has only one of the blue or red marks indicating the number of correct answers they gave, this indicates that the pre- and post-test scores obtained by a participant are the same.

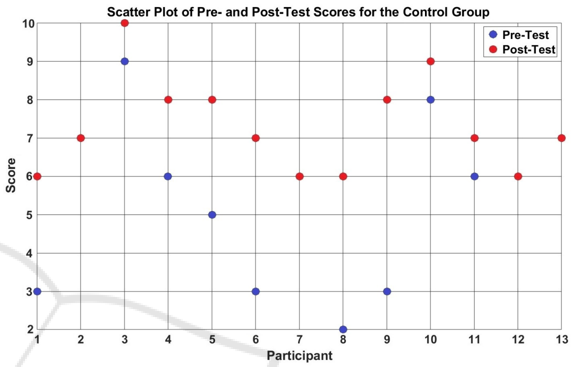

Figure 7: Scatter Plot of Pre- and Post-Test Scores of the Control Group.

In Table 1, a t-test was conducted to examine the achievement levels of the control group by comparing pre- and post-test scores. The analysis demonstrated a significant difference between the pre- and post-test scores, with a p-value of 0.0027, which falls below the significance threshold of 0.05. The analysis revealed a significant difference The average score for the pre-test was recorded as 5.46, while the average score for the post-test was recorded as 7.31.

Table 1: t-test results between Pre-Test and Post-Test for the Control Group.

	Mean	Variance	Standard Deviation	P
Pre-test	5.46	4.6	2.15	0.0027
Post-test	7.31	1.56	1.25	

5.2 Sample Group 1 (Users of the AR Application)

Figure 8 shows the pre- and post-test scores of each participant in sample group 1 in a scatter plot.

In Table 2, a t-test was conducted to examine the achievement levels of sample group 1 by comparing pre- and post-test scores. The analysis demonstrated a significant difference between the pre- and post-test scores, with a p-value of 0.0004, which falls below

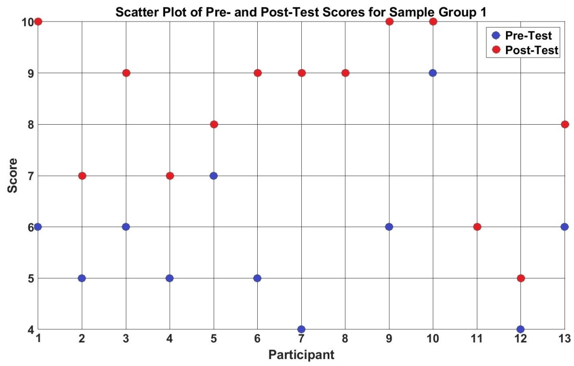

Figure 8: Scatter Plot of Pre- and Post-Test Scores of Sample Group 1.

the significance threshold of 0.05. The average score for the pre-test was recorded as 6, while the average score for the post-test was recorded as 8.23.

Table 2: t-Test results between Pre-Test and Post-Test for Sample Group 1.

	Mean	Variance	Standard Deviation	P
Pre-test	6	2.5	1.58	0.0004
Post-test	8.23	2.53	1.59	

5.3 Sample Group 2 (Users of the VR Application)

Figure 9 shows the pre- and post-test scores of each participant in sample group 2 in a scatter plot.

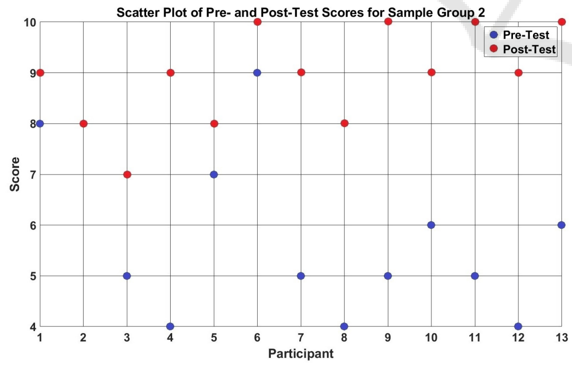

Figure 9: Scatter Plot of Pre- and Post-Test Scores of Sample Group 2.

In Table 3, a t-test was conducted to examine the achievement levels of sample group 2 by comparing pre- and post-test scores. The analysis demonstrated a significant difference between the pre- and post-test scores, with a p-value of 0.0001, which falls below the significance threshold of 0.05. The average score for the pre-test was recorded as 5.85, while the average score for the post-test was recorded as 8.92.

Table 3: t-Test results between Pre-Test and Post-Test for Sample Group 2.

	Mean	Variance	Standard Deviation	P
Pre-test	5.85	2.81	1.68	0.0001
Post-test	8.92	0.91	0.95	

5.4 System Usability Scales

Two different system usability scales were prepared to get feedback from the participants in the user study and to make qualitative analyses about the booklet and the AR and VR applications developed. The first one was presented to the control group (readers of the booklet) because it was paper-based content. The second one was presented to sample groups 1 and 2 (users of the AR and VR applications, respectively) because the applications were used through certain devices.

The statements for the control group and sample groups 1 and 2, along with their corresponding numbers, are given in Tables 4 and 5, respectively. Bar charts depicting the opinions of the control group and sample groups 1 and 2 about the applications are given in Figures 10 and 11, respectively.

Table 4: Statements in the System Usability Scale for the Control Group.

Statements	Number
I think I would like to use this booklet frequently.	1
I found the booklet unnecessarily complex.	2
I thought the booklet was easy to read.	3
I think that I would need the support of a technical person to be able to read this booklet.	4
I found the various functions in this booklet were well-integrated.	5
I thought there was too much inconsistency in this booklet.	6
I would imagine that most people would learn very quickly by reading this booklet.	7
I found the booklet very cumbersome to read.	8
I felt very confident reading the booklet.	9
I needed to learn a lot of things before I read this booklet.	10

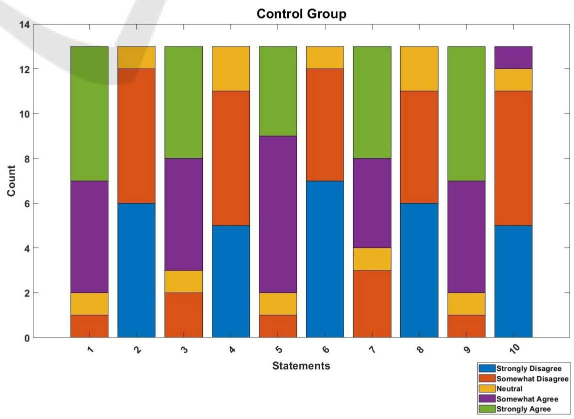

Figure 10: System Usability Analysis for the Control Group.

Table 5: Statements in the System Usability Scale for Sample Groups 1 and 2.

Statements	Number
I think I would like to use this application frequently.	1
I found the application unnecessarily complex.	2
I thought the application was easy to use.	3
I think that I would need the support of a technical person to be able to use this application.	4
I found the various functions in this application were well-integrated.	5
I thought there was too much inconsistency in this application.	6
I would imagine that most people would learn to use this application very quickly.	7
I found the application very cumbersome to use.	8
I felt very confident using the application.	9
I needed to learn a lot of things before I could get going with this tool.	10

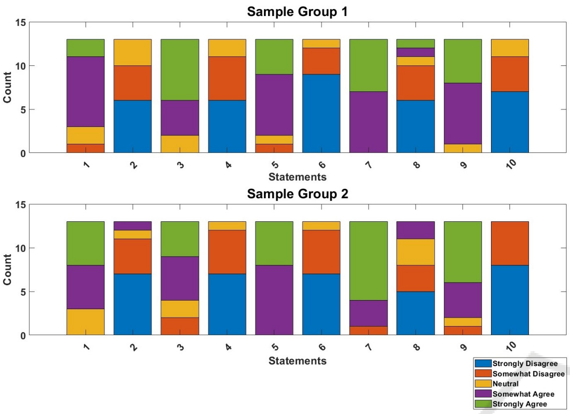

Figure 11: System Usability Analysis for Sample Groups 1 and 2.

6 CONCLUSION

In recent times, it has been observed, in the context of physics terminology, that AR and VR have converted their potential energy into kinetic energy in education, particularly in engineering education, and the projected development of these technologies is expected to accelerate exponentially. Such technologies provide users with an entirely new experience through the elements of immersion and interaction.

Firstly, the tests and analyses conducted demonstrated that both sample group 1 (users of the AR application) and sample group 2 (users of the VR application) showed a statistically significant improvement in comprehension from the pre-test to the post-test (2.23 and 3.07, respectively, $p < 0.05$). Thus, hypothesis 1 (H1) was confirmed.

Secondly, it was concluded that the rate of comprehension improvement from the pre-test to the post-test was greater in sample group 2 (3.07) compared to sample group 1 (2.23). Thus, hypothesis 2 (H2) was confirmed.

Thirdly, it was suggested that the rate of comprehension improvement from the pre-test to the post-test was greater in both sample group 1 (2.23) and sample group 2 (3.07) compared to the control group (readers of the booklet) (1.85). Thus, hypothesis 3 (H3) was confirmed.

These findings finally conclude that VR and AR applications are more effective than conventional methods in enhancing learning comprehension, with VR showing the most substantial impact.

Following the analysis of system usability for the control group, it was determined that 84.62% of this group expressed a favorable inclination towards frequent utilisation of the booklet. Moreover, 92.31% of the group did not perceive the booklet as excessively intricate. Furthermore, 76.92% of respondents in the group regarded the booklet as user-friendly. An additional noteworthy finding was that 84.62% of the group did not deem it necessary to seek technical assistance to operate the booklet effectively.

In the assessment of functional integration for the control group, 84.62% of the group reported a high degree of coherence in the various functions within the booklet. Additionally, a unanimous consensus was reached, with 100% of the participants in the control group concurring that there was no significant inconsistency in the booklet. Furthermore, 69.23% of the group expressed a belief that most individuals would quickly acquire proficiency in using the booklet.

In terms of usability challenges for the control group, 100% of the group did not think that there were significant issues regarding the cumbersome nature of the booklet. As for user confidence, 84.62% of individuals in the control group reported a high level of self-assurance in their ability to navigate and utilise the booklet. Moreover, it was revealed that 84.62% of the group did not perceive a substantial requirement for extensive learning before initiating the use of the booklet.

Following the analysis of system usability for sample groups 1 and 2, it was determined that 76.92% of sample groups 1 and 2 expressed a favorable inclination towards frequent utilisation of the applications. Moreover, 76.92% of sample group 1 and 84.62% of sample group 2 did not perceive the applications as excessively intricate. Furthermore, 84.62% of respondents in sample group 1 and 69.23% of respondents in sample group 2 regarded the applications as user-friendly. An additional noteworthy finding was that 100% of individuals in sample groups 1 and 2 did not deem it necessary to seek technical assistance to operate the applications effectively.

In the assessment of functional integration for sample groups 1 and 2, 84.62% of sample group 1 and 100% of sample group 2 reported a high degree of coherence in the various functions within the applications. Additionally, a unanimous consensus was reached, with 100% of participants in sample groups 1 and 2 concurring that there was no significant inconsistency in the applications. Furthermore, the majority of respondents, specifically 100% of sample group 1 and 92.31% of sample group 2, expressed a belief that most individuals would quickly acquire proficiency in using the applications.

In terms of usability challenges for sample groups 1 and 2, 84.62% of sample groups 1 and 2 did not think that there were significant issues regarding the cumbersome nature of the applications. As for user confidence, 92.31% of individuals in sample group 1 and 84.62% of individuals in sample group 2 reported a high level of self-assurance in their ability to navigate and utilise the applications. Moreover, it was revealed that 84.62% of participants in sample group 1 and 100% of participants in sample group 2 did not perceive a substantial requirement for extensive learning before initiating the use of the applications.

7 LIMITATIONS

The primary limitation of this study is the sample size. Our user study involved a total of 39 participants, with each teaching environment (booklet, AR, VR) being tested by 13 participants. While this provided initial insights into the comparative effectiveness of these methods, the small sample size limits the generalisability of our findings. A larger participant pool could offer a more comprehensive understanding of the effectiveness of these educational tools across different learning styles.

8 FUTURE WORK

In response to the limitations and to further our research, we plan to expand the scale of the study. Future work will involve increasing the number of participants to enhance the reliability and validity of our results. By involving a larger group of learners, we aim to obtain more robust data that can offer deeper insights into the effectiveness of VR and AR in educational settings.

Additionally, we plan to enhance the VR application by integrating more interactive agents and personalised learning elements. This development aims to create a more engaging and adaptive learning environment, catering to individual learning needs and styles. We anticipate that these improvements will not only make the VR experience more immersive and interactive but also contribute to a more nuanced understanding of how personalised and interactive elements in VR can enhance the learning of abstract programming concepts.

Through these enhancements, we aim to address the current limitations and significantly contribute to this evolving field, particularly in the context of teaching complex and abstract subjects like programming.

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