Digital Innovation in Vocational Training: Utilising Mobile Augmented Reality to Enhance Learning Experiences

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ABSTRACT

Augmented Reality (AR) has gained significant attention across various domains, aligning with Industry 4.0. Although AR has emerged as a useful tool in various educational applications, its implementation in Technical Vocational Education and Training (TVET) remains underexplored. This study was designed to develop a marker-based AR instructional tool for TVET to enhance technical competencies and learning motivation of trainees, particularly in the microcontroller module. The mobile Augmented Reality for TVET instructional tool was built using Blender 3D, Unity 3D, and Vuforia. There are eight microcontroller components and four simulation circuit assemblies included in the tool. Rasch model was used to assess the validity and reliability of the survey instruments and to ensure uniform functioning of the survey data. Data was collected using the Technology Acceptance Model (TAM) and the Attention, Relevance, Confidence, Satisfaction (ARCS) model to determine usability, engagement and motivation levels. The results obtained from the study shows that 97.4% of the trainees confirm that the mART application is a helpful tool for helping in understanding the microcontroller module. The findings indicate that the mART

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instructional tools assist trainees in enhancing knowledge retention, engagement and technical skills in TVET education. Since there is a need to bridge the gap between what is being thought in the classrooms and what is obtainable in the field of practice, it implies that, this adoption in the form of AR-based instructional tools is therefore recommended for TVET institutions to ensure the readiness of trainees with industry-oriented skills in the ever-changing and fast developing technological development.

Keywords: Augmented reality, instructional technology, microcontroller training, mobile augmented reality application, technical vocational education and training

INTRODUCTION

Microcontrollers are incredibly important to both the technical and engineering domains. Trainers from Pedas Industrial Training Institute confirmed that students are unable to visualise programming logic in practice R. B. Ramli and Z. B. A. Razak (personal communication, 2020). A survey of 36 trainees across four TVET institutions further revealed that Competency Unit 7C (Basic Microcontroller) was the least understood unit, a finding supported by lecturers (Muthu et al., 2022).

Studies by Milne & Rowe, (2002), Mladenović et al., (2021), and Mohd Najid et al., (2019) highlighted how programme visualisation tools can support improved understanding as one aspect of microcontroller education. Further contributing factors for this problem include insufficient instructional examples and lack of creative teaching aids, as mentioned by Mohamad Ali and Md Derus, (2014). Altogether, these challenges underscore the urgent need for innovative instructional strategies to improve trainees' understanding and engagement.

In the context of teaching Technical Vocational Education and Training (TVET) subjects, such as a microcontroller programme, hands-on and skill-based learning becomes crucial. Interactive and experiential training is necessary to facilitate trainees learn practical competencies (Ramly et al., 2022). The growth of new future technologies, and the rapid increase of Fourth Industrial Revolution (IR 4.0), requires inserting own solutions based on innovative technologies, such as Augmented Reality (AR). AR is an approach that uses mobile devices to help users access different types of contextual information. AR gives students the chance to dive into various subjects, helping them deepen their knowledge with virtual elements and mobile technology (Velázquez & Méndez, 2018; Angra & Jangra, 2025). In terms of learning, AR can also deliver immersive hands-on experiences, enabling trainees to interact with the microcontroller parts and the circuit assembly, effectively reducing the gap between theory and practice (Zhao et al., 2023).

A needs assessment identifies the difference between what is currently available and what is needed. A needs assessment has revealed that a considerable number of TVET institutions still do not have electronic learning resources. This gap highlights the need for

electronic instructional materials to produce quality accessible technical education during the COVID-19 pandemic and other disruptions (Akinradewo et al., 2024; ILO-UNESCO, 2020). Moreover, one of the main components to prepare TVET trainees to compete in the IR 4.0 workplace is providing them with digital literacy and technology-based skills (Kenayathulla, 2021). The purpose of this training is to provide them with the skills that allow them to succeed in the technology-driven workplace that Industry 4.0 will bring about. Enhancing professional teaching practices and supporting educators with innovative instructional tools have also been identified as critical priorities for meeting industry standards (Balyer & Öz, 2018).

The mass development of technical improvements based upon IR 4.0 has penetrated the workplace, allowing businesses at present to search for new ways of generating alternative value through automation and digitalisation. According to Madsen (2019), there is an increasing trend toward fostering the evolution of digital ecosystems and facilitating broad customer participation. These changes have created demand for a skilled workforce that is knowledgeable in IR 4.0 technologies such as robotics, Artificial Intelligence (AI) and Internet of Things (IoT) particularly in manufacturing, service industries and logistics. To align with this demand, the inclusion of new technology in the processes of education became an important part of the modern education ecosystem (Liangyu et al., 2024). Incorporating elements of hypermedia and multimedia in the curriculum of TVET could improve the academic performance of trainees, an aspect of teaching that must be enhanced (Abd Majid et al., 2025; Al-ansi et al., 2023; Mohd Jamil et al., 2024)

Mobile Augmented Reality in Education

Through the utilisation of Mobile Augmented Reality in Education (MAR), trainees can understand and thoroughly master complex operations without putting themselves in any risk (Radu et al., 2023). The potential for Mobile Augmented Reality (MAR) application in engineering education is enormous. The authors noted that recent advances in technology have increased the accessibility and motivational potential of AR via mobile devices (Patricio et al., 2019). The common devices used for experiencing MAR are smartphones (Lim et al., 2019). However, it is significant to recognise that the practicality of incorporating cameras directly into the AR applications of MAR leads to increased power consumption, unlike desktop AR (Chen et al., 2018).

MAR has been identified as a successful approach to improving trainees' motivation to participate in academic practice (Bacca et al., 2018). The gap identified in current educational practices by (Anderson et al., (2024) presents an opportunity for further research on the integration of Augmented Reality (AR) into the education sector. According to (Upadhyay et al., (2024) AR system is specifically necessary to enhance the learning and training experience of undergraduate trainees.

Learning Experience using Mobile Augmented Reality

A learning experience is defined as learners' cognitive, behavioural, and emotional involvement in learning within instructional activities, tasks, and environments (Halverson & Graham, 2019; Wang et al., 2018). An AR-enhanced learning allows, learners to experience more engagement, more task efficiency, more emotional engagement, more focussed realism, and more satisfaction providing a compelling pedagogy value (Wang et al., 2018).

It has been concurred that the use of MAR in education can lead to trainees' engagement, boost their morale, increase performance, enhance comprehension and be able to execute task effectively. This leads to a more impactful learning experience (Ciloglu & Berk, 2023; Frederick Bulagang & Baharum, 2017; Negi, 2024). According to Frederick Bulagang and Baharum, (2017) mobile learning is a process of learning with mobile or wireless devices, which are capable of mobility. Mobile learning is the outgrowth of e-learning, as mobile devices have become more popular. AR, on the other hand integrates real-life environment with digital elements. It is applied in education through AR devices such as smartphones or tablets, which can run AR applications.

Previous studies have highlighted that MAR can be beneficial for education by improving perceived learning, perceived satisfaction, and perceived self-efficacy, especially in higher education (Negi, 2024). In addition to all the benefits discussed, existing studies have proven the effectiveness of AR-based tools in technical fields like Computer Science (Alzahrani, 2025) where AR has been utilised to enhance learning experience and served as strong evaluation platform for outcomes. Building on these findings, this study investigates the integration of MAR within the TVET context to address specific challenges in skill-based education, emphasising its role in improving trainee engagement and learning efficiency.

Augmented Reality in TVET Education

Just as the internet and smartphones changed the way we interacted and learned over the past ten years, virtual technologies, including Virtual Reality (VR) and AR, are transforming the way people connect and gain knowledge (Cao & Yu, 2023). Now, with low-cost headsets and mobile devices, students can engage in immersive experiences that can aid learning at primary to higher education levels, including TVET. These applications facilitate interactivity and hands-on participation, allowing the trainee to make decisions, interact with each other, and to obtain feedback, which inspires learning through analysis and reflection (Alzahrani, 2025). An AR application was found to have the capability to increase students' engagement (Lampropoulos et al., 2022). As a result, AR may be employed as a powerful tool in higher education for mobile learning (Cabero-Almenara et al., 2019). Building on this foundation, this study explores the integration of AR to enhance engagement and learning outcomes in TVET.

This paper presents the Mobile Augmented Reality for TVET (mART), a new AR-based educational mobile platform for TVET trainees. Besides, mART has been integrated into the TVET and provide a special and gamified space for trainees to learn how to programme microcontrollers and assemble circuits. Established models such as the Technology Acceptance model (TAM) and the ARCS (Attention, Relevance, Confidence, Satisfaction) model were used to determine the trainee's level of engagement, motivation, and satisfaction upon using the mART apps.

The research aimed to design an AR-aided instruction tool on TVET curriculum in skill-based training that enhances the practical skills of trainees. The AR tool was implemented as an aide to traditional teaching and was tested for its effectiveness compared with conventional teaching tools using measured data in terms of learner performance, retained knowledge, and learner participation. Moreover, the research also attempts to investigate user engagement with and acceptance of mART through established theories of Technology Acceptance Model (TAM) and the Attention, Relevance, Confidence, and Satisfaction (ARCS) model, which is designed to guarantee the relevance and usability of mART and its prospective adoption in real educational settings.

MATERIALS AND METHODS

The methodology of this study was structured into four systematic phases: content development, AR instructional tool design and development, instructional efficiency evaluation, and expert validation. This structure was guided by established instructional design frameworks such as the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) (Othman et al., 2019). The Design-Based Research (DBR) approach used in this study emphasises iterative, real-world development and testing of educational tools (Spector, 2011).

The process began with the analysis of the Basic Microcontroller curriculum and the development of instructional content and storyboard tailored for TVET trainees in the Telecommunication Programme. Subsequently, the mART application was developed using Unity 3D and Vuforia, embedding key microcontroller concepts into an interactive MAR environment. Evaluation was conducted through structured questionnaires to assess the tool's usability, learning engagement, and effectiveness. Finally, expert feedback from TVET trainers was gathered to validate the pedagogical and technical reliability of the AR-based instructional tool. This methodology offers a structured yet flexible framework for the integration of MAR in enhancing microcontroller education in TVET settings.

Research Framework and Overall Methodology

The development process of content and storyboard creation starts with constructing content, followed by a storyboard for the Basic Microcontroller module. This involved

pre-mapping the interactive components with teaching and learning materials. The referencing was based on the Written Instructional Manual, which serves as a guide for TVET teaching and learning in technical studies. The mART Instructional Tool was created by developing a mobile AR application including 3D modelling, AR environment design for integrating educational content into an interactive AR learning experience using Unity 3D application and C# scripting. The effectiveness of the AR application was assessed with experiments where conventional teaching methodology was compared against the teaching methodology using AR as part of the teaching and learning process. Questionnaires were distributed, and data were collected using the Instructional Materials Motivation Survey (IMMS) (Bacca et al., 2018) and the Technology Acceptance Model (TAM) (Elshafey et al., 2020).

Design and Content Development Strategy

The Basic Microcontroller module was developed in a MAR environment to help trainees in visualising and assembling microcontroller circuits. The design process began with identifying key learning components from the existing curriculum, followed by creating 3D models of microcontroller parts for integration into the MAR environment. This new method was designed to create an interactive training environment, probing trainees to see, touch and manipulate components of the microcontroller in a virtual environment. The AR model effectively connected the theoretical lessons with practical applications, enabling trainees to interact with virtual components in a way that mirrors real lab work.

Based on the Written Instructional Manual (WIM) of the Basic Microcontroller module, the mART pedagogical design was applied in three parts which is understanding the function of components in the microcontroller module, perform programming, and finally testing of assembled circuits. The Subject Matter Expert (SME) validated the types of components and circuits to be used in the kit to ensure its relevance to the TVET syllabus. Using a step-by-step flowchart, content was written and storyboarded before converting it to the AR format. The Unity 3D programming and the Vuforia AR engine were used for programming and real-time interactivity. Blender was used as shown in Figure 1 to model these hardware components.

The Substance Painter was applied to texture the 3D assets as in Figure 2. This step is to mimic real-life training setups with breadboards, LEDs, resistors, and Arduino Uno boards. By doing this, the final AR environment was able to be as close to real practical situation as possible which truly merged the theoretical training received and provided practical training in AR.

The mART application consisted of two main mART interface modes which is, "Learn" and "Test". In the "Learn" mode, trainees followed a structured path where they could identify microcontroller components, learn about the Integrated Development Environment
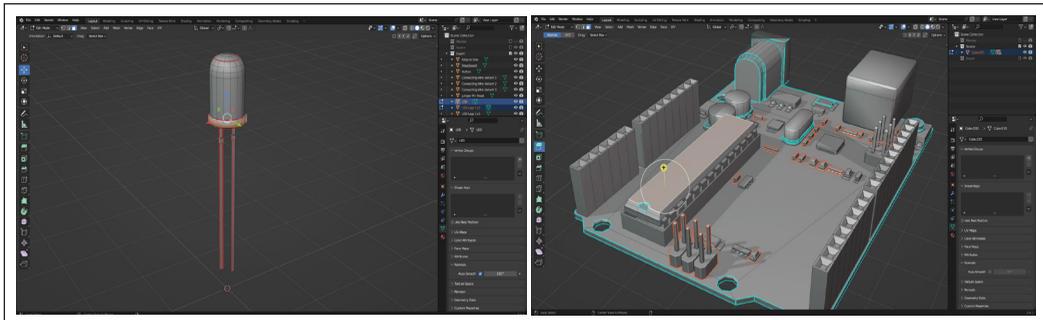
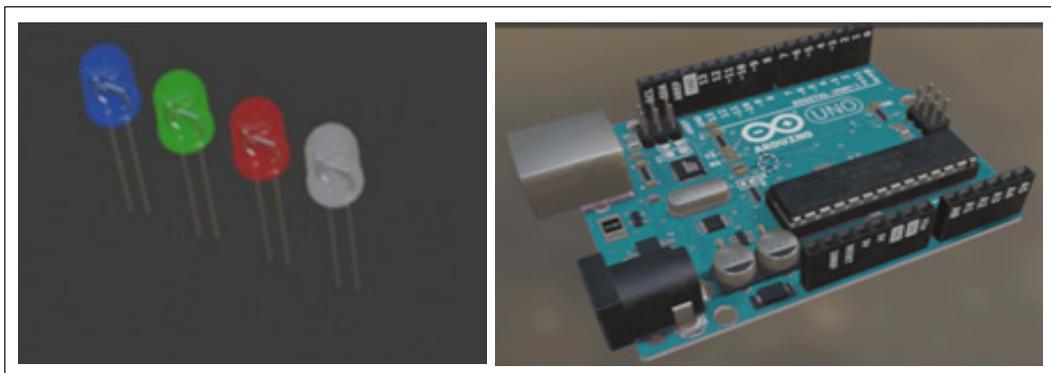*Figure 1.* 3D assets of the LED and Arduino Uno board using Blender

Figure 2. 3D models of the LEDs and Arduino Uno board using Substance Painter

(IDE) which is a software platform used to write, compile, and upload microcontroller programmes and then proceed to assemble their circuits through interactive, step-by-step instructions. Introducing the IDE at this stage allowed trainees to link hardware assembly with coding logic. This course had augmented segments included that provided a holistic view about the hardware and programming aspects of the microcontroller. Additionally, the "Test" mode prompted trainees to utilise their newly formed knowledge by assembling the circuit on their own. This mode graded their performance with a star rating system and detailed feedback, which allowed trainees to identify weaknesses, and reinforced their practical skills through repetition.

Development of Mobile Augmented Reality Instructional Tool

Unity 3D was selected as the primary development platform for the mART application design, leveraging its robust capabilities for customisationthrough C# scripting and the integration of the Vuforia Engine to enable AR functionality. Usability testing of the mART application was conducted following ISO 9241-11 (Negi, 2024) standards to ensure user-friendliness and accessibility.

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For the creation of 3D models and the AR environment, custom blender 3D was used in collaboration with unity 3D for accurate and realistic AR environments. In this research, the Arduino Uno R3 and its related components were modelled in Blender, and high-res textures were applied using Substance Painter for realistic detail. The detailed models were tested iteratively within Unity 3D for realism and interactive and functionality, ensuring they worked within the AR application. This approach, along with realistic textures and interactive elements, emulated real-world training environments and substantially enhanced the usefulness of the application as a teaching device.

This new educational tool combines 3D models, guided instructional elements, and interactive components to facilitate the learning of both, the microcontroller parts and the way to assemble its circuit. The tool interacted with the trainees' knowledge base in a way that made learning fun while also helping with understanding of both theory and a hands-on learning experience. The application was developed for Android devices, taking advantage of the ubiquity of the Android platform amongst TVET trainees, allowing mART to be accessible and usable amongst the trainees.

Usability Testing

The usability evaluation of the mART application followed the ISO 9241-11 guidelines to ensure a user-friendly and accessible application is developed. The feedback from the Subject Matter Expert (SME) was on interactive components, such as button sensitivity and labelling. The feedback was used to simplify the interface to make navigation easier. 3D models of components, such as the Arduino Uno and the breadboard, were prototyped and retested to get a realistic result. Highly realistic textures and interactive elements sought to provide a real-world learning environment and further increase the application's usability.

Table 1 summarises the key observations and recommendations provided by the experts during development. These insights served as a critical reference in refining interface elements, improving interaction flow, and resolving usability issues. Following the incorporation of these improvements, the application underwent thorough testing, which confirmed enhanced performance, improved user satisfaction, and smoother task execution.

Upon SME approval, the final version of the mART application was deemed ready for deployment and was made accessible to TVET trainees. Figure 3 shows a comparison between the initial and enhanced mART user interface. The revised design features enlarged USB cable and breadboard buttons to improve touch sensitivity and overall usability. Revisions were made based on feedback from the SME, enhancing both the circuit diagramme and programming sections in the final mART output.

Table 1

Functionality and usability test results of mART by SME

| Dimension	No.	Evaluation Question	Trainer Feedback	Revision based on Feedback
Effectiveness	1	Is it easy for the user to interact with the augmented components?	The augmented features facilitate user interaction.	None.
	2	Is it simple to use the "Learn," "Test," "Quit" and other UI buttons?	1. USB cable and wire indicators are not sensitive. 2. Arduino IDE video lacks forward/rewind option.	1. UI button sizes (USB cable and breadboard) enlarged. 2. Horizontal scrollbar added via Unity3D (UI > scrollbar).
Satisfaction	1	Is there a good variety of ways to engage with the system?	Drag and drop features are interesting.	None.
	2	Have your teaching and learning needs been met by the proposed mART application?	1. Content aligns with the syllabus. 2. Labelling helps new learners.	1. No changes to content. 2. Labels added to LED, breadboard, and Arduino board.
	3	Are you satisfied with the mobility of interactive components and circuit assembly?	There is freedom of movement.	None.
Efficiency	1	Do virtual objects load quickly enough?	Yes, about 2–3 seconds.	None.
	2	How hard is it for first-time users to learn the mART application?	User-friendly and easy to operate.	None.
	3	Does the camera/sensor detect the marker and allow component movement?	Excellent marker detection.	None.
	4	Is it clear what the user is supposed to do?	Step-by-step guidance is useful.	None.
	5	Are there hardware/environmental requirements?	User must print the marker.	Suggested marker less option for future improvement.
	6	Do all circuits function correctly?	Output is accurate; LEDs blink correctly.	None. Bugs fixed in earlier stage.
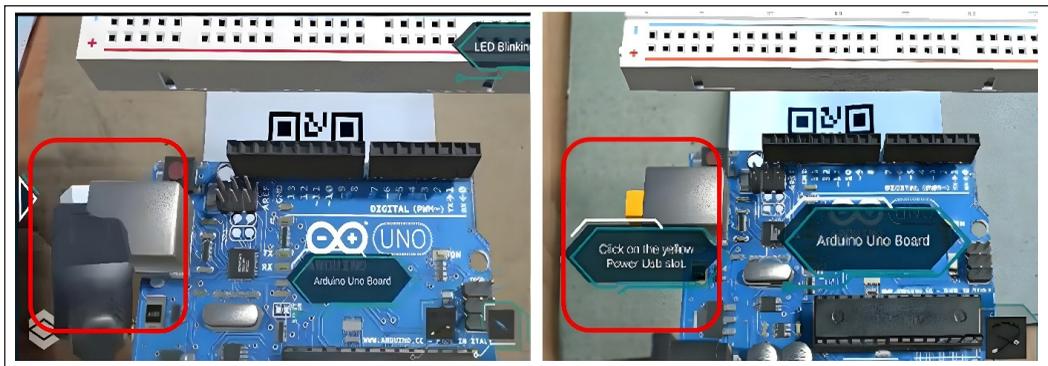
Figure 3. Comparison between initial USB cable slot and enhanced mART USB cable with indicator buttons to improve touch sensitivity and usability

Experimental Design

The experimental design aimed to compare performance between traditional Virtual Learning Environment (VLE) users and mART users. The control cohort utilised the VLE approach (Group A), while the experimental cohort engaged with mART (Group B) for 6 months. Figure 4 illustrates the experimental design framework adopted for the mART study, which outlines the overall research process from participant recruitment to data analysis.

The framework demonstrates the systematic procedure undertaken to compare the effectiveness of the traditional Virtual Learning Environment (VLE) and the developed mobile Augmented Reality for TVET (mART) application in enhancing learning outcomes among TVET trainees. Written informed consent was obtained, and trainers attended participants' coordination meetings to facilitate implementation.

All trainees followed the same syllabus with Basic Microcontroller module content and were compared during a final examination that served to contrast the learning outcomes of the two groups. The study involved 37 Level 3 Malaysian Skill Training (SKM) trainees. Although the number of participants differed slightly between cohorts (18 in the control cohort and 19 in the experimental cohort), stratified random assignment was employed to ensure baseline equivalence. A pre-test analysis confirmed no statistically significant difference in initial competency levels between the two cohorts ($p > 0.05$), thereby supporting the validity of the comparative outcome analysis.

Group A, which is the control cohort, was exposed to theoretical exposure of the Basic Microcontroller module, followed by the conventional practical experiment and the virtual learning environment. The online assignment contains YouTube videos and website resources. Whereas Group B trainees from the experimental cohort were exposed to theoretical exposure of the Basic Microcontroller module, followed by the
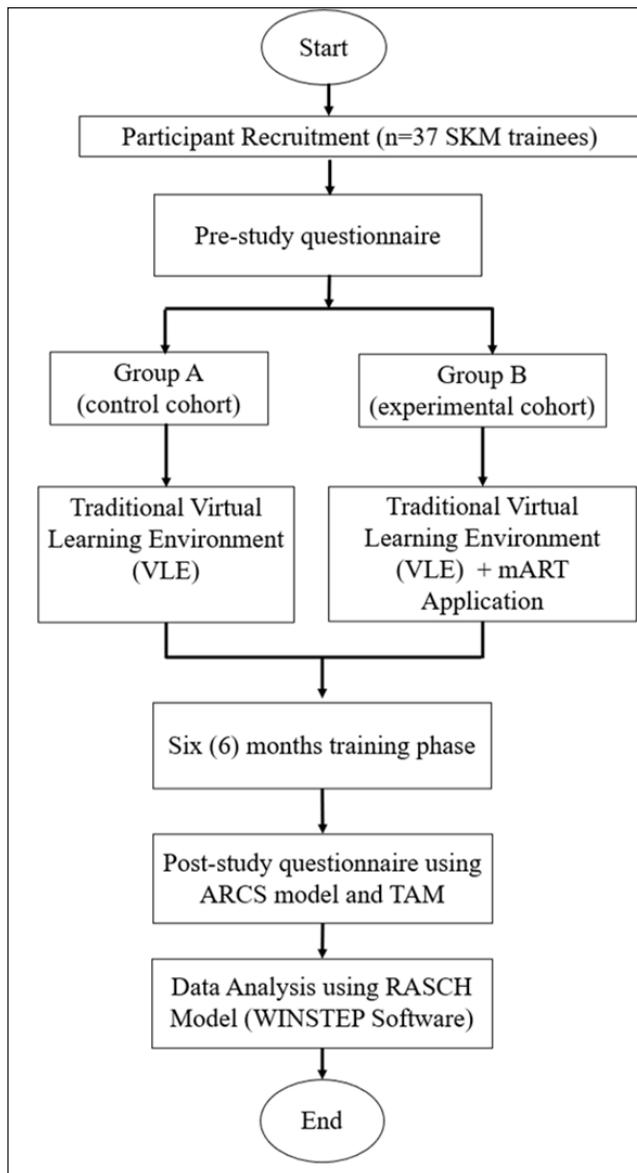
Figure 4. The experimental design framework adopted for the mART study

conventional practical experiment and added on with training using the developed mART application.

Applications, such as Vysor, were used to project the mART interface on laptops, thus, enabling the demo and easing the process of training the trainees on the installation and setting up procedure for mART as an educational tool. Attitudes and motivation of trainees were measured with a pre-study and a post-study questionnaire. Background

Figure 5. Group B trainees from the experimental cohort engaged in Basic Microcontroller module training using the developed mART application

data on prior AR experience, comfort with technology and expectations of the mART application of the trainees were obtained through a pre-study questionnaire. Like pre-study assessments, post-study assessments were conducted to identify changes in attitudes and motivation because of using the mART instructional tool.

The data collected through the experiment was analysed using Rasch model with WINSTEP software. This is done to determine the level of effectiveness of this study towards the attitude and motivation of the trainee. Figure 5 illustrates the trainees from Group B (experimental cohort) actively engaging with the developed mART application during the Basic Microcontroller module training sessions. The integration of this mobile Augmented Reality tool provided a more immersive and interactive learning experience, allowing trainees to visualise circuit components and assembly processes in real time.

Engagement and Acceptance Analysis using ARCS and TAM models

Established models were used to evaluate trainees' involvement and acceptance of the mART applications. The models that the study used are ARCS Model (Attention, Relevance, Confidence, Satisfaction), which is used to measure the study of motivation and engagement

of the trainees during learning and Technology Acceptance Model (TAM), which is used to measure perceived usefulness, ease of use and intention to use mART continuously. These models offered valuable insights into trainees' learning experiences and highlighted areas of strength and potential improvement for the AR platform.

RESULTS

The mART instructional tool is a virtual learning environment for learning of technical skill training, it includes eight (8) microcontroller components, and four (4) circuit assemblies. The mART instructional tool is an application which is built with AR technology using an Android platform. mART is built to support the TVET curriculum. It has a user-friendly interface and interactive AR and is suitable for the trainees of telecommunications department. This AR environment promotes active learning by allowing trainees to engage in real-time coding and virtual circuit assembly.

Practical Application of mART

The validation process for the mART application focussed on the analysis of which components would be suitable for conversion to AR. The components that were assessed included the breadboard, USB cable, LED, Arduino Uno board, push button, resistor, and connecting wires. Additionally, a video recording of the Arduino Integrated Development Environment (IDE). Subject matter experts (SMEs) reviewed these components and unanimously agreed on eight components for AR conversion, with a 100% agreement score, indicating full endorsement by the ten SMEs. On the other hand, components such as the sensor, motor, capacitor, transistor, and relay were not taken into consideration due to their limited selection by the experts. As a result, this validation reinforces the quality-oriented selection of AR modules following consensus of expert opinion.

It is crucial to address scenarios where none of the components achieve unanimous acceptance. In such instances, the decision-making process was guided by a majority consensus model. For example, components with greater than or equal to 70% agreement (7 out of 10 SMEs) may be suitable for submitting for inclusion in the mART application. This approach ensures substantial expert support while acknowledging that unanimity may not always be possible. The components that significantly enhance the learning experience, align directly with the curriculum, and are feasible to implement within the AR environment were prioritised. Time and logistical constraints influenced the number of SMEs consulted, highlighting the importance of efficient expert engagement in the validation process. This process also highlights the need for flexible decision-making thresholds and the importance of comprehensive expert inputs in educational technology development.

The LED flashing circuit, the running light circuit, the push-to-activate running light circuit, and the traffic light circuit were the four distinct types of circuits that were

Table 2

Evaluations and remarks following each exam

Marks	Comments
0	Circuit does not function & did not follow instructions.
50	The circuit functions and complete but the delays are not right.
50	The circuit functions but did not follow the right sequence.
50	The circuit functions but missing some components.
50	The circuit functions but does not follow the instructions.
100	The circuit functions and follows instructions.

chosen for this study. As a result of the limited voting capacity of the trainers, the circuits for temperature sensors, digital clocks, keypad connections, and ultrasonic distance measurement were not eligible for selection. To pick the circuit schematics, several criteria were taken into consideration, with the primary focuss being placed on the operational directives that are associated with the circuits.

The field of Telecommunication engineering has placed a significant amount of attention on the development of circuits that are not only functional but also user-friendly. A foundational understanding of microcontrollers is achieved by studying basic circuits before progressing to more complex concepts. The integration of coaching, collaboration, reflection, and motivation was systematically incorporated into the learning process through the mART instructional tool to enhance engagement and knowledge acquisition.

The trainee's work was assessed and recognised using a star rating segment. The assessment of marks is determined by calculating the mean of the cumulative scores that trainees have obtained for each question completed. If a learner provides an incorrect response, the application assigns a lower star rating to assess their overall performance in the programme. The mART instructional tool provides feedback as shown in Table 2, to help the learner rectify their errors and enhance their level of understanding.

Android is preferred by trainees of technical vocational education and training (TVET) over Apple's iOS due to its cost-effectiveness, extensive feature set, adaptability, and user-friendly design. It is important to note that Android users have access to the Quick Settings panel, which enables fast customisation. Figure 6 depicts the outcome of the investigation. The Android platform dominates as the preferred choice among trainees, with 83% selecting Android compared to only 17% who prefer alternative options.

The mART was developed for Android operating system users. The emphasis on Android development also ensures that the platform is easily accessible and functional for most users, aligning with the widespread adoption of these devices among the TVET trainees. Through such customisation of the application for this operating system, the
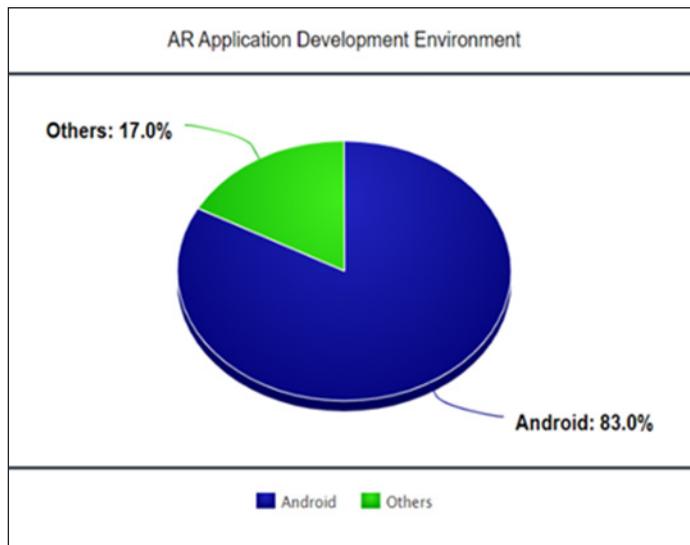
Figure 6. Preference of trainees to use Android for AR applications compared to other applications

development that follows aims at maximising users' experience and benefiting from Android technology being widely dispersed among the target audience of TVET trainees.

The decision to focuss on Android users is strategic, considering the widespread use of Android devices among the target audience in the TVET sector. This intentional design adaptation reflects a commitment to inclusivity, ensuring the mART platform can reach a wider group of users. The mART application seeks to enhance availability, affordability and ease of use in a bid to assist TVET trainees.

Mobile Augmented Reality for TVET

The AR interactive environment was created using Unity 3D with Vuforia Engine integration. The AR application was designed to fulfil a set of desirable requirements. The role of the user interface was to provide options for learning, options for testing what has been learned, and the option to quit the application. Upon completion of the programme's development, trainees were introduced to the three core parts of the User Interface (UI). A representation of the design and purpose of the main user interface (UI) for the mART programme, which was developed in Unity 3D together with the specific mART modules, is displayed in Figure 7.

The "learn" icon allows users access to an introductory module on the introduction of components and circuit assembly, and the "test" symbol allows users to assess their understanding through tests that follow the courses delivered. The purpose of the "quit" icon is used to terminate the application. The research incorporated interactivity as a key aspect, which was accomplished by using Unity 3D as the primary engine. This enabled the 3D objects and movies to be integrated.
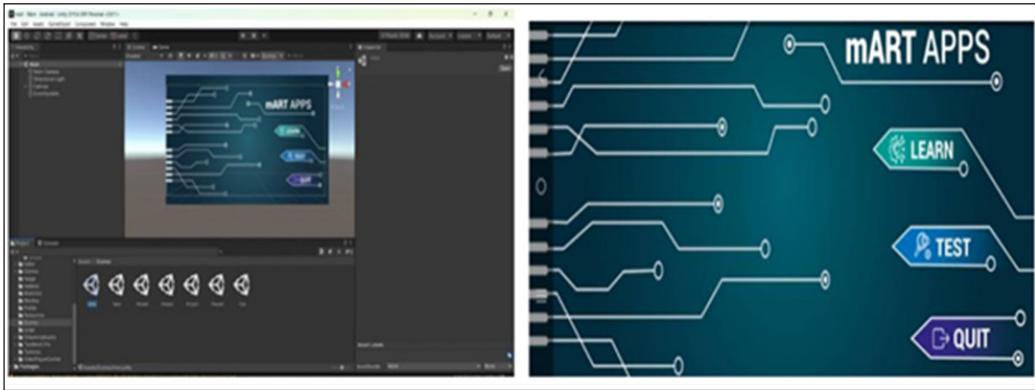
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Figure 7. User interface for mART

The Unity 3D is a flexible and user-friendly platform, which is adopted in the development of different applications. With the ease of deployment on smartphones, Unity 3D becomes a good tool for efficient programme distribution, and the extensive documentation and C# scripting support ensure its practicality for developers. The availability of a free personal-use version further broadens its accessibility, particularly for beginners, enabling them to utilise its intuitive drag-and-drop features for streamlined development. Moreover, a dynamic and supportive developer community surrounding the platform contributes significantly to its utility and attractiveness in development environments by offering vital resources and guidance.

mART's design enables real-time assistance for all the modules, providing a guided approach. For example, they follow theoretical working instructions on the individual components of the drive to achieve practical skills by learning the placement of the parts and settings for the programming mode. For instance, the "Running Light" circuit in Figure 8 illustrates how programming modes affect the circuit, linking the theory to practice.
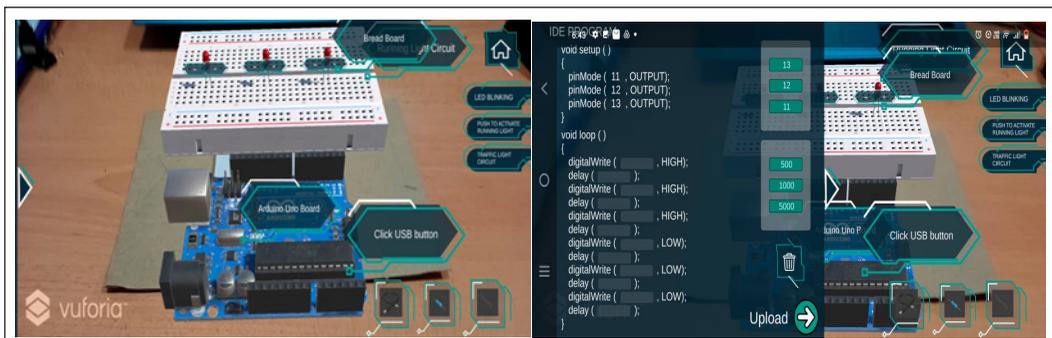

Figure 8. Running light circuit

Functionality and Usability Assessment of mART

Functionality and usability testing are key components in the development of mART application, focussing on how real users interact with the application to perform specific tasks. These tests are important for identifying the challenges or difficulties that trainees, as the end users, may face, thereby ensuring a user-friendly experience for trainees. Google Meet discussions with subject matter experts were held to review the functionality and usability of the mART application.

These iterative refinements were essential to ensure the effectiveness of mART application in delivering TVET content through AR satisfactorily. Constant usability testing and iterative improvements were done to uphold the application's effectiveness and ensure that it complies with user satisfaction. By addressing the inputs received and upgrading the application thoroughly, mART tool offered improved features, which provided the trainees with an excellent learning environment. This iterative process enabled the app to be developed according to the high standards of educational applications, hence enhancing the quality of the learning experience for TVET trainees on mobile devices.

Prior to reviewing the mART application, the subject matter experts were introduced to the process of installing the mART application. A functionality and usability checklist was developed, which adhered to the new application assessment criteria. Feedback related to the functionality and usability of mART apps from experts was compiled using the checklist after using the mART application on mobile devices. Feedback from the functionality and usability checklist provided valuable information to identify and resolve problems with the mART application. The performance, user satisfaction, and overall efficiency of the mART application were extensively evaluated and validated due to the implementation of essential changes and improvements to the application.

Based on the evaluation by the subject matter expert, the numerical data from the assessment results of functionality and usability testing of the mART application are shown in Table 3. Overall, the data show that a total of thirteen (13) feedback points regarding the functionality and usability of the application use case. The results show that nine (9) out of thirteen (13) feedback points represented by sixty-nine per cent (69%) were positive, which indicates that the subject matter experts found it all good. These positive reviews

Table 3

Numerical data for functionality and usability test of mART instructional tool

Data representation	Positive feedback	Revisions Required
Effectiveness	33% (1 out of 3)	67% (2 out of 3)
Satisfaction	75% (3 out of 4)	25% (1 out of 4)
Efficiency	83% (5 out of 6)	17% (1 out of 6)
Total	**69% (9 out of 13)**	**31% (4 out of 13)**

highlight the strengths of mART in usability and functionality. However, four (4) feedback points representing thirty-one per cent (31%) highlighted areas requiring revisions. These areas of improvement were important to address for enhancing the overall effectiveness and user experience of the mART application.

This detailed numerical model reveals how experts perceive mART application and serves as a platform to enhance mART application. By addressing the identified areas for improvement, the development team ensured that the application meets the standards necessary for an effective instructional tool, eventually contributing to a more engaging and user-friendly learning environment for TVET trainees. The final modified version of the mART application was prepared for deployment and released to TVET trainees following approval by subject matter experts. The development of the mART application is aligned with the instructional principles as described in the Written Instructional Manual (WIM). Figure 9 provides a visualisation of the final prototype of the mART instructional tool with components modified as recommended by the trainers for solving the problems identified during testing sessions.

Figure 9. A WIM-based mobile augmented reality for TVET (mART) instructional tool

Thus, the improvements made to the circuit diagramme and programming section have resulted in the refined instructional tool now identified as mART. Each of these improvements represents efforts to optimise the usability and effectiveness of the mART instructional tool. The developers have aimed to create a more accessible and user-friendly experience for learners involved in TVET by focussing more on the circuit diagram and programming aspects. mART is also attractive because its design focusses on the intersection of mobile technology with AR, emphasising its application within the educational context, particularly for TVET.

Item Reliability Analysis using the Rasch Model

A questionnaire was distributed to thirty-seven (37) trainees, consisting of twenty questions, and the administered questionnaire was analysed based on the Rasch model calculation of infit and outfit statistics to assess reliability using Winstep. According to Hidayat et al., (2023), a person reliability value above 0.90 was interpreted as "very good," indicating a high level of internal consistency. Similarly, an item reliability value ranging from 0.80 to 0.90 is considered "good," and indicates a reliable measurement of item difficulty. The item reliability values are further classified as:

i. Above 0.94: "Excellent"

ii. Between 0.91 and 0.94: "Very good"

iii. Between 0.81 and 0.90: "Good"

iv. Between 0.67 and 0.80: "Adequate"

v. Below 0.67: "Poor"

In this study, the person reliability value of 0.96 represents "very good" reliability, supporting strong internal consistency among trainees. The item reliability value of 0.80 is classified as "good," reflecting a reliable measurement of item difficulty. The high person reliability value of 0.96 signifies strong internal consistency among the trainees, while the item reliability value of 0.80 confirms that the items used in the study are reliable and suitable for assessing the targeted competencies. These reliability metrics substantiate the effectiveness and dependability of the mART application in enhancing the learning experience for TVET trainees as illustrated in Figure 10.

Figure 10. Rasch model calculation of infit and outfit statistics using Winstep

Calculation of scores for 'A,' 'R,' 'C,' and 'S':

The provided data Table 4 contains the Point Measure Correlation (PTMEA CORR) values for 20 items, each assigned to one of the ARCS components. To determine the quality of the reliability values, the PTMEA CORR values for each component was summed, and the average was calculated to compare their scores.

Table 4
Average PTMEA CORR values by component

Component	Item Numbers	PTMEA CORR Values	Sum of PTMEA CORR	Average PTMEA CORR	Rank
Attention (A)	1, 2, 3, 4, 5	0.90, 0.87, 0.88, 0.90, 0.90	4.45	0.890	2
Relevance (R)	6, 8, 9, 12, 13	0.88, 0.87, 0.91, 0.89, 0.89	4.44	0.888	3
Confidence (C)	7, 10, 11, 14, 15	0.86, 0.84, 0.91, 0.82, 0.83	4.26	0.852	4
Satisfaction (S)	16, 17, 18, 19, 20	0.86, 0.91, 0.92, 0.91, 0.89	4.49	0.898	1

The average PTMEA CORR values for each component are ranked as follows:

1. Satisfaction (S): 0.898

2. Attention (A): 0.890

3. Relevance (R): 0.888

4. Confidence (C): 0.852

It becomes evident that the Satisfaction component of mART receives the highest score with an average PTMEA CORR value of 0.898. This suggests that trainees generally express contentment with the application's features and find it particularly enjoyable to use. The high satisfaction rating implies that mART effectively meets the expectations and preferences of the trainees, aligning with their needs and preferences. Table 5 shows the twenty items that was evaluated.

Table 5
Twenty items evaluated

No.	Questions
1.	Something was interesting in the mART application that caught my attention.
2.	The 3D images, video and graphics that I have been exposed to through mART application were very attractive.
3.	The manner of organising the information in mART helped me keep my attention.
4.	I believe that the mART application makes learning more interesting by being more engaged.
5.	The quantity of repetition of exercises in mART increased my understanding.

Table 5 *(Continued)*

No.	Questions
6.	I find the mART application has been useful for learning Basic Microcontroller module.
7.	The content and information in mART application made it easier to study the Basic Microcontroller module.
8.	I would like to use the mART application frequently to learn Basic Microcontroller module.
9.	I was able to relate the content of the mART application to previously learned lessons.
10.	The mART application was an excellent tool for learning about Basic Microcontroller.
11.	It was easy to explore and become skillful in using the mART application as it is user friendly.
12.	I think the mART application was fun because it allows us to learn while playing.
13.	After working on this mART application for some time, I was sure that I would be able to complete exercises related to the Basic Microcontroller module.
14.	The mART application makes learning more enjoyable with interactive functions.
15.	The good organisationof the lessons helped me to be sure that I would learn the module.
16.	Completing the exercises provided in mART application gave me a sense of achievement.
17.	I have enjoyed studying and doing exercises using mART application so much that I would like to keep on using it.
18.	Using the mART application was fun.
19.	I felt good to complete the exercises successfully.
20.	It was a pleasure to work with such well-designed augmented reality application.

Analysis of User Experience and Acceptance through ARCS and TAM Model

The exam results reveal a significant performance difference, with Group B (using mART) scoring an average of 87.87% compared to Group A (using VLE) at 63.00%. This shows a 39.48% improvement. These results highlight mART's effectiveness in bridging theory and practical experience, demonstrating a substantial performance advantage of using mART over conventional methods.

The trainees' experience with the mART application was assessed using Keller's Instructional Materials Motivational Survey (IMMS), which includes the Attention, Relevance, Confidence, and Satisfaction (ARCS) model. The highest scores were related to the satisfaction component, reflecting a very positive impression from the trainees. The average PTMEA CORR per component was calculated, and the satisfaction component obtained the highest average PTMEA CORR, suggesting that trainees were very comfortable with the application's features and found it particularly enjoyable to use.

The average PTMEA CORR values for each component in descending order:

1. Satisfaction (S): 0.898

2. Attention (A): 0.890

3. Relevance (R): 0.888

4. Confidence (C): 0.852

With an average PTMEA CORR of 0.898, the Satisfaction component ranks the highest, indicating that trainees generally express significant contentment with the mART application's features and find it particularly enjoyable to use. Such a high satisfaction rate indicates that the mART application is suitable for trainees and meets the expectations of the trainees, aligning well with their needs. This high satisfaction score is due to, among other things, the ease of use, interactivity and practical benefits that mART brings in the training process. By ensuring that the application addresses the users' needs and expectations. The Satisfaction aspect greatly enhances the success and acceptability of mART application among TVET trainees because it assures that the application meets the needs and expectations of the users.

Based on the ARCS survey model, a few implications with respect to the mART application can be derived. Trainees reported that AR activities significantly improved their understanding of the Basic Microcontroller module, thereby highlighting the educational potential of AR technology. The mART application offers an interactive and immersive learning experience through its unique features, which include the interactive experience, gamified training process on how to to assemble a circuit, and an evaluation system with a star rating. These elements contribute significantly play a role in their in-class engagement, contributing to creating a better learning environment. In addition, the introduction of AR technology in Technical Vocational Education and Training (TVET) has been demonstrated to be able to enhance trainees' performance, indicating that innovative educational tools can effectively support teaching and learning process in TVET.

Technology acceptance model (TAM) was also used to assess trainees' perception of the mART application. The survey data was analysed through R statistical analysis to examine the perceived usefulness, perceived ease of use, intention to use, attitude towards use, perceived enjoyment, behavioural intention, and usage behaviour of the mART application. Strong positive correlation outcomes show the higher degree of relationship that exists between motivational factors and technology adoption, and this confirms the positive influence of mART towards enhancing motivational level and user acceptance.

PTMEA CORR calculations per each of the Technology Acceptance Model (TAM) and TAM2 constructs show that users believe positively in the mART application. The Perceived Usefulness (PU) of the application shows an average of 0.884, which suggests that users find the application substantially useful. The Perceived Ease of Use (PEU) had a mean of 0.880; this indicates that users find the application easy to use. The average of Perceived Enjoyment (PE) is 0.886, which refers to the enjoyment of an application that the user gets from using it. The Attitude Towards Use (AU) averaged 0.880, reflecting a positive attitude toward using the application. Moreover, the Intention to Use (IU) averaged 0.880, signifying that users were also strongly inclined to continue the usage of the application.

For the mART, the results show strong positive correlations between the ARCS model Testing and the Technology Acceptance Model (TAM), with the correlation coefficients between 0.852 to 0.898 for ARCS model and 0.880 to 0.886 for TAM. The strong
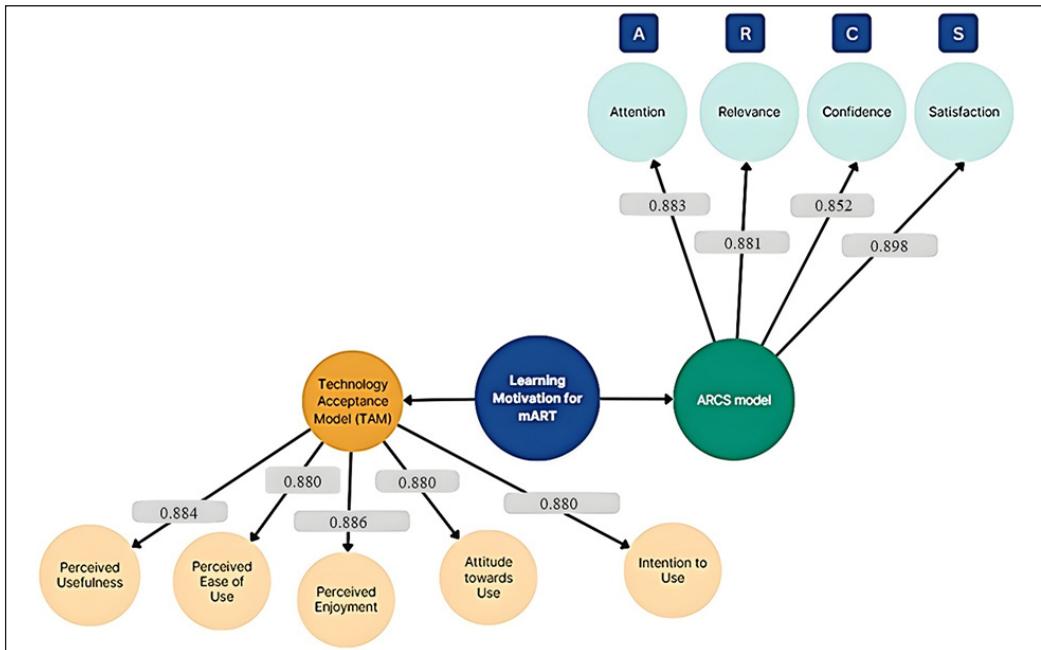
Figure 11. Correlation coefficients for ARCS model and TAM

correlation coefficients imply a strong relationship between motivational components and technology adoption. These findings underscore the promising role of mART concerning user satisfaction and acceptance, indicating its effectiveness as a training tool in TVET environments. The findings show that learning and teaching are enhanced by using AR, and the satisfaction and engagement of the users are increased. Summary of the results of both the ARCS and TAM have been presented in Figure 11.

The ARCS evaluation signals a strong motivation among trainees, with high ratings for satisfaction and attention, affirming mART's capacity to capture and retain trainee interest. These findings align with the results from the TAM which shows that trainees expressed high levels of perceived usefulness and ease of use with mART indicating that it is a valuable tool to aid learning and is enjoyable to use for trainees. The mART application has also shown its applicability to education providers apart from TVET institutions. This framework provides detailed outcomes and impact measures, showing how mART can serve as a replicable model for AR-based skill training in other technical subjects within the TVET curriculum. The survey data shows that there is significant potential for commercialisation, where ninety-seven point four per cent (97.4%) (n=37) of the trainees agreed that the mART application should be integrated into current training programmes. The integration phase examined relationships between various elements of AR adoption, such as design activities, the need for AR, relevant implementation areas, and potential benefits.

DISCUSSION

According to the findings, mART notably improves TVET technical skills training. mART connects theory with practice, leading to greater understanding and enhanced performance of trainees based on engaging and real-time participation. The research has uncovered significant insights by identifying eight distinct microcontroller components and four circuit assembly types, each featuring unique programming modes. The mART instructional tool ensures that the instructional materials cover a wide range of microcontroller elements and circuit configurations, catering to different skill levels that exist in the Telecommunications Programme.

The microcontroller is essential in supporting a wide range of topics in Telecommunication. These features were effectively utilised in the mART platform to support entry-level training comprising introduction to components, circuit diagram assembly and programming. Furthermore, ability of mART to support higher-order tasks, such as virtual assembly of LED blinking circuit, running light circuit, push to activate running light circuit and lastly traffic light circuit together with gamified programming, has increased its possibility of application across the TVET curriculum, showcasing its relevance as a practical skills learning tool.

The incorporation of TAM and ARCS models proves that the application of mART education results in better learning outcomes, increased motivation and satisfaction of the trainees, therefore mART becomes a scalable model for skill-based AR applications in TVET. The mART application increases motivation, satisfaction, and engagement, which have been the limitations of traditional instructional tools by integrating technological capabilities and psychological support. The mART instructional tool has a distinct instructional approach that presents a unique AR adoption approach for TVET education, emphasising enhancing motivation, satisfaction, and engagement. This aspect provides a new, psychologically supportive approach to AR instruction.

The effectiveness of this approach has been confirmed in the research, indicating that it can improve users' engagement with practical e-learning tools. In addition, the mART teaching aid shows how the incorporation of AR into motivational and psychological factors can advance the effectiveness of instructional tools in vocational training, providing a replicable model for future AR educational applications in TVET contexts.

Future research will investigate various methods of storing and managing scores for a trainee, considering both cost and the potential integration of technological advancements. Other options that are currently being researched are content generation, database creation, and utilisationof marker less features via the mART application to deliver a better and more versatile teaching tool for the Telecommunications Programme.

This research seeks to not only address the technical aspects but also the practical considerations of cost and accessibility. The research aims to contribute to the broader goal of fostering effective and inclusive learning experiences in the field of telecommunications.

Although mART application has shown promising results, it still has challenges, including equipment cost and the need to continuously update AR content. AR technology can be applied to all disciplines; future research should focuss on refining AR applications and exploring their broader implementation across various educational fields.

CONCLUSION

Using AR in TVET provides tremendous opportunities for increased engagement and motivation of the students. In conclusion, the mART app demonstrates the applicability and effectiveness of AR in learning contexts; a pedagogical instrument that can be used in TVET and other environments. This example of the mART application shows how AR can engage and drive TVET education to a new level through immersive, interactive learning experiences.

Introduction of mART application in higher educational settings will ensure that the trainees receive better learning opportunities. Introducing instructional tools that maximise user engagement and educational achievements helps the trainees to understand complex ideas better and enhances their interests and skills. The empirical data and user feedback from trainees strongly support the effectiveness of the mART instructional tool in transforming the teaching and learning experience, providing an innovative model for future education.

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