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Virtual Reality Technology in Teaching Computer Hardware: A Prototype and Assessment from User Perspectives

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Abstract **– Computer courses in public schools are typically taught by traditional methods, that involve images and written text explanations. This makes the content of learning materials unclear and hard to understand. Moreover, it is not easy for public schools to equip computer labs with the required devices, as schools have limited budgets. In this paper a protype using VR technology was introduced and assessed in terms of usability, and acceptance. The aim was to provide an interactive virtual learning environment for teaching/learning computer hardware with the most effective method that allow keeping pace with the rapid evolution in this field. The prototype was based on the use of a VR headset to allow the user to explore the internal components of a computer. A test in terms of functionalities and usability was conducted. Results confirmed that the prototype functions were successfully implemented. Subsequent tests on usability proved satisfactory. It is expected that the proposed prototype and study will enrich the teaching methods of public schools with limited budgets - especially for practical and applied courses.**

Keywords **– Virtual Reality, computer hardware, teaching, learning, technology acceptance, usability.**

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1. Introduction

Virtual Reality (VR) is an interactive computer-generated experience taking place within a simulated environment. VR makes it possible to experience anything, anywhere, anytime [1]. This study aimed to use this technology to facilitate teaching approaches with limited resources, and more specifically, for computer education. Teaching computer hardware (HW) components, and inner architectures, is challenging for teachers and students if the required resources are limited. This study aimed to address the resource limitations that public schools face when teaching students computer components. The rapidly evolving computer industry makes it very difficult, and costly, for schools to provide students with direct access to the most recent computer hardware. Computer courses in most public schools are taught solely using books containing images and written text explanations – they lack practical components. Although some schools have computer labs, they still face difficulties providing up-to-date resources and keeping track of new technologies.

The results of a survey, presented later in this paper, showed that traditional approaches to teaching with limited resources makes the content of the learning material unclear and hard to understand. In addition, it does not allow students to explore the internal components of computers, which leads to less engagement and poorer learning. According to learning theories, application and practical practice is crucial to the knowledge acquisition stage of the learning process, and affects subsequent cognition and retention [2].

Consideration of these difficulties and learning needs was the motivation for this study to employ VR technology in teaching computing courses. The features that it provides allows students to explore and interact with computer components in a virtual environment. This aim was inspired by the ability of VR to meet the learning objectives identified by Bloom [2]. A prototype for teaching computer hardware is proposed, and its usability and acceptance assessed, based on the ease of use and usefulness from students' and teachers' perspectives.

The use of VR technology in teaching has been the subject of much research, but, to the author's knowledge, the acceptance of this technology from teachers' and students' perspectives still awaits investigation. To achieve this, the current study conducted an experiment in which a prototype was developed using VR technology and tested on a group of teachers and students in Saudi Arabia. Accordingly, this study aims to answer the following research questions:

- **RQ1**: Does the proposed learning system using VR technology work as expected?
- **RQ2:** Do students accept the usage of VR technology in their learning?
- **RQ3:** To what extent are students satisfied with the ease of use and usefulness of VR technology?

The rest of this paper is organized as follow. Section 2 gives the background to VR technology and its relation to pedagogical theories. Section 3 reviews the literature related to VR and education. Section 4 presents an overview of the feasibility of the current study. Section 5 describes the design and methodology. The results are presented in Section 6, followed by the discussion and conclusion, presented in Section 7.

2. Background

This section provides an overview of the VR technology and its relation to pedagogical theories.

2.1. Virtual Reality

VR enables users to interact with objects and information not physically present in the user environment [3]. Computers are used to create a virtual environment that is experienced by the user in a manner that mimics real physical interaction [1]. The technology employs the principle of immersion which refers to the ability of the user to explore (be immersed in) a virtual world through sensory feedback. The sensations are generated and controlled by computer software while hardware devices, such as VR gloves and head mounted displays (HMDs), feed the sensory input to the user. As Yuan et al. [4] describe, the sensory inputs are generated by sophisticated software that combines the visuospatial information of a virtual world to create real-time sensory inputs to the user that are experienced as if the simulated world was physically present.

2.2. Virtual Reality and Pedagogical Theories

VR technology has been used in teaching for some time and researchers have examined how its use relates to teaching and learning theories and educational objectives.

Bambury in [5] proposed that the development of VR software for educational objectives should maintain the specific skill levels, and learning styles, of the Bloom Taxonomy. This would ensure that the developed software fulfills needs that cannot be met using alternative, more traditional, teaching methods. Consequently, this study aimed to use VR technology as a method for teaching computer hardware components, while achieving the educational objectives identified in the Bloom Taxonomy. An overview of this taxonomy is presented below.

The Bloom Taxonomy

The framework proposed by Bloom [2] places learning objectives within cognitive, affective, and psychomotor hierarchies, based on their complexity and specificity. The 'Cognitive' domain has been the focus of educators' attention for a long time, and has been considered widely in designing educational curriculum for grades Kg-12. Bloom and his colleagues classified the cognitive domain into six hierarchal levels, as presented in Figure (1). 'Remember' is the first level in the pyramid, and concerns students' ability to recall basic concepts and facts. 'Understand' reflects students' ability to explain and discuss concepts, 'Apply' concerns the student's ability to use and demonstrate knowledge in different situations. 'Analyze' reflects students' ability to differentiate, relate and organize ideas. 'Evaluate' reflects students' ability to critically appraise knowledge; and at the top of the pyramid is 'Create' which relates to students' ability to produce new or original work from acquired knowledge.

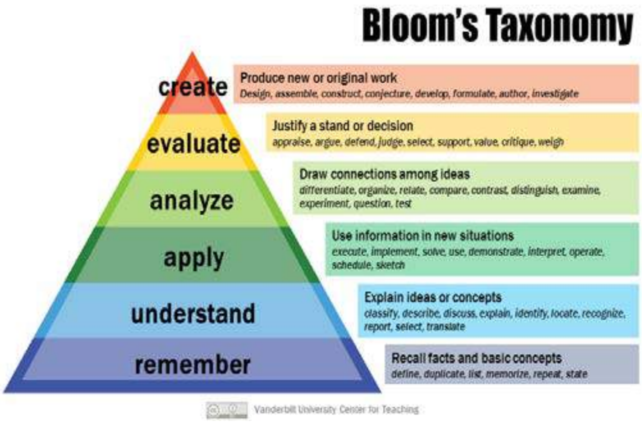


Figure 1. Bloom's Taxonomy- levels of cognition [6]

Bloom's Taxonomy and Virtual Reality

Educators have found the use of VR technology as an assistive tool for teaching and achieving the educational objectives identified in Bloom's Taxonomy to be controversial.

Bambury in [5] believed VR technology to be capable of tackling all levels of the cognitive domain despite doubts concerning the lowest level 'Remember'.

He related the taxonomy to VR technology as shown in figure (2) and believed that VR had many advantages for education.

VR technology has much to offer education at many levels. It allows students to be immersed in the learning environment in a way not possible using traditional approaches. The younger generation is now more accustomed to technology and novel methods. By using VR, learners can employ a variety of cognitive skills, and experiment and evaluate ideas in different scenarios. The visceral and immersive nature of VR technology leads to more engagement in a way that cannot be accomplished with other teaching methods [5]. However, how the educational objectives of Bloom's Taxonomy are met depends on the specific system/application being developed [7]. Although VR technology provides the capabilities to address these educational objectives, applications should be designed carefully to allow learners to analyze, synthesize, evaluate, and even create or experiment.

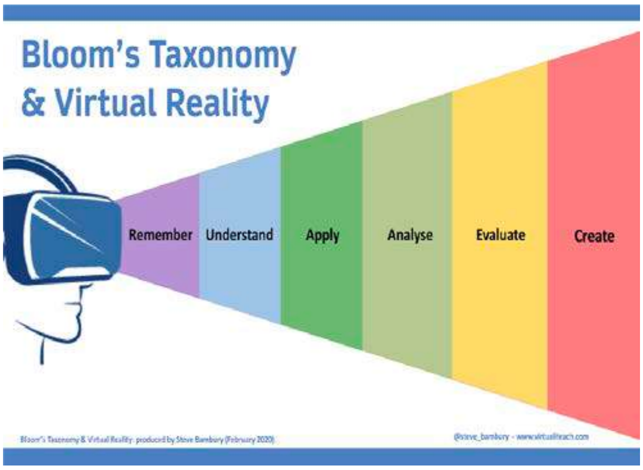


Figure 2. Bloom's Taxonomy and VR Technology [5]

The design of any system for learning computer HW components should consider the educational objectives of each level. Learners should be able to explore and understand the HW components by watching lessons, applying, analyzing, and by being able to practice assembling and setting up HW. The evaluation and creativity objectives could be achieved by allowing students to explore how different HWs affect features and capabilities. The current study shows that VR technology offers a teaching method that is both effective and acceptable to the learning sector.

3. Similar Work

Assessing the efficiency and impact of using VR technology in learning has undergone much research. VR-based simulated environments have been employed to support learning in courses with technical and practical elements, such as engineering, and been shown to have positive effects on learning outcomes [8]. Compared to two dimensional virtual/remote laboratories, VR-based environments achieve better learning and a more positive user interface experience [9]. The study presented in [10] found VR to be an efficient and relevant technology for developing interactive learning environments for engineering. This finding complies with a study on engineering students where the use of VR technology to introduce engineering concepts for first year engineering students was found to enhance retention [11]. Other studies have shown how VR supports practice, and the demonstration of practical knowledge, in engineering curricula [12]. This is also concords with the findings in [13] where the VR approach was found to have significant effects on the distribution of cumulative project grades (which are largely practical in nature). In addition, Harms and Hastings in [14] tested the use of VR across Computer Science (CS) curricula and found that it increased the retention rate from 54% to 64% in addition to helping students express creativity and innovation. VR technology thus supports creativity and enables immersion in the project design component of engineering courses. The study presented in [15] showed that VR boosts engagement, retention and motivation in the Network design element of computer science courses. Student motivation has also been found to be increased by using VR technology [16].

VR technology has also been found to be beneficial in domains other than engineering. Šašinka and his colleagues in [17] showed the effectiveness of VR technology, and its immersive learning environment, for teaching Geography. Another study examined immersive VR in teaching and training students in the medical sector [18]. Although applications of VR technology can be found across diverse domains, their impact, efficacy, effectiveness, and acceptance remain controversial.

To summarize, the previous literature identified many benefits of using VR technology in engineering education and other domains. It can improve learning efficacy [8], increase motivation [16], and support retention and knowledge acquisition in practical projects [15].

The aim of the current study was to determine how beneficial VR technology could be to schools when teaching computer hardware components, and whether the technology could be employed as a sustainable resource that can be continually updated with minimal effort, waste, and cost.

4. Feasibility of the study

The feasibility and needs of the proposed systems were assessed by collecting data using two methods. First, interviews were conducted with computer teachers in public schools to assess the teaching situation and the difficulties they encounter. In addition to the interviews, questionnaire data was collected that targeted the parents and students in public schools (intermediate and secondary level). The questions were designed to get their perspectives and opinions on the learning and teaching of hardware components and their knowledge about virtual reality technology. A web-based 5-point Likert scale questionnaire using Google forms was distributed to students and their families by the invitation of teachers to participate in this study. Participation was completely voluntary, and anonymous, and gave a total of 302 responses. The questionnaires were in Arabic as this is the main language in Saudi Arabia where this study was held. The questionnaire items are shown in Table 1 and the 5-point scale used by the volunteers to rate their agreement with the items (apart from item 7 where the Yes/No response was a precursor to the subsequent statements).

Table 1. Pre-study questionnaire

	Questions
1	I understand the curriculum of the computer hardware components without difficulty.
2	The school has the necessary equipment and tools to learn hardware components in practice.
3	I am satisfied with the learning tools provided to learn hardware components.
4	Technical teaching aids are an effective way to consolidate and understand information.
5	The use of technical educational aids in explanations makes it more enjoyable and easier to understand.
6	A traditional theoretical explanation without any practice may adversely affect the understanding of the curriculum.
7	Are you aware of VR technology?
8	If yes, the use of VR technology in teaching computer components will contribute to facilitating and easing the teaching and learning process.
9	Using VR technology in teaching computer components will make the learning process more enjoyable.

The questionnaire results found that 35.1% of the participants agreed that they have a good understanding of computer components while 29.5% were neutral. It was also found that only 18.3% agree that schools offer the required equipment and tools to learn hardware components in practice. 55% of participants were satisfied with their currently provided learning techniques. In terms of motivation, 61.8% fully agreed that using technologies and technical educational aids in learning explanations makes them more enjoyable and easier to understand. In addition, 63.3% agreed that using typical theoretical teaching methods negatively affects the understanding of the courses. Participants' knowledge of VR technology showed that 48.2% were aware of VR and 77.1% of those strongly agreed that using this technology would contribute to facilitating and easing the teaching and learning process. Moreover, 54.1% fully agreed that learning computer hardware components would be more enjoyable using this technology. For the interviews, two teachers were interviewed using a set of open-ended questions aimed at collecting their perspectives about teaching methods and equipment in their schools, students' progress and engagement in class, assessment methods, and their thoughts about using VR technology. It was found that both teachers had not explained assembling and setting up computer components in practical and relied solely on pictures and videos. One of them stated that there was no equipment provided at all, so neither the teacher nor the students had practiced during lessons. The other teacher stated that the provided equipment was limited and led to limited practice during lessons. Furthermore, teachers mentioned the difficulty in assessing this practical part of the curriculum, as they could not measure students' ability to assemble or connect hardware components, and instead had to give a traditional paper test. During the interview, teachers were asked about their perception of using recent technology in supporting teaching methods, and more specifically, VR technology. Both teachers emphasized that having such a technology would be expected to support teaching and learning and student engagement during lessons. Furthermore, they expected that it would overcome the shortages and challenges of providing equipment in some schools.

The results suggest that using VR technology for teaching and learning computer hardware components can facilitate both teaching and learning and confirms the motivation for the current study.

5. Design and Methodology

This study aims to evaluate the use of VR in facilitating learning and, more specifically, in teaching and learning computer hardware components to students in public schools. The focus of the study was on two aspects of the acceptability of the technology: perceived ease of use and perceived usefulness. RQ1 checks whether the system performs as expected and this can be accomplished by system testing. RQ2 and RQ3 aim to measure the acceptance of VR technology in learning and the satisfaction of learners. To answer these questions, an experiment was devised by developing a learning system using VR and subsequently testing its usability. This was followed by a survey designed in accordance with the Technology Acceptance Model (TAM) model [19] which measures the perceived ease of use, and perceived usefulness, from user perspectives based on 5-point Likert scale. TAM is a widely used method for assessing the acceptance of new technologies and is based on these two factors. To measure ease of use, the survey collected users' subjective thoughts on the ease of learning, controllability, flexibility, clarity, and the ability to master the technology. To measure usefulness, the survey focused on users' perspectives about the speed of work, performance, productivity, effectiveness, and usefulness. This information was obtained using a questionnaire that participants answered after experiencing the proposed system. The questionnaire items are shown in Table 2.

Table 2. Post testing questionnaire based on TAM model

		Questions	Strongly agree	Agree	Natural	Disagree	Strongly disagree
Perceived ease of use	Q1	Using VR technology in learning computer HW is easy for me.					
	Q2	Interaction with VR technology in learning computer HW is clear and understandable.					
	Q3	Interactive VR technology in learning computer HW is flexible and easy.					
	Q4	It is very easy to become skilled at using VR technology in learning computer HW.					
	Q5	VR technology in learning is easy to use.					
Perceived usefulness	Q6	Using VR technology in learning computer HW components helps me learn faster.					
	Q7	Using VR technology increases my performance in learning computer HW components.					
	Q8	Using VR technology in learning computer HW components increases my ability to achieve learning objectives.					
	Q9	Using VR technology makes learning the computer HW components easier.					
	Q10	In general, VR technology will be of great benefit to learning computer HW components.					

Design and implementation of system prototype

To carry out the study, a system was constructed to teach computer hardware components in schools, that incorporated VR technology. The system was designed to conform with the curriculum of computer courses taught in Saudi intermediate schools, and with the assistance of the schools' teachers.

The system was developed using the Unity platform [20] making it compatible with the VR headset (head mounted display) and the input controller. The main high level use case diagram of the proposed system is illustrated in Figure (3), and shows the two main characters: the user, who could be a student or teacher and the admin, who could be a moderator of the system contents and upgrades.

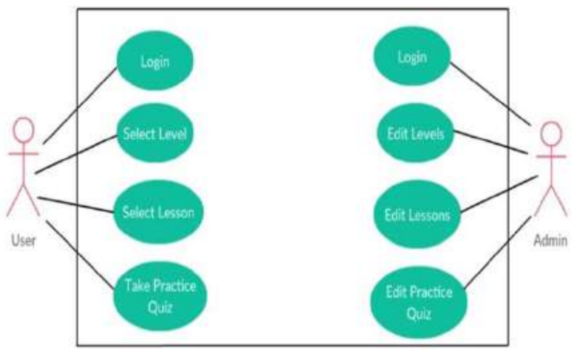


Figure 3. The main high level use case diagram of the proposed system

Admin should be responsible for updating system contents based on the curriculum's requirements. This includes the lessons, levels (the different categories of lessons (i.e., internal components, such as motherboard and RAM, external components, such as mouse and monitor, and network related components), and practical assessments. The user should be able to select the level and lesson, and take practical assessments. In this study prototype construction was developed and tested based on user functionality. The main functional and non-functional requirements of the system and prototype were identified and shown below, while some screenshots of the system showing different user functionalities are shown in Figures (4-8):

Functional Requirements

1. The ability of the user to login to the system.
2. The user should be able choose to learn or practice:
   a. The user can select from external components, internal components, and network components.
   b. The user can watch the lesson supported by text and voice instructions.
   c. When practice is chosen, an immediate true or false result is given.

Non-Functional Requirements

1. Usability: the design of the system should be user friendly.
2. Performance: the system should have high sensitivity to hand movements.

Figure 4. The main (Start) screen

Figure 5. After users choose the internal components they choose which components to learn

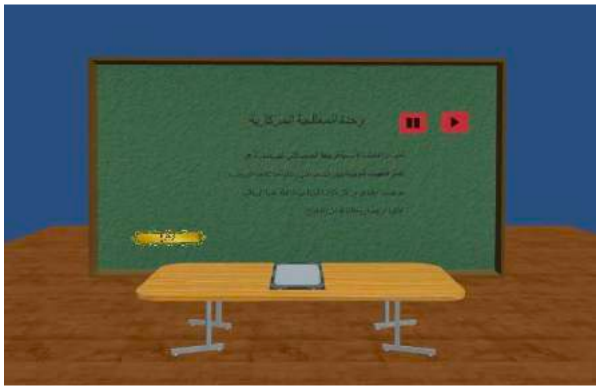


Figure 6. Lessons scene

Figure 7. Practice assessment scene in which the user installs RAM into the motherboard using the controller

Figure 8. Practice scene in which the user needs to connect external components to the PC using the controller

6. Experiment and Results

This section presents the results of this study. First the result of the system and usability testing is presented followed by the results of the technology acceptance survey.

6.1. System and usability testing

After the prototype was fully developed with the proposed functionality, system testing was conducted to assess the validity of all functionalities and whether they worked as expected. Unit testing and integration testing were both conducted, and all functions passed the test successfully.

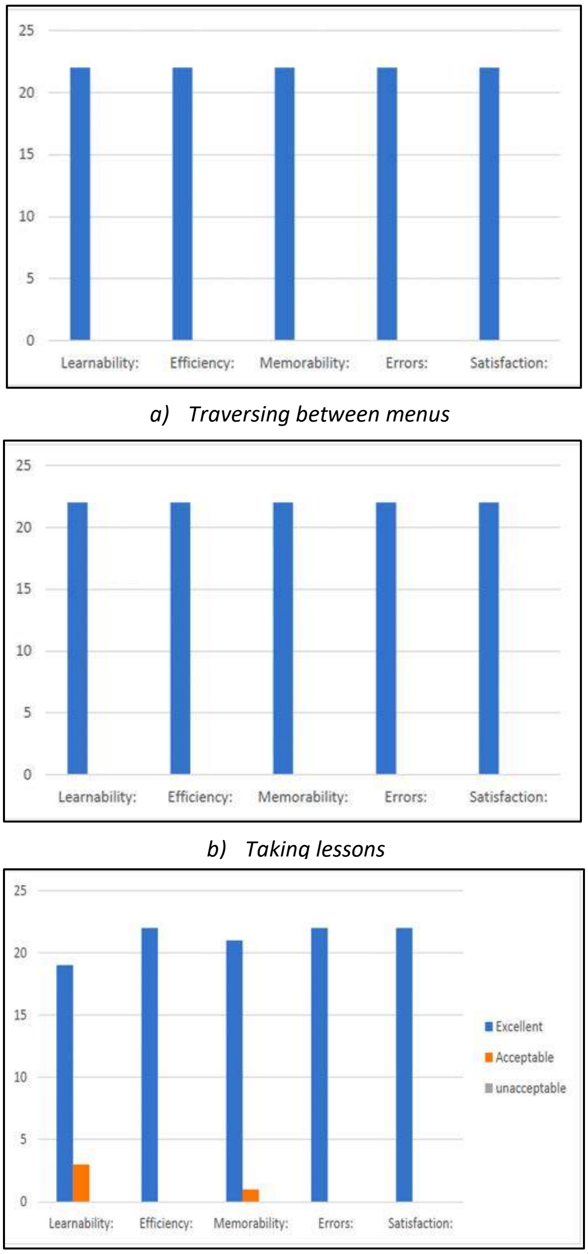
In addition to system testing, a usability test was conducted to evaluate the user experience of the system. This stage of testing was based on Nielsen's criteria of learnability, efficiency, memorability, error, and satisfaction [21]. Tests of the main functions were based on the following criteria:

- Learnability: Was it easy to use this application for the first time to accomplish a task?
- Efficiency: How fast was the task accomplished?
- Memorability: Was it easy to accomplish a task after using the application?
- Error: Does the application help you avoid errors when performing any task?
- Satisfaction: How satisfied are you with the application?

Each of these criteria were categorized as either 1) Excellent: The user accomplished the task directly without making mistakes; 2) Acceptable: The user needed help to accomplish the task / made one mistake; or 3) Unacceptable: The user did not accomplish the task / made two or more mistakes.

The prototype was tested on students at intermediate schools and their behavior observed. Feedback from the students was taken after testing. 22 students participated in the experiment and their usage was observed for the following functions: Traversing between menus, taking lessons, and practicing. The results of the usability of these functions were based on the Nielsen criteria are shown in Figure 9. It can be noticed that all students traversed between menus well and took lessons for the five criteria. However, for practicing, some students showed poor learnability and memorability. This could have resulted from their unfamiliarity with the use of VR technology and most likely would improve with more practice and assistance from their teachers.

The results of the system and usability testing demonstrate that the proposed protype works as expected and answers the first question (RQ1) of this study positively.



a) Traversing between menus

b) Taking lessons

c) Practicing assessments

Figure 9. The results of usability testing based on Nielsen criteria

6.2. Technology Acceptance Survey

The usability testing was followed by a user acceptance rating of VR in learning computer hardware components which was designed based on the TAM framework [19] and described earlier. 22 students who used the prototype were asked to provide their opinions using the questionnaire items presented in Table (2). Perceived ease of use showed more than 90% of the participants strongly agreed or agreed to all questions as shown in Figure (10-a).

Only one participant (4%) experienced any difficulty and strongly disagreed that VR technology was easy to learn with. Despite that, this student gave a neutral response, when asked whether VR technology was easy to use (Q5). Therefore, while it is expected that some students might encounter difficulties when using VR for the first time, with more practice, and consequent familiarity, with the technology they are likely to find it easier to use.

As can be seen from Figure (10-b), more than 90% of the students strongly agreed, or agreed, to all questions about perceived usefulness. Only a small percentage was neutral and again the author believes that this may simply be due to the unfamiliarity with VR technology and differences in people's adaptability to new technologies. More practice is expected to help this group of students overcome such difficulties.

The questionnaire results answer the second research question, and indicates a high level of VR technology acceptance among students and teachers in public schools. For the third research question, figure 10 shows that most students found the prototype to be easy to use and useful. This is a positive indication that the use of VR technology would be accepted by students and teachers, and could become a powerful assistive tool for teaching in public schools.

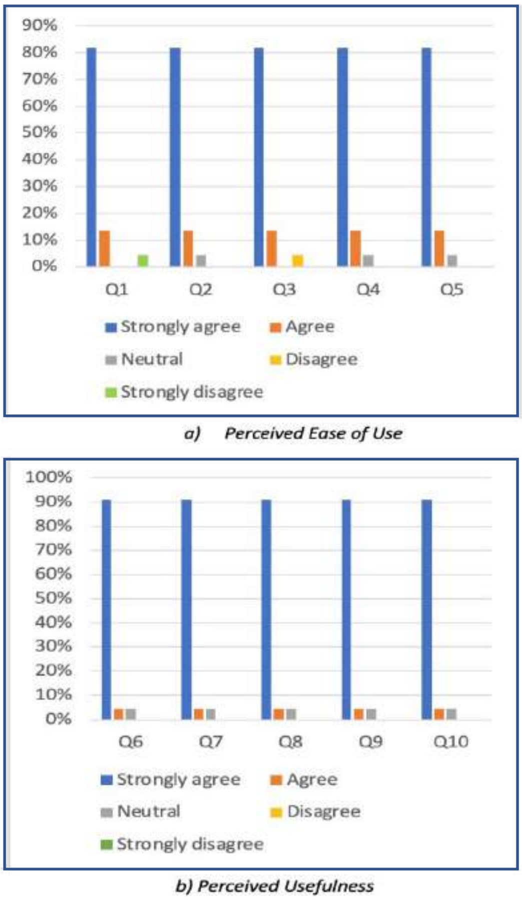


Figure 10. the results of TAM questionnaire

7. Conclusion and Discussion

VR is a contemporary technology that can be used in many different domains, one of which is teaching and learning where VR can be used as an assistive tool to immerse students in the learning environments. The current study found the approach to be effective and beneficial for aspects of the learning process that included motivation, retention, cognition, and overall performance. Together with the features of VR technology, the results indicate how the use of VR can support the teaching of computer HW components in public schools. Teaching this course requires practical knowledge and hands on learning with prepared labs and equipment. Providing the latest and most recent HW components in public schools for these practical aspects can be costly, and difficult to maintain, under the continuous rapid development of computer science and technology. The use of VR circumvents this problem, and provides a manageable and cost-effective means to keep curricula up to date with such developments. Initiating such a system may be costly, but it delivers a more sustainable and maintainable system in the long term, which can easily, and continually, be updated.

Several studies have shown the effectiveness of VR in teaching computer and engineering courses, but to the author's knowledge, testing the acceptance of this technology from teachers and students' perspectives had still to be investigated. This study introduced a model designed for teaching computer HW using VR technology. The functional and nonfunctional requirements of the system were proposed, and a protype was developed and tested. The study also focused on measuring the usability of the proposed system based on Nielsen's criteria of learnability, efficiency, memorability, error, and satisfaction [21]. 22 students participated in the study and the results showed both high satisfaction and usability. In addition, the study measured the acceptance of VR technology using the TAM model, which evaluates acceptance in terms of perceived ease of use and perceived usefulness [19]. The results showed that most of the participants who used the prototype, and provided their perspectives through the questionnaires, agreed that the system was useful and easy to use. In conclusion, this study demonstrated the benefits of VR technology in teaching computer-related courses in public schools, and suggests that the technology could be a promising sustainable alternative to traditional approaches to teaching.

Future work and development could be applied to the proposed prototype. More functionalities could be added to enrich the system and support the teaching and learning process.

These could include student profiles, assessment tools, progress monitoring, and even the ability to make individual adaptions based on student progress. In addition, further research could be carried out in public schools focused on student motivation, learning efficacy and cognition.

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