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VR Serious Game for Learning the Computer Organisation and Architecture Course

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Abstract—Computer Organisation and Architecture is a core subject in Computing Science (CS) in Higher Education. Some topics in this subject are thought to be dry by students through traditional teaching, such as computer functions and interrupts, as students are unable to visualize these multiple-step procedures of how the CPU performs. This research aims to utilize the virtual reality (VR) serious game to help students learn better these topics and absorb abstract concepts or comprehend scenarios that would be difficult in a typical classroom setting. It also enables an engaging and motivating platform, achieving successful learning for CS students. The effectiveness of the designed VR serious game is evaluated with two groups of participants: control group and experiment group. The results reveal that the serious game is able to provide students with positive learning efficiency as well as an engaging and self-motivated experience. The research provides an effective way of teaching and learning modality of the Computer Organisation and Architecture subject for CS students.

Keywords—Virtual reality, serious game, learning efficiency, Computer Organisation and Architecture,

I. INTRODUCTION

The study of Computer Organisation and Architecture is essential in Computing Science (CS) of Higher Education. This subject requires students to comprehend the functioning of a computer system, including central processing unit (CPU), memory, input/output, etc. It covers knowledge of low level hardware of computer organisation and computer architecture, e.g., internal architecture and computational capabilities of the CPU. Learning of the Computer Organisation and Architecture subject is perceived by many CS students to be dry, tough, and complex, as there are many different concepts to master, dry material to memorize, and multi-step processes to understand how the computer works and the CPU functions. The traditional teaching method of this subject is uninteresting [1]. Students encounter difficulty in understanding the materials since they cannot visualise the processes [2]. Students consider this subject to be tedious and difficult to understand [3]. It is beneficial to learners by utilizing visualization approaches because they can comprehend how computer systems operate [4], and encourage engagements using gamification [5].

Technology like Virtual Reality (VR) to intelligently visualize the working procedures could be a way to aid in the comprehension of the learning of this subject. Therefore, embarking on the VR technology will enable students to visualize such topics in this subject and learn them more effectively. It produces a technology enhanced learning approach that encourages active learning and is secure enough for students to grasp the lesson goals. Students are motivated and maintained their interests in the subject matter while playing the serious games by using the gamification approach.

This research aims to develop a VR serious game to aid university novice students learning Computer Organisation and Architecture subject to visualize the procedures of various CPU functions, including instruction cycles, interrupt service routines, and context switches, etc. It is to motivate and engaged students in a serious game environment while learning the topics.

II. RELATED WORK

The usage of gamification has good effects to promote student interests and enhance learning comprehension. Game-based learning improves students' conceptual understanding and learning outcomes compared to traditional teaching methods [6]. The popularity of educational games is rising [7]. The use of game dynamics in the context of education and learning is demonstrated [8]. The findings of another study demonstrate that students' learning performance fared better in the gamified environment than in the non-gamified environment [9].

Gamification in Higher Education could help students to study effectively [10]. Students are more motivated in learning their computer programming skills with serious gaming [11]. VR enables learners to absorb abstract concepts as an
alternative setting [12]. Immersive VR is effective in helping understand and visualize spatial relationships in conceptual tasks [13]. Combining VR and serious gaming can potentially improve student understanding and performance of the subjects [14]. Utilizing VR serious gaming for educations would be able to engage, motivate, and achieve effective learning for modern age students. VR offers users the sense of involvement and paints a picture of the subjects, allowing users to become more focused and visualized the topic while operating the game [15]. Learning could be efficient and successful when employing VR to encourage and motivate students [16], as it gives learning experience that is more effective than traditional learning.

VR might lead to some side effects, e.g., using VR may have adverse physiological effects on people, such as nausea and cybersickness [17]. The third-person shooter view in using VR can be a substitute to lessen the effects of cybersickness if the first-person shooter view is thought to be more thrilling [18], as the camera motion control of the third-person perspectives allows for smoother movement. Third-person shooter views are more comfortable for players as they can concentrate their gazes on a fixed object [19]. The third-person viewpoint in one game makes cybersickness improbable because there is little sensory conflict [20]. There is a sizable difference between the symptoms of cybersickness obtained when playing first-person adventure games compared to third-person games [21].

There are three types of VR settings: “fully-immersive”, “non-immersive” and “semi-immersive” [22]. First-person perspectives increase immersion, according to studies [23]. The intensity of cybersickness varies. The type of VR environment influences the degree of cybersickness. Non-immersive VR (such as desktop VR) has a lower likelihood of causing the physiological effect [24][25]. Switching to a third-person shooter view lessens the sense of presence and immersion of the VR game, it also lessens the risk of cybersickness occurring at the gameplay. It leads us to implementing the serious game in both full immersive using the Head-Mounted Display (HMD) and non-immersive VR in this research. The non-immersive VR can be used by some participants, if they are not comfortable with full immersive VR.

Although there are prior works with VR simulations for the Computer Organisation and Architecture subject [26][27], but most of them are not interactive and does not have step-by-step instruction for the learners to visualize the procedures of CPU functions. Our research has different aspects and contributions, as it focuses on learning and interacting with the low level hardware assembly in the CPU which is more of a training for general CPU internal architecture knowledge. Students can visualize and practice their hands-on skills to learn how the CPU fetches instructions from memory into the registers; how the CPU executes these instructions; how the CPU handles interrupts or context switches; and how the CPU perform other tasks in the serious game. To the best of our knowledge, there are no learning games built in literature to help students in learning these topics of Computer Organisation and Architecture subject.

III. SERIOUS GAME DEVELOPMENT

Fig. 1 shows a brief overview of the computer organisation and architecture [28]. The computer system performs functions in three stages: fetch cycle, execute cycle and interrupt cycle. It involves a set of CPU registers, memory, system bus, and input/output modules. The CPU fetches instructions from the memory into the Instruction Register during the fetch cycle, according to the values in the program counter (PC) register. The instructions are decoded and executed in the execute cycle, with operands or data needed being loaded into the memory buffer register, input/output buffer register or accumulator register of the CPU. After the execute cycle, if the interrupt is enabled, the CPU goes to the interrupt cycle to handle the interrupt routines and context switches if any interrupts are occurring or pending. Otherwise, the CPU goes to the next fetch cycle to load the next instruction from the memory. Such computer functions keep running for all the processes in the computer system iteratively.
The storyboard is planned to enable the player to learn the topics when playing the serious game. The screenshot of the introductory phase of the serious game is shown in Fig. 3. A virtual tutor avatar will provide a virtual key to the player to access Room 1 after the introduction of gameplay in the main lobby. A second virtual key will be given to access Room 2, if the player completes learning tutorials, assignments, and quizzes on “Fetching and Executing Instructions” with at least 50% scores. A third virtual key will be given to access Room 3, if the player completes the Room 2 learning tutorials, assignments, and quizzes on “Interrupt Handling”, “Interrupt-Driven I/O” and “Context Switches” with at least 50% scores. In Room 3, the player will be assessed on the topics covered in the prior two rooms. The overall game flow is shown in Fig. 4.

The game starts from the main lobby scene where the player can select whether to play in “HMD Mode” to play in the full immersive VR using the HMD or in “Non-immersive Mode”. The player avatar stands in front of the camera view when the virtual tutor avatar introduces how to play the serious game. At any time if the player clicks the “Quit” button before receiving the key, he will be brought to the replay menu scene.

A learning tutorial of “Fetching and Executing Instructions” in Room 1 is shown in Fig. 5. Multiple data are stored in the memory with different addresses. Some CPU registers: Program Counter (PC), Accumulator (AC), and Instruction Register (IR) are utilised to load instructions and data. The player must drag and drop the correct data from memory into the PC, AC and IR registers. Help frames information is provided to the player in the learning tutorials, such that the player can learn in the step-by-step manner. Upon the completion of the tutorials, the player is then asked to perform self-guided assignments to fetch instructions and data into the corresponding CPU registers, without any help frames information provided. It is to train the player to perform the tasks according to the fetch cycle and execute cycle of the computer system. Once the player completes the self-guided assignments successfully, a graded quiz with several questions will be prompted. If the player can score above 50% in the graded quiz, he can acquire the virtual key to Room 2.

The screenshot of learning tutorials "Interrupt Handling” in Room 2 is shown in Fig. 6. There are a few blocks of numbers that represent the user program, interrupt handler, and multiple interrupts with different priorities. The player is required to
drag and draw the arrows to activate the next interrupt handler or continue with the current interrupt handler, in order to respond to the right interrupts. The player then carries on learning tutorials for the “Interrupt-Driven I/O” and “context switches” knowledge shown in Fig. 7. The player learns sequential interrupt processing, nested interrupt processing, and context switches, etc. Next, the player is asked to conduct self-guided assignments without the help frames information, that is followed by the graded quiz in Room 2. Once the player receives the third virtual key, he can proceed to access Room 3. If he completes assignments in Room 3 with at least 50% scores, he is brought to the “Game Completion” scene.

IV. EVALUATIONS

12 university students were invited to the experiments of the VR serious game. Out of the 12 participants, two of them had prior knowledge for Computer Organisation and Architecture subject. The rest of the participants were currently still going through the university journey, range from first year to third year and had never attempted this subject. They are divided into two groups: Control Group and Experiment Group. Each group is made up of one participant with prior knowledge. In the experiment, Experiment Group was learning the subject using the serious game, and Control Group was learning using lecture notes extracted from the textbook. Three out of the six participants in Experiment Group played the game using the HMD. Control Group who learned through lecture notes were also invited to play the serious game after the quiz to evaluate the game.

SD was also almost the same between the two groups. The results showed that there is no improvement through game-based leaning. Further analysis is conducted to find out that some students in Experiment Group were unable to understand the meaning of “Executing Instructions”. This may be due to the unclear instruction in the serious game, where it did not specifically indicated “carries out the action of an instructions” in the gameplay.

![Mean & SD of Total Score](image)

Fig. 8. Mean and SD: Overall Scores of both groups

In the experiments, both groups attempted the quizzes to gauge their understanding once they had finished their learning of these topics. A collection of quiz questions was developed for evaluating the learning effectiveness, with one mark carried for each question. The first five questions in the quiz were taught in Room 1 of the serious game which cover “Fetching and Executing Instructions” topics, and the last four questions were taught in Room 2, covering the topics of “Interrupt Handling” and “Interrupt-Driven I/O”. The consolidated mean and Standard Deviation (SD) values of the overall quiz scores of both groups are shown in Fig. 8. It is seen that Experiment Group obtains better mean and SD values.

The mean and SD results for the five quiz questions of “Fetching and Executing Instructions” are shown in Fig. 9(a). Experiment Group achieved a slightly lower mean score. The

![Mean & SD of “Fetching & Executing Instruction”](image)

![Mean & SD of “Interrupt Handling” and “Interrupt-Driven I/O”](image)

(a) For topics in Room 1 (b) For topics in Room 2

Fig. 9. Mean and SD values learned in two rooms

The mean and SD results for the four quiz questions for “Interrupt Handling” and “Interrupt-Driven I/O” topics are shown in Fig. 9(b). It is observed better mean and SD values of Experiment Group achieved, that indicated Experiment Group is performing better in these topics.

<table>
<thead>
<tr>
<th>TABLE I. SURVEY FEEDBACKS</th>
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<tr>
<td>Participant ID</td>
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<td>Experiment Group</td>
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Next, a survey was conducted for all participants after they have played the VR serious game to collect their feedback through the Google forms. The survey consists of simple “Yes and “No” and some short answer question to elaborate their points. TABLE I shows the feedbacks gathered from all participants. It is shown that they had enjoyed the gameplay and would like to try out more of such serious games to learn about computer architecture. It was also shown in the survey results that all participants felt that the serious game had help them to understand these topics. This had directly shown a positive result for students felt more engage and motivated when using game-based learning.
Three participants felt the effect of cybersickness when playing the game using the HMD mode for fully immersive VR. The possible reason was that it was the first time for them to use HMD for VR game play. One of the common feedback items was that the robot avatar manoeuvring was slow, but it was not presented when developing the VR serious game on the developer’s laptop with GPU. It was possibly due to the frame rates difference when participants were playing the serious game on different electronic devices.

V. CONCLUSIONS

The research shows that the VR serious game can offer students engaging and efficient ways to learn about how the computer performs functions internally. It provides an effective way of teaching and learning modality for CS students. It is observed that the mean scores and SD values increase through game-based learning. The survey feedback indicates that game-based learning could engage and motivate the player to attempt all the tasks in the serious game. It enables students to understand the abstract concepts and complex procedures of Computer Organisation and Architecture subject.

There are still some improvements that can be made for future works. The problem of slow robot avatar manoeuvring can be resolved by amending the game scripts to enable selecting different frame rates to prevent slowing down the robot movements. The help frames information in the game can be further enhanced by providing more specific explanations, as the unclear information leads to the participants unable to understand what to perform in the game play. Currently the sample size is small in the experiments. It needs to increase the number of participants in the further experiments and evaluations to help in sieving more accurate results.

REFERENCES