UDC 378.147.63:004.4:378

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GAMIFIED ACTIVE LEARNING AND 3D TECHNOLOGIES FOR ENHANCING STUDENTS' ACADEMIC ACHIEVEMENTS

Abstract. Gamified active learning has been shown to improve students' academic performance and engagement while facilitating the establishment of more social connections compared to standard course settings. The objective of our study was to evaluate the effectiveness of gamification within a single course. We developed a gamified environment using 3D technology to enhance the students' comprehension and interest in the course material. Additionally, we assessed students' attitudes towards gamification, including their perception of its usefulness. The study was conducted using an experimental group (class with gamification implementation - selection two forms of gamification, such as 2D and 3D technologies, which can play an important role in achieving the best results) and a control group (class without gamified activities). The results indicated that the use of gamified educational courses can indeed enhance students' academic performance and acquired competencies, providing more diverse learning methods and motivation. A qualitative analysis was conducted to gain insights into students' perceptions of gamified learning. The feedback obtained during the experiment highlighted the positive impact of gamification on students' motivation, enjoyment, and overall satisfaction with the course. Moreover, gamification allowed for easy modifications to cater to different learning needs. The incorporation of 3D modeling technology provides a more engaging and interactive approach to learning, leading to a better understanding of the subject matter and ultimately improving the quality of education.
The conducted experimental study demonstrated a significant in the formation of skills in Computer Science throughout the study process. The utilization of this game-software tool, which employs 3D modeling, is particularly convenient and effective during crisis situations like the COVID-19 pandemic and war, as it facilitates conducting educational activities in a distance format. It also promotes the quick adaptation of students to use IT-technologies in their learning journey.

Keywords: Gamification; 3D modeling; game-based learning; online learning; educational software; interactive learning; PC components.

1. INTRODUCTION

In recent years, the use of technology in education has become increasingly popular, as it offers new and innovative ways to engage students and enhance their learning experiences. One area that has shown great potential is the integration of gamification with 3D modeling in teaching. This technology enables the creation of realistic and interactive models, providing students with a visual and tactile understanding of how various objects and systems work.

Th COVID-19 pandemic and the implementation martial law have triggered a crisis in education, affecting the organization of the educational process [1-3]. The transition to remote learning necessitated the use of diverse web servers, platforms, resources, social networks, and corresponding software. Distance learning presented challenges for all participants in the educational process, including teachers, students, and parents. Organizing quality education

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using digital technologies, managing the educational process remotely, engaging and motivating students to learn, maintaining interaction between all participants, and mastering communication tools proved to be quite challenging.

Traditional teaching methods during this time may not be effective in providing a comprehensive understanding of the technical subject matter. Many students struggle to grasp complex concepts and technical terminology associated with technical education, which can hinder their ability to succeed in their studies.

The problem statement. The rising popularity of digital games for personal entertainment has sparked interest in exploring the efficacy of gamification for enhancing academic performance and educational relevance in the digital age [4]. The concept of gamified learning extends the application of traditional teaching strategies by instructors and provides an engaging method that fosters student engagement, leading to improved academic success. Therefore, this article investigates an approach that combines gamification with 3D modeling technology to enhance the learning experience and create a more appealing and interactive educational environment. The objective of this approach is to enhance understanding and knowledge among students in technical education, ultimately leading to better achievements and brighter prospects.

Analysis of recent studies and publications. Gamified active learning has the potential to enhance student engagement, foster enthusiasm, provide instant feedback, and create more social connections than standard settings of online courses [4]. However, the costs associated with implementing a gamified instructional design with effective game plans and course content delivery can be challenging, especially for instructors lacking deep knowledge in computer games and/or a budget to create such an environment. Additionally, finding alignment between the available games in the market and the educational objectives of a course can be difficult. Furthermore, instructors may lack the resources and training in online learning technology to even initiate game implementation in online courses. To leverage the potential benefits of gamification and overcome the aforementioned challenges in online learning environments, there is a pressing need for the development of innovative gamified activities based on the capabilities of existing methods and accessible tools for collaboration within the most commonly used learning management systems.

Research shows that gamification of educational courses can have a positive impact on student motivation, engagement, and learning. It creates a more interactive and engaging learning environment, stimulating competition and collaboration, and promoting deeper understanding and retention of information.

A study conducted by [4-5] highlighted the effectiveness of gamification in online courses. They found that a gamified approach promotes greater student participation, improvement in their performance, and reduction in dropout rates. The researchers also noted that gamification can contribute to the development of a deeper understanding of the material and enhance skills such as problem-solving and decision-making.

Other studies confirm these findings, emphasizing the positive effects of gamification on student motivation and learning. One such study conducted by [6] examined the influence of gamification on the learning process and revealed a positive correlation between gamified methods and increased academic motivation among students.

Furthermore, research has been conducted focusing on various aspects of gamification, such as the use of reward systems, leaderboards, and quests. These studies demonstrate that properly designed gamification can enhance motivation, collaboration, and academic performance among students [7].

In [8] explored the impact of incorporating 3D technologies into a gamified course. The researchers found that the use of 3D models and simulations in a gamified learning environment enhanced student engagement and facilitated a deeper understanding of complex concepts. The interactive nature of 3D technologies allowed students to visualize and manipulate objects, fostering a more hands-on and experiential approach to learning.

Another research by [9-11] investigated the effects of using virtual reality (VR) as a gamification tool in educational courses. The researchers found that the immersive and interactive nature of VR enhanced student motivation, attention, and knowledge retention. By integrating gamified elements within the VR experience, such as challenges, rewards, and progress tracking, students were further motivated to actively participate and explore the learning content.

These researches highlight the potential benefits of combining gamification with 3D technologies in educational courses. By leveraging 3D models, simulations, and virtual reality, instructors can create visually rich and engaging learning experiences that promote active exploration, problem-solving, and collaboration among students. Such an approach not only enhances motivation and engagement but also facilitates a deeper understanding of complex concepts through interactive and immersive experiences.

The research goal. Overall, the integration of 3D technologies within gamified educational courses has the potential to revolutionize the way students learn, providing them with unique and impactful learning experiences that are both educational and enjoyable.

To contribute to the current knowledge of gamification in online learning and higher education, the objectives of our research were (1) to investigate whether gamified actions for online courses in computer architecture can improve students' academic performance, (2) to explore whether the implementation of gamification can enhance the engagement of online students, and (3) to examine whether the use of 3D models compared to 2D increases students' interest in the instructional course.

2. THE THEORETICAL BACKGROUNDS

The participants of the study were undergraduate students who took an online computer architecture course over two academic years (2019-2022) at a university in Ukraine. The university's web-based tools (similar to Moodle) were used to set up online survey questions for the research participants. The participants (n=100) were randomly assigned to either the experimental group (students with two gamified events - 2D, 3D) or the control group (students without gamification).

There were 50 students in the experimental group and 50 students in the control group. The academic performance of the participants in both the experimental and control groups was compared based on their average exam scores, as well as their technical competence (evaluated through ten self-assessed questions). Additionally, before and after the exam, an application was administered to the experimental group to assess their perceived usefulness and motivation towards the online course before and after the implementation of gamification.

The variables examined in the current study included academic performance, measured by the average of all exam scores (on a scale of 0 to 100). To assess students' competencies, a ten-item questionnaire. The questionnaire employed five-level measure of competency was used, ranging from 0 (not confident) to 4 (extremely confident).

First, existing computer programs that teach computer hardware were analyzed, and then a survey of 100 technical students aged 17-23 years, who are the target audience of the project, was conducted. The survey was conducted online, and the participants were asked to briefly describe the problems they encountered while learning about the computer hardware.

The results showed that the main problems encountered by the participants were the difficulty of distance learning and reviewing previously learned materials, as well as the monotony of the learning process due to the similarity of most lectures. The study also considered the success of students in mastering the topic and their preferred learning methods.

It was found that students perceive information in different ways, and there are four main types of information perception [12]: visual, auditory, kinesthetic, and discrete (see Fig. 1). Visual learners use images, texts, and diagrams to better remember information. Auditory learners use sound and prefer lectures, music, or audiobooks to learn new information. Kinesthetic learners use touch, feelings, and experiences to learn, and they need to apply new knowledge immediately. Discrete learners prefer information that is presented logically and with clear arguments.

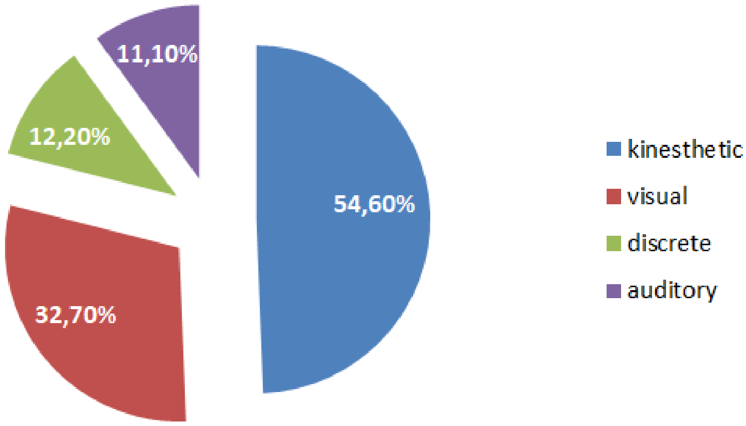

Figure 1. The results of the student survey

3. RESEARCH METHODS

Based on the results of the survey, the main types of information perception of the participants were identified. Moreover, we developed a digital learning program that utilizes 3D modeling to provide a more immersive and engaging learning experience. The computer program was designed to cater to the specific learning preferences of the participants and aimed to enhance their learning experience.

The process of creating a 3D model involves two stages: modeling and texturing. During modeling, a rough sketch is created, the general geometry of the model is developed, and details are added using smaller parts. Texturing involves creating, editing, and assigning materials and textures to all the surfaces of the model, adjusting parameters to achieve the closest match to the actual object. Personal computer parts and Internet photographs were used as references. For texturing, edited standard Maya textures were mostly used, with modifications to color and parameters such as metallicness, transparency, and reflectivity. This process resulted in textures that closely resembled the real-world objects [13].

During the work process, the following components of a system unit were modeled:

- Motherboard
- RAM
- Graphics card
- Cooler
- Radiator
- Hard drive
- Power supply unit
- CPU

Figure 2 shows the some modeled PC components.

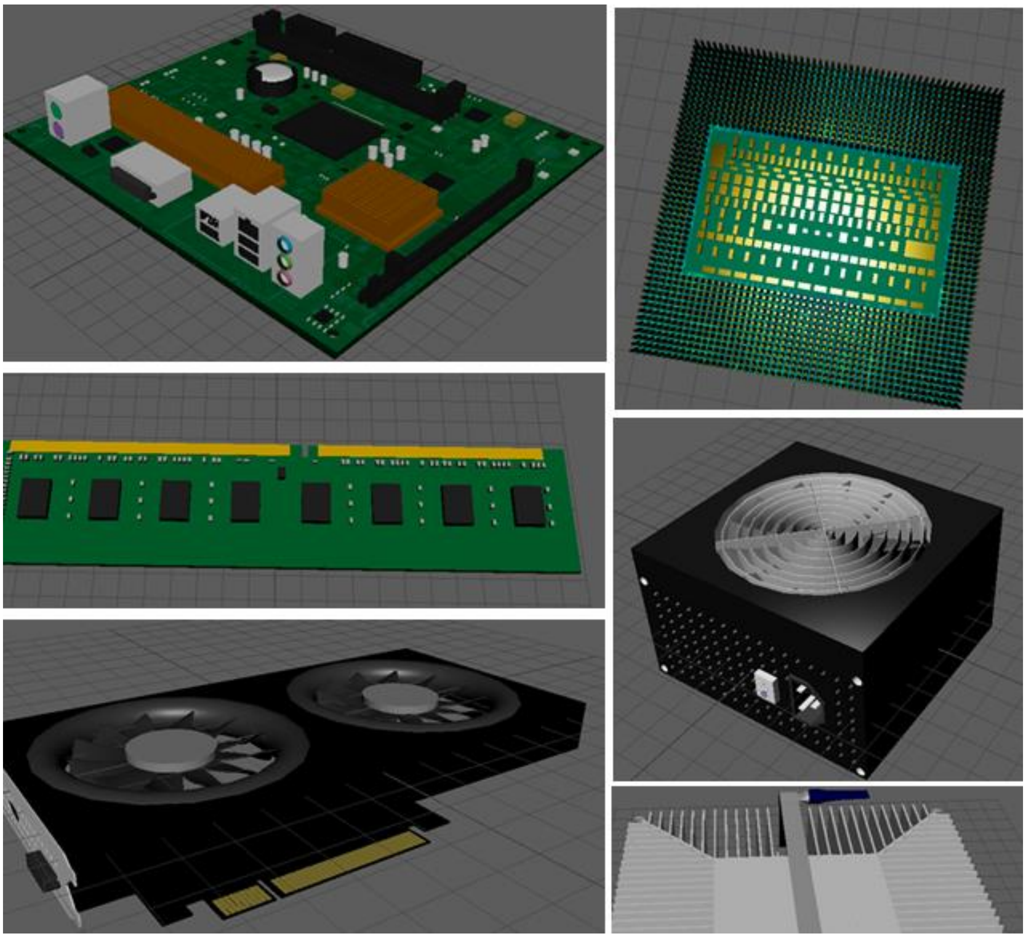

Figure2. 3D PC components

In computer program, the user is presented with a main menu scene containing three buttons that correspond to different program modes and program exit. The menu also displays the program name, brief operational instructions. The computer program has two working modes: standard and “sandbox”.

In the standard mode, the user sees a screen displaying the framework of a computer system unit with module silhouettes and information on the first module. The user must select a module and use prompts to insert it into the correct location within the chassis. Once the module is in place, a new module appears on the scene, and the old framework is replaced with a new one with the newly installed module.

The “sandbox” mode allows for free exploration of the modules. Only the components of the computer system unit are present on the scene. The user can freely move or rotate any module.

Both modes offer the option to restart the level (using the “R” key on the computer keyboard) and return to the main menu (using the “Escape” key).

This computer program provides an interactive user experience for learning about computer system units by allowing users to manipulate and interact with different modules in a simulated environment.

A collider is an invisible area around or inside an object that typically triggers certain actions upon interaction. A collider defines the shape of the object for physical collisions. Unity has several built-in collider options for different object shapes, allowing developers to choose the collider that best fits their needs. For more detailed shape, various types of colliders can be overlaid as child objects, including “Mesh Colliders” that allow for more accurate replication of the object's shape. However, Mesh Colliders require significantly more computing resources to process and are used less frequently than basic colliders, such as those in the shape of a box or sphere, which cover most development needs. In the case of animating an object that changes its shape, the use of a standard cubic collider may not be appropriate, and a collider is typically created separately for each key animation point. Figure 3 shows the collider of an object (a video card) represented by a green rectangle.

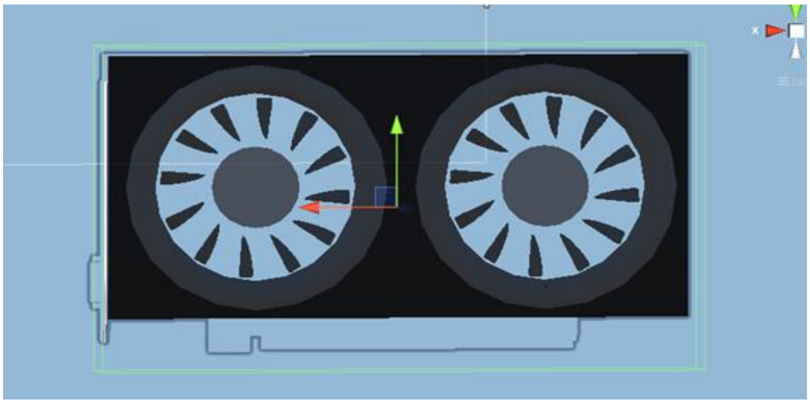

Figure 3. Object collider visualization

After all the necessary modules have been properly installed, the computer case is closed to finalize the assembly of the system unit. This process is carried out in the same way as any other computer case assembly. A brief summary of the components present within the system unit is displayed in a specific order.

When the computer program execution was completed the user can choose to restart the process or exit to the main menu using the keyboard commands. Figures 4-5 depict the appearance of the screen during program execution and after the installation of all modules.

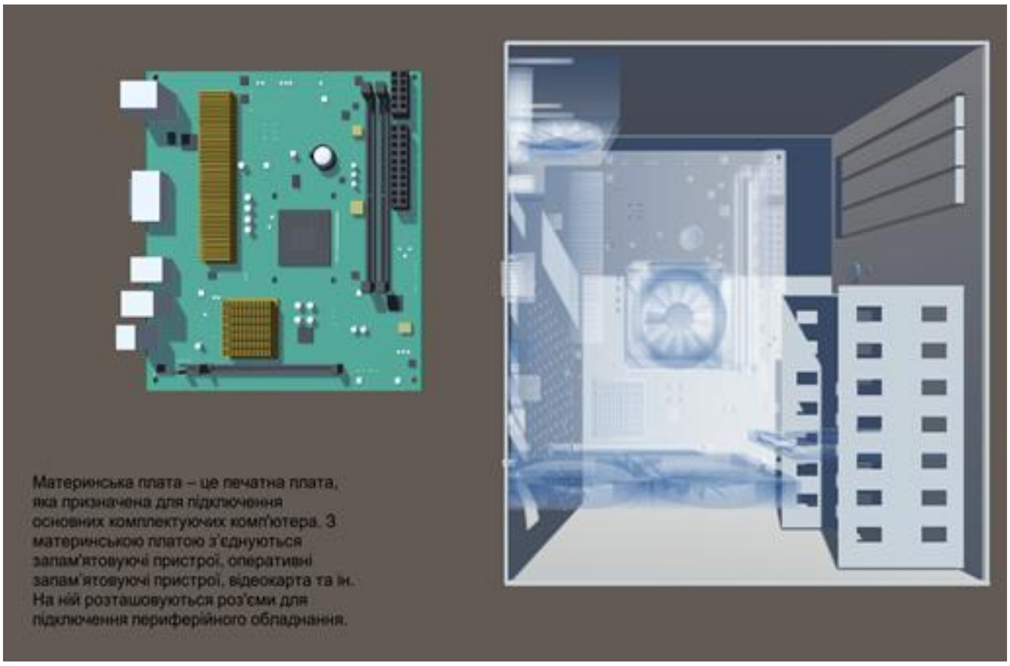

Figure 4. Standard computer program mode

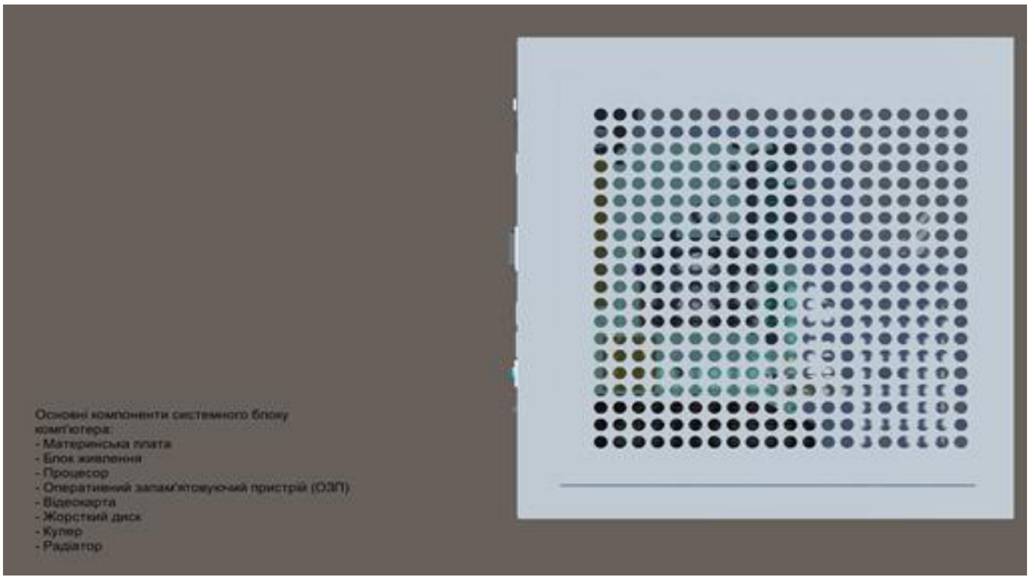

Figure 5. Completed task mode

The "Sandbox" mode. To provide better learning opportunities, the user is offered a single working mode called "sandbox". In this mode, the function of moving and rotating objects is implemented. Objects are rotated using keyboard keys. This will help to better understand the structure of the components of the system unit, review learned information, and consolidate knowledge. This is the best way to examine each module in detail, as the main mode of this function does not provide this option. In this mode, the user is not given any tasks and can freely move and examine modules. Figure 6 shows the appearance of the screen in the "sandbox" mode. By providing a "sandbox" mode, users are given the opportunity to not only learn about the structure of the system unit but also to explore it in greater depth. This mode allows for hands-on learning and encourages exploration and experimentation. By allowing users to manipulate the modules, they are better able to understand how they work and how they interact with one another.

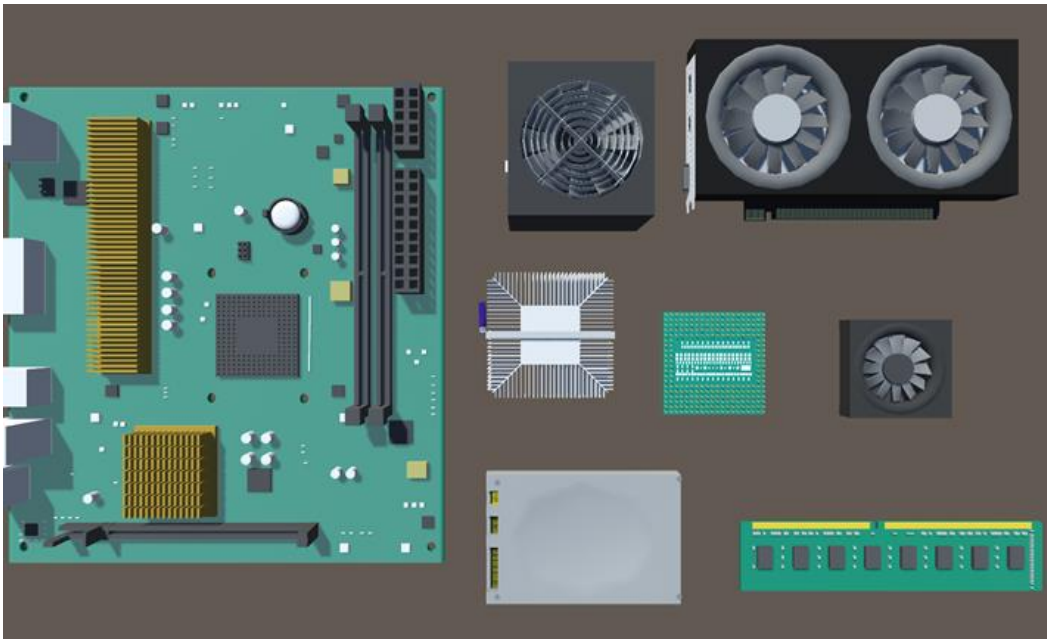

Figure 6. The "Sandbox" mode

Furthermore, permitting users to repeat and review information as many times as they need to, the learning experience becomes more personalized and effective. Additionally, the ability to restart the mode as needed ensures that users can consolidate their knowledge and understanding of the system unit at their own pace. Overall, the “sandbox” mode can provides an engaging and effective way for users to learn about the system unit and develop a deeper understanding of its components. By offering a mode for exploration and experimentation, users may better comprehend the workings of the system unit and how its modules interact with one another. The ability to repeat and review information may also personalize the learning experience and improve the quality of knowledge acquisition.

An additional scene and script were created. The main functions in the implementation repeat the main mode of the computer program. Added magnification of the object when selecting, which makes it possible to better look at the models of the elements. The increase of the object is realized thanks to the increase of the applique coordinate (Fig. 7). After pressing the mouse button again, the objects are reduced to their original size.

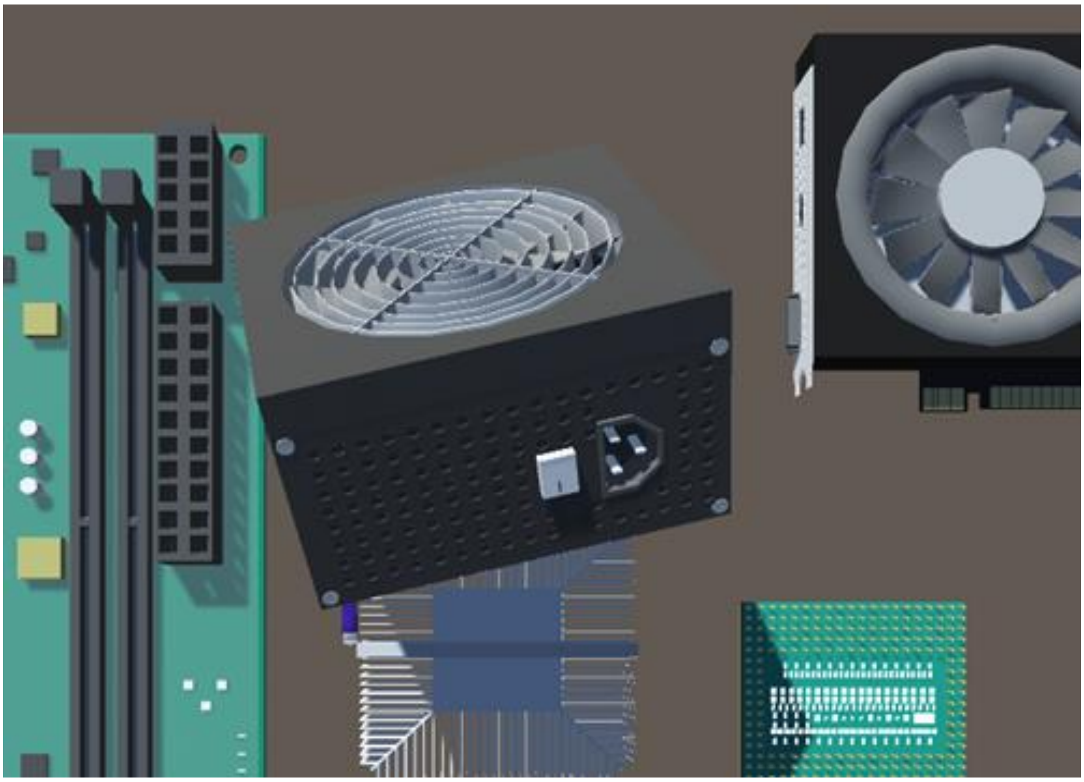

Figure 7. Power supply model after rotation

To testing the assimilation of knowledge in a 2D environment, the same game was used, but redesigned in 2D without the “Sandbox” mode

4. THE RESULTS AND DISCUSSION

We conducted a comparison between two samples: 1) experimental group with a mean (M_1) of 85.6 out of 100 possible points, a standard deviation (SD_1) of 7.95, and a sample size (n_1) of 50; and 2) control group with a mean (M_2) of 76.4 out of 100 possible points, a standard deviation (SD_2) of 10.35, and a sample size (n_2) of 50.

By performing a t-test, we found that the calculated t-value was approximately 3.184. With a chosen significance level of $p = 0.05$ and degrees of freedom (df) equal to the sum of sample sizes minus 2 ($df = n_1 + n_2 - 2 = 98$), the critical *t*-value was approximately 1.984 (for a two- tailed test).

As the calculated t-value ($t \approx 3.184$) exceeded the critical *t*-value (1.984), we conclude that there are statistically significant differences between the mean scores of the experimental and control groups at the $p = 0.05$ level of significance.

Based on the new information, where the experimental group is divided into two subgroups (2D and 3D games), and the significance level is set at $p = 0.01$, we conducted a comparison between these two subgroups. To calculate the Student's *t*-distribution [14-15] and determine the statistical significance of the differences between the subgroups, we computed the t-value and compared it to the critical *t*-value. The formula used for calculating *t*-value was $t = (M_1 - M_2) / sqrt((SD_1^2 / n_1) + (SD_2^2 / n_2))$. To determine the critical t-value at a significance level of $p = 0.01$ and with degrees of freedom $df = n_1 + n_2 - 2 = 48$, we consulted the Student's t-distribution table. With $p = 0.01$ and $df = 48$, the critical t-value was approximately 2.678 (two-tailed test). Therefore, since the computed t-value ($t \approx 5.87$) exceeds the critical t-value (2.678), we can conclude that there are statistically significant differences between the mean values of the 2D and 3D subgroups at a significance level of $p = 0.01$. In conclusion, the results indicate that the 2D and 3D subgroups within the experimental group exhibit statistically significant differences in mean values at a significance level of $p = 0.01$. The results from Student's distribution, t-test can be found in Table 1.

Table 1

Student's distribution (t-distribution) Between Average Exam Scores From the Experimental and Control Groups

Groups	**Exam scores**					
	n	*M*	*SD*	*p*	*t-test*	critical *t-value*
Control group (without implementing the games)	50	76.4	10.32	0.01	3.184	1.984
Experimental group (with implementing the games)	50	85.6	7.95			
2D games	25	80.2	9.01		5.870	2.678
3D games	25	91.0	6.89			

In comparison to the control group, the experimental group, which included gamified activities, achieved significantly higher mean scores. This indicates that gamification can have a positive impact on academic performance and student achievement.

Within the experimental group, statistically significant differences were found between two subgroups: the group using 2D games and the group using 3D games. This confirms that the use of different forms of gamification, such as 2D and 3D technologies, can have varying effects on students' academic outcomes.

The overall conclusion is that gamification can be an effective tool for educational purposes in improving students' academic performance. However, the selection of specific forms of gamification, such as 2D or 3D technologies, can play an important role in achieving the best results. Further research and analysis would be valuable in determining the most effective forms of gamification in different educational scenarios and contexts.

As shown in the Table 1, the experimental group (with implementing the games) have an average score of 85.6 control group (without implementing the games) have an average score of 76.4 which increased on 9.2 in the experimental group. Also, these results indicate that the use game with the 3D models had a significant positive impact on the learning outcomes of the experimental group on 10.2 points.

Furthermore, the students in the experimental group reported higher levels of engagement and motivation when using the software compared to the control group. The interactive nature of the 3D models made it easier for them to visualize and understand the components of the computer system unit. The software also provided students with immediate feedback, allowing them to quickly identify areas where they needed to improve.

The implementation of a ten-item questionnaire with a five-level measure of competency has provided a comprehensive assessment of students' competencies. The questionnaire's scale, which ranges from 0 (not confident) to 4 (extremely confident), allowed for a detailed evaluation of students' levels of confidence in various competencies. This approach provides valuable insights into students' self-perceived competence levels, which can be helpful in identifying areas where further support and development may be needed.

Overall, these findings suggest that the use of 3D modeling technology in educational game software can be an effective way to enhance the learning experience and increase the quality of education for students in computer architecture. The interactive and engaging nature of 3D modeling technology has the potential to improve student engagement and motivation, leading to a deeper understanding of the subject matter.

4. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

The conducted study showed that the game-educational software developed with 3D modeling technology had a significant positive impact on the learning outcomes of the experimental group of students in computer architecture. The group of students who used the software had a significantly higher level of knowledge and understanding of computer components than the group who did not use the software. The study also found that the students in the experimental group reported higher levels of engagement and motivation when using the software compared to the control group. These findings suggest that the use of 3D modeling technology in educational software can be an effective way to enhance the learning experience and increase the quality of education for students in computer architecture.

However, further research is needed to explore the full potential of 3D modeling technology in enhancing the learning experience of students in other subjects. Additionally, more research is needed to investigate the effectiveness of 3D modeling technology in different educational settings and for different types of information perception, such us a visual, auditory, kinesthetic, and discrete.

Furthermore, future research could focus on developing more sophisticated 3D models that can be used to teach more advanced concepts in computer architecture. This could include the development of models that can simulate the behavior of computer components under different conditions, providing students with a more comprehensive understanding of how computer systems function.

In conclusion, our findings support our objectives of implementing meaningful and effective gamified activities with multiple purposes: (1) improving students' academic performance, (2) fostering engagement and social interaction among students and instructors, (3) creating an inclusive online learning community for reviewing key concepts, and (4) alleviating potential frustration with the technical aspects by providing additional opportunities to review critical concepts through gamification, including a 3D mode.

Through our experiences in developing online gamification and observing its impact on self-directed and active learning, we have identified a novel online teaching strategy that can enhance students' academic performance and engagement. This approach not only focuses on knowledge acquisition but also promotes a dynamic and interactive learning environment.

While our findings have provided valuable insights, it is important to consider the limitations when interpreting the results. First, the participants may have been aware of the researchers' objective to assess the effectiveness of gamification, potentially introducing a slight bias. Second, although the study examined students' perceptions and attitudes towards gamified activities, the specific impact of gamification attributes (such as challenge, goals, and rules) on academic performance was not individually evaluated. Third, the study focused on the influence of gamification in a PC architecture course, limiting the generalizability of the findings to other post-secondary courses.

For future research, it would be beneficial to isolate the effects of different gamification components and examine their individual influence on academic performance and students' feedback. This approach would provide a more comprehensive understanding of the relationship between gamification and learning outcomes across various educational contexts.

Therefore, the study demonstrates that implementing gamified active learning strategies, particularly through the use of 3D technology, can yield significant benefits in terms of students' academic performance, engagement, social connections, and perceived usefulness. By comparing an experimental group that received gamification with a control group that did not, the researchers observed improvements in academic performance, competencies, and motivation among students exposed to gamified educational courses. Moreover, the flexibility of gamification allows for customization to accommodate diverse learning needs. The incorporation of 3D modeling technology further enhances the learning experience by providing an engaging and interactive approach, resulting in improved comprehension and overall educational quality. These findings support the effectiveness of gamification as a valuable tool for enhancing student outcomes and promoting more dynamic and enjoyable learning environments.

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Text of the article was accepted by Editorial Team 17.07.2023

ГЕЙМІФІКОВАНЕ АКТИВНЕ НАВЧАННЯ ТА 3D-ТЕХНОЛОГІЇ ДЛЯ ПІДВИЩЕННЯ АКАДЕМІЧНИХ ДОСЯГНЕНЬ СТУДЕНТІВ

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Анотація. Гейміфіковане активне навчання покращує залученість студентів до навчання, їх академічну успішність і допомагає їм налагодити більше соціальних зв'язків, ніж стандартні налаштування курсу. Нашою метою було оцінити ефективність гейміфікації в межах одного курсу. Гейміфіковане середовище було розроблено з використанням 3D-технологій, щоб покращити розуміння та інтерес студентів до навчального матеріалу. Ми перевірили ставлення студентів до гейміфікації, включно з їх уявленням про її корисність. Дослідження проводилось з використанням експериментальної групи (група із впровадженням гейміфікації – вибір двох форм гейміфікації, як-от 2D та 3D-технології, що відіграють важливу роль у досягненні кращих результатів) та контрольної групи (група без гейміфікованої діяльності). Результати показали, що використання гейміфікованих навчальних курсів може підвищити академічну успішність студентів і набути компетентності, а також забезпечити більш різноманітні методи навчання та мотивацію. Проведений якісний аналіз сприйняття учнями ігрового навчання. Отримані відгуки під час експерименту підкреслюють позитивний вплив гейміфікації на мотивацію студентів та загальне задоволення курсом. Впровадження технології 3D-моделювання забезпечує більш захоплюючий та інтерактивний підхід до навчання, що веде до кращого розуміння предмету та, зрештою, покращує якість освіти.
Результати проведеного експериментального дослідження засвідчили підвищення рівня сформованості навичок з інформатики під час навчання. Цей ігровий програмний засіб із використанням 3D-моделювання в кризових ситуаціях (наприклад, пандемія COVID-19 і воєнний стан) є зручним і простим для проведення освітніх заходів, дозволяє легко інтегрувати процес навчання в дистанційний формат. Це також сприяє швидкій адаптації студентів до використання ІТ-технологій у навчанні.

Ключові слова: гейміфікація; 3D-моделювання; ігрове навчання; онлайн-навчання; освітнє програмне забезпечення; інтерактивне навчання; компоненти ПК.

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