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Impact of the 3-D simulation model strategy on students' computer science learning at Northern Border University

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ABSTRACT

This study examines the effects of 3-D simulation models on students' learning outcomes, satisfaction, and motivation in a computer science course at Northern Border University. Seventy-two students were assigned to three groups: No 3-D Simulation (N3D), Premade 3-D Simulation (P3D), and Interactive 3-D Simulation (I3D). Learning outcomes were measured using posttests and retention tests, while satisfaction and motivation were assessed through surveys. The results showed no statistically significant differences in posttest or retention scores among the groups, although the P3D group performed slightly better. Students in the P3D and I3D groups reported higher satisfaction and motivation levels compared to the N3D group, but these differences were not statistically significant. A moderate effect size was observed between the N3D and P3D groups in retention scores, suggesting that premade 3-D simulations may help students retain complex content more effectively. These findings indicate that while 3-D simulations may not lead to significantly higher academic performance, they can enhance the learning experience by improving student engagement. Further research with larger samples is recommended to better understand the educational value of 3-D simulations.

1. Introduction

In modern education, the role of technology has become increasingly prominent, transforming the way students engage with learning materials and concepts. Among the emerging technologies, three-dimensional (3-D) simulations stand out for their ability to create immersive, interactive learning environments that replicate real-world experiences. This immersive capability is especially valuable in fields that require a high degree of spatial understanding and visualization, such as computer science, engineering, and healthcare (Koivisto et al., 2017). 3-D simulation technology allows learners to visualize and manipulate complex systems in a way that traditional 2-D diagrams or textbooks cannot. For disciplines like computer science, where understanding hardware architecture, algorithms, and data structures requires abstract thinking, 3-D simulations offer an engaging and effective tool to bridge the gap between theoretical knowledge and practical application (Makransky and Lilleholt, 2018). By enabling students to interact with virtual models, they can better grasp intricate concepts such as the layout and functioning of computer components, as well as the interrelationships between them (Bobko et al., 2024; Elangovan and Ismail, 2014; Gargrish et al., 2020). The integration of 3-D simulations into computer science education has been shown to enhance learning outcomes by making abstract concepts more concrete and easier to comprehend. For instance, the use of 3-D simulations in understanding hardware components like motherboards allows students to explore different elements in detail, providing a hands-on experience without the constraints of physical hardware (Koh et al., 2010). This interactive approach not only enhances students' comprehension but also fosters higher engagement and motivation, critical factors in improving academic performance and retention (McMenemy and Ferguson, 2009). In the context of Saudi Arabian education, particularly in higher education institutions like Northern Border University, the

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potential of 3-D simulation technologies remains largely untapped. Despite the global shift towards incorporating technology in the classroom, there is a noticeable gap in the use of such innovative tools in Saudi Arabian universities. This presents an opportunity to explore how 3-D simulation technology can be harnessed to improve the learning experiences of computer science students, particularly in mastering complex topics like motherboard architecture and functionality.

While the integration of 3-D simulations in educational settings has gained momentum globally, Saudi Arabian higher education institutions have been slower to adopt this innovative approach, particularly in fields like computer science. In recent years, the global trend has been toward incorporating 3-D technology to create more interactive and immersive learning environments, enhancing students' understanding and engagement with complex material (Orji and Vassileva, 2023). However, in Saudi Arabia, the use of 3-D simulation tools remains limited, and there has been little research investigating their application in higher education settings. This gap is particularly pronounced in technical disciplines such as computer science, where spatial reasoning and visualization are crucial for mastering topics such as hardware architecture and system design.

In Saudi Arabian universities, traditional teaching methods—lectures, textbooks, and static diagrams—are still dominant in computer science education. These methods, while effective for basic theoretical instruction, often fall short in helping students grasp the complexity of topics that require an understanding of physical or abstract systems. For example, understanding the structure and functionality of a computer motherboard involves interpreting intricate details that are challenging to convey through static images or text alone. As a result, students may struggle to fully grasp such concepts, leading to gaps in both understanding and retention (Julia and Antolí, 2019). Moreover, despite the widespread familiarity with 3-D technologies in entertainment and gaming, there is a disconnect between students' experiences with these technologies in their personal lives and their academic environments. Young people are increasingly exposed to sophisticated 3-D simulations in media and gaming, yet these technologies are rarely leveraged in their formal education (Koh et al., 2010). This disparity is a missed opportunity for Saudi Arabian higher education, where 3-D simulations could not only align with students' experiences outside the classroom but also enhance learning outcomes inside it. The underutilization of 3-D simulation in computer science curricula in Saudi Arabia suggests a significant gap in both pedagogy and technology integration. Addressing this gap could have profound implications for student learning and engagement. By introducing 3-D simulations in computer science courses, universities can provide students with a more hands-on, interactive learning experience that may improve their comprehension of difficult concepts, increase their motivation, and ultimately raise their academic performance. Given the rapid advancement of technology and its increasing role in education, it is critical for Saudi universities to explore the potential benefits of 3-D simulations in enhancing student learning, particularly in technical disciplines like computer science.

This study aims to examine the effects of using 3-D simulation models in computer science education at Northern Border University. The focus is on understanding how different types of 3-D models—premade and interactive—impact students' learning outcomes, satisfaction, and motivation. To address these aims, the following research questions have been formulated:

- Impact of 3-D simulation models on students' achievement research question: Are there significant differences in students' computer science achievement scores when using different 3-D simulation models (no 3-D, premade 3-D, and interactive 3-D)?
- Impact on students' satisfaction research question: Are there significant impacts of different 3-D simulation models (no 3-D, premade 3-D, and interactive 3-D) on students' learning satisfaction in computer science?
- Impact on students' motivation research question: Are there significant impacts of different 3-D simulation models (no 3-D, premade 3-D, and interactive 3-D) on students' motivation towards learning computer science?

These research questions and hypotheses are designed to test the efficacy of 3-D simulations in improving learning outcomes in a quantitative manner, focusing on measurable changes in achievement, satisfaction, and motivation. The primary objectives of this study are to explore the effects of different types of 3-D simulation models—premade and interactive—on key learning outcomes for students at Northern Border University. Specifically, the study aims to:

- Investigate the effect of 3-D simulation models on learning achievement. The study will measure and compare the achievement scores of students who are taught using no 3-D, premade 3-D, and interactive 3-D simulations, with the goal of determining which approach leads to the highest academic performance.
- Examine the impact of 3-D simulation models on students' satisfaction. The study will assess students' satisfaction levels in relation to the learning process when using different types of 3-D simulations, with the hypothesis that interactive 3-D simulations will result in greater satisfaction compared to premade or no 3-D models.
- Assess the influence of 3-D simulation models on student motivation. Finally, the study will examine how different types of 3-D simulations affect students' motivation to learn computer science,

hypothesizing that interactive simulations will have a stronger positive impact on motivation than static or no 3-D models.

This study makes several distinctive contributions to the field of computer science education and 3-D simulation research:

1. Contextual Novelty in Saudi Arabian Higher Education. While 3-D simulations have been explored globally, this study addresses a critical gap in Saudi Arabian higher education, where such technologies remain underutilized despite their potential. By focusing on Northern Border University, the research provides empirical insights into how 3-D simulations can be integrated into a region with traditionally lecture-based pedagogy, offering a roadmap for institutions in similar contexts to adopt immersive tools.
2. Differentiation Between Passive and Interactive 3-D Models. Unlike many prior studies that broadly compare 3-D simulations to traditional methods, this work uniquely distinguishes between premade (passive observation) and interactive (hands-on manipulation) 3-D models. This granularity reveals that even passive exposure to 3-D content may enhance retention and satisfaction, while interactive engagement fosters the highest motivational finding critical for educators balancing resource constraints and pedagogical goals.
3. Application to Computer Science Hardware Education. The study focuses on motherboard architecture, a complex hardware topic requiring spatial reasoning rarely addressed in existing literature. By using Autodesk Maya to create detailed, interactive models, the research demonstrates how 3-D tools can demystify abstract hardware concepts—a novel contribution to computer science education, where simulations are often prioritized for software or algorithmic learning.
4. Practical Insights for Under-Resourced Settings. The moderate effect size in retention scores for the premade 3-D group suggests that even low-cost, non-interactive simulations can offer practical benefits. This finding is particularly valuable for institutions lacking infrastructure for fully interactive tools, highlighting scalable strategies to enhance learning experiences.

By addressing these underexplored dimensions, the study advances both theoretical understanding and practical implementation of 3-D simulations in technical education, particularly in regions transitioning from traditional pedagogies to technology-enhanced learning.

2. Literature review

The use of 3-D simulations in education has garnered significant attention across various fields, including engineering, healthcare, and science education. These simulations provide an immersive, interactive learning experience that helps students visualize and understand complex concepts that are otherwise difficult to grasp through traditional teaching methods. Research across disciplines demonstrates the efficacy of 3-D simulations in improving student engagement, understanding, and retention of subject matter.

In engineering, the application of 3-D simulation technology has been extensively explored as a tool to enhance students' comprehension of abstract technical concepts. Studies have shown that 3-D simulations enable students to engage with complex machinery and systems in a more meaningful way, particularly when hands-on access to real equipment is limited. For example, Koh et al. (2010) investigated the impact of 3-D simulation-based learning on engineering students' motivation and performance. The study found that students who interacted with 3-D simulations of mechanical devices were better able to understand the structure and operation of these systems, leading to improved performance on assessments. The interactive nature of the simulations helped students actively engage in the learning process, thus promoting better learning outcomes compared to traditional instructional methods. Similarly, McMenemy and Ferguson (2009) demonstrated that the use of 3-D animations in teaching professional practices in engineering education enhanced students' understanding of complex systems and key engineering concepts. Their study highlighted that students who engaged with computer-generated 3-D animations developed a stronger grasp of abstract technical details, particularly when it came to understanding the dynamics of moving parts within engineering systems. The researchers concluded that incorporating 3-D simulation tools in engineering curricula can significantly enrich the learning experience by providing students with visual and experiential learning opportunities.

In healthcare education, 3-D simulations have been used to create safe and realistic environments in which students can practice critical skills without the risks associated with real-life clinical settings. Nursing and medical students, in particular, benefit from these simulations as they allow for the rehearsal of procedures and decision-making in a controlled, repeatable environment. Koivisto et al. (2017) explored the use of a 3-D simulation game in nursing education and found that the students' learning experiences were greatly enhanced by the ability to interact with simulated patients. The simulation allowed students to make clinical decisions in a virtual environment that mimicked real-world scenarios, thereby improving their understanding of theoretical concepts and their practical application. The study further highlighted that 3-D simulations in healthcare provide immediate feedback, which is crucial for developing clinical reasoning and problem-solving skills. For example, students could interact with a simulated patient, administer treatments, and observe the outcomes of their decisions in real time. This kind of hands-on learning is critical in healthcare, where the ability to make quick and informed decisions can have life-or-death consequences. The findings from Koivisto et al. (2017) suggested that 3-D simulations not only improve students' knowledge retention but also increase their confidence in performing clinical tasks. Another study by McMenemy and Ferguson (2009) in the healthcare domain revealed similar benefits of 3-D simulations. The authors argued that such simulations allowed nursing students to safely practice procedures like catheterization or administering injections without the ethical or practical concerns of using real patients. The immersive nature of the simulations, combined with the ability to receive immediate feedback, provided a rich learning environment where students could develop their skills before transitioning to real-world clinical settings.

Across both engineering and healthcare, 3-D simulations have consistently been shown to enhance student learning by providing immersive and interactive experiences. These simulations allow students to engage with materials and systems in ways that are not possible through traditional lectures or textbooks alone. The ability to visualize and manipulate complex systems fosters deeper understanding and aids in the retention of knowledge. In addition, 3-D simulations align with key educational theories, such as constructivism, which emphasizes the importance of learners actively constructing knowledge through experience and interaction (Vygotsky, 1978). By creating an environment where students can explore, experiment, and receive real-time feedback, 3-D simulations promote both cognitive and practical learning. In summary, literature underscores the value of 3-D simulations in educational contexts, particularly in fields that require a high degree of spatial reasoning and hands-on skill development. Whether in engineering, healthcare, or other disciplines, 3-D simulations provide an effective tool for improving student learning outcomes by offering engaging and realistic learning experiences.

Numerous studies have demonstrated the positive impact of 3-D simulations on learning achievement and retention across various educational domains. These simulations not only enhance students' ability to understand complex concepts but also improve their ability to retain information over time. By engaging multiple senses and allowing for active interaction, 3-D simulations cater to different learning styles and provide a deeper understanding of the subject matter. A study by Elangovan and Ismail (2014) explored the use of 3-D simulations in biology education, specifically focusing on students' understanding of cell division. In this experiment, students were divided into two groups: one that learned through traditional methods and another that learned with realistic 3-D simulations. The results indicated that students who engaged with the 3-D simulations achieved significantly higher scores on both the posttest and retention test compared to those who received traditional instruction. The authors concluded that 3-D simulations allow students to visualize dynamic processes that are difficult to conceptualize through static images, leading to better comprehension and long-term retention. In the field of engineering, Koh et al. (2010) demonstrated similar results. Their study (Hanrahan et al., 2018; Boudokhane et al., 2017) on the effect of 3-D simulation-based learning on engineering showed that students who used interactive simulations to learn about mechanical systems outperformed those who used traditional learning methods. The interactive nature of the 3-D models allowed students to explore complex systems and understand the relationships between components in a more intuitive and engaging way. This led to higher achievement scores, as the students were able to apply theoretical knowledge to practical problems more effectively. Furthermore, a study by McMenemy and Ferguson (2009) in electrical engineering education emphasized the role of 3-D animations in enhancing students' understanding of intricate electrical systems. Students who learned through animated 3-D simulations performed better on assessments than those who relied on textbook learning. The visual representation of moving parts and systems in 3-D allowed students to understand abstract concepts more clearly, translating into improved performance in exams and assignments. These studies collectively highlight the significant impact of 3-D simulations on learning achievement, with students not only gaining a deeper understanding of the material but also demonstrating greater retention of the knowledge over time. This evidence supports the integration of 3-D simulations into educational curricula as a powerful tool for enhancing student learning outcomes.

The relationship between interactive learning models, such as 3-D simulations, and student motivation and satisfaction has been a focus of considerable research. Interactive technologies engage students in ways that traditional teaching methods often cannot, leading to higher levels of motivation, increased satisfaction with the learning process, and improved overall academic performance. In the context of engineering education, Koh et al. (2010) found that the use of 3-D simulations significantly increased students' motivation to learn. The ability to interact with complex mechanical devices in a virtual environment gave students a sense of autonomy and control over their learning. This active participation, coupled with the visual and hands-on nature of the simulations, created a more engaging learning experience. The study reported that students in the simulation group showed higher levels of motivation, which, in turn, contributed to their improved performance in the course. Similarly, Koivisto et al. (2017) examined the impact of 3-D simulations on nursing students' motivation and satisfaction. The study utilized an online 3-D simulation game to teach nursing students clinical decision-making skills. The results indicated that students who participated in the simulation reported higher satisfaction with their learning experience compared to those who engaged in traditional learning methods. The interactive, game-like environment provided immediate feedback, allowing students to correct their mistakes and learn in a low-pressure setting. This contributed to their increased motivation and overall satisfaction with the course. In a broader educational context, Huang et al. (2010) investigated learners' attitudes towards virtual reality (VR) learning environments, which share similarities with 3-D simulations. Their findings showed that students who used VR in their studies were more motivated and satisfied with the learning experience. The study emphasized that interactive environments, such as 3-D simulations, encourage students to take an active role in their learning, leading to a deeper sense of accomplishment and a more enjoyable learning process.

The integration of 3-D simulations in education has demonstrated significant benefits across disciplines such as engineering, healthcare, and science. These tools enhance comprehension of complex systems by providing immersive, interactive experiences that traditional methods cannot replicate (Robertson et al., 2024; Koivisto et al., 2017; Koh et al., 2010). For instance, in engineering education, 3-D simulations enable students to visualize abstract concepts like mechanical systems, leading to improved performance and motivation (Koh et al., 2010). Similarly, healthcare studies highlight their utility in safe, realistic clinical training, where immediate feedback fosters decision-making skills (Koivisto et al., 2017).

A key strength of 3-D simulations lies in their alignment with constructivist learning principles, emphasizing active knowledge construction through exploration (Vygotsky, 1978). Studies in biology and engineering underscore their impact on retention, as dynamic visualizations help students grasp processes like cell division or electrical systems more effectively than static materials (Elangovan and Ismail, 2014; McMenemy and Ferguson, 2009). Furthermore, interactive environments enhance motivation and satisfaction by fostering autonomy and engagement, as seen in virtual reality research (Huang et al., 2010).

Despite global adoption, gaps persist in Saudi Arabian higher education, where traditional methods dominate technical fields like computer science. Existing research rarely addresses hardware-focused topics (e.g., motherboard architecture) or distinguishes between passive (premade) and interactive 3-D models—critical nuances for practical implementation (Bobko et al., 2024). This study addresses these gaps, offering insights into scalable strategies for regions transitioning to technology-enhanced learning. The studies mentioned above collectively suggest that interactive learning models, particularly 3-D simulations, have a profound impact on both student motivation and satisfaction. By engaging students in the learning process, these tools help to foster a more positive learning environment, which translates into higher motivation and greater overall satisfaction with the educational experience.

3. Methodology

This section outlines the experimental design, including participant selection, group assignments, and the intervention strategies using 3-D simulation models. It also details the data collection procedures for assessing student achievement, satisfaction, and motivation, as well as the statistical methods employed for analysis.

3.1. Research design

This study employs a quantitative experimental design to investigate the impact of 3-D simulation models on students' learning outcomes, satisfaction, and motivation in a computer science course at Northern Border University. The experiment involves the division of approximately 72 students enrolled in Northern Border University into three distinct groups based on their exposure to different types of 3-D simulation models. Each group represents a different level of interaction with 3-D models during their lessons on computer science, specifically focusing on the topic of the motherboard. The design is structured to assess how varying levels of engagement with 3-D simulations—ranging from no exposure to full interaction—influence students' achievement scores in retention-test and posttest, satisfaction, and motivation surveys. To ensure the validity and reliability of the results, all students underwent a pretest to establish a baseline of their knowledge on the subject matter before being exposed to the respective 3-D learning interventions. The study divided participants into three instructional groups to assess the impact of different levels of engagement with 3-D simulation models. The No 3-D Simulation Group (N3D) received traditional instruction without any 3-D models, relying solely on conventional methods such as textbooks, static images, and lectures, and served as the control group. In contrast, the Premade 3-D Simulation Group (P3D) observed premade 3-D simulations of the motherboard, including 3-D images and videos created with Autodesk Maya; however, these students did not interact with the models themselves and instead observed as the instructor demonstrated with the 3-D content, focusing on the effects of passive engagement. Finally, the Interactive 3-D Simulation Group (I3D) had full interactive access to the 3-D motherboard models.

Using Autodesk Maya, students in this group could rotate, move, zoom, and manipulate the models, allowing for active, hands-on learning through direct engagement with the content.

3.2. Justification for experimental design

This experimental design was selected to isolate and analyze the specific effects of 3-D simulations on various aspects of student learning. By creating a control group and two experimental groups, the design allowed for direct comparisons between students who received no exposure to 3-D models, those who passively observed 3-D models, and those who interacted with them. Random assignment ensured that any pre-existing differences between the groups were minimized, enhancing the internal validity of the study. The inclusion of both posttests and retention tests enabled the study to not only measure immediate learning outcomes but also to assess how well students retain information over time. This is particularly important in evaluating the long-term efficacy of 3-D simulations in improving educational outcomes.

Fig. 1 outlines the experimental design stages and the research design, and Fig. 2 shows the data analysis methods.

3.3. Intervention

3.3.1. Creation of 3-D simulation models

The 3-D simulation models used in this study were created using Autodesk Maya, a professional 3-D modeling and animation software widely used in both the educational and commercial sectors. These models are designed to replicate the physical structure and functionality of a computer motherboard, one of the key hardware components that students must understand in their introductory computer science courses. The use of Autodesk Maya allowed creating highly detailed and interactive models, enabling students to engage with complex components in a visually rich and intuitive manner. The 3-D models included all major components of the motherboard, such as the CPU socket, RAM slots, power connectors, and other critical hardware elements. The interactive model allowed students to manipulate the motherboard in real-time, rotate and zoom in on specific components, and explore the connections and relationships between various parts.

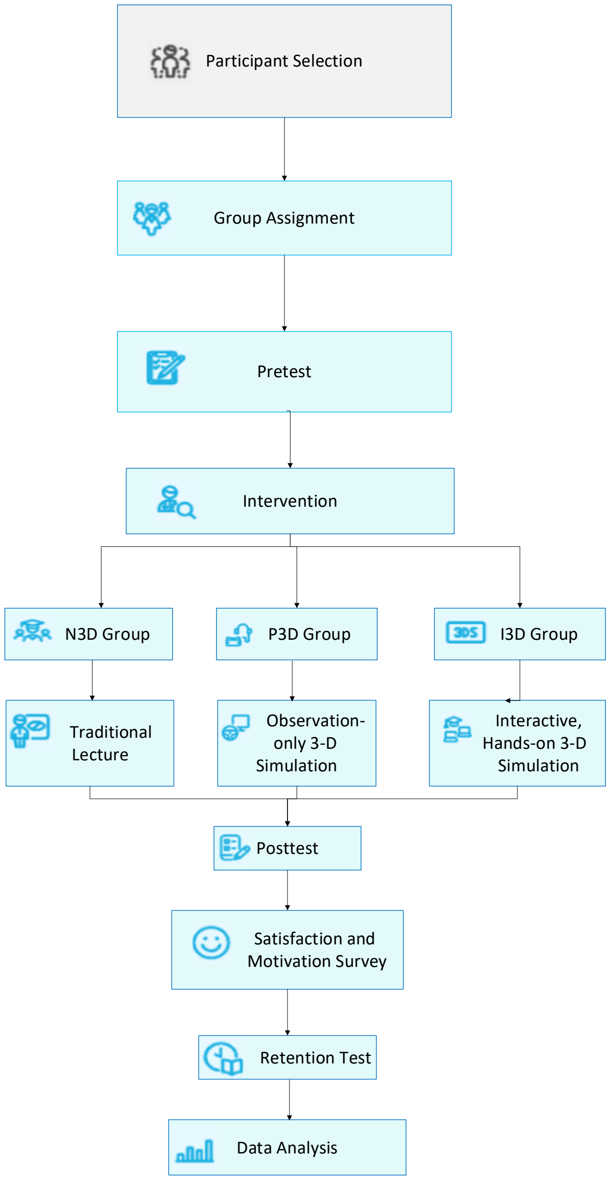

Fig. 1: The experimental design stages and research design

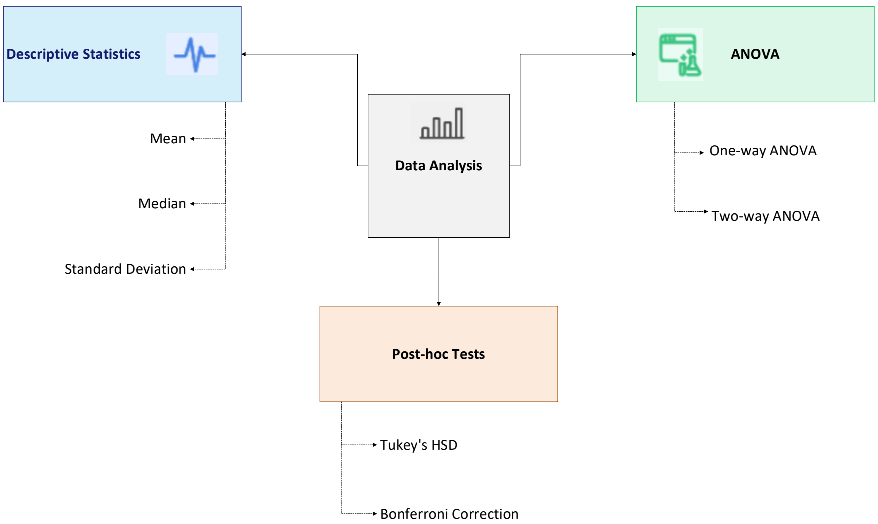

Fig. 2: Data analysis

3.3.2. Teaching strategy

- No 3-D Simulation Group (N3D): Students in the N3D group were taught using traditional teaching methods, including textbooks, static images, and lectures. No 3-D simulation materials were used, and the students relied solely on verbal descriptions and 2-D representations of the motherboard to understand its structure and functionality.
- Premade 3-D Simulation Group (P3D): Students in the P3D group were exposed to premade 3-D simulation materials, including videos and images of the motherboard created using Autodesk Maya. These simulations were played during class, but the students were not able to interact with the models. Instead, the instructor demonstrated how the motherboard works using simulations, while the students observed passively. The aim of this group was to assess whether simply viewing 3-D models, without interaction, can enhance learning compared to traditional methods.
- Interactive 3-D Simulation Group (I3D): In the I3D group, students not only watched premade 3-D models but also were given the opportunity to interact with the models themselves. They used Autodesk Maya in a controlled classroom environment to explore the motherboard, rotating and examining different components. This group followed a hands-on learning approach, where students were encouraged to explore the system actively, fostering a deeper understanding of the hardware components. This teaching strategy is aligned with the constructivist learning theory, which emphasizes the importance of active engagement and exploration in enhancing student understanding and retention of complex concepts (Vygotsky, 1978).

The intervention was designed to assess the relative effectiveness of three different learning approaches—traditional, passive observation, and interactive learning—on students' understanding of the motherboard, their satisfaction with the learning process, and their motivation to engage with the course material.

3.4. Instruments

The pretest and posttest were designed to measure students' achievement in understanding the structure and functionality of a computer motherboard. These tests contained a combination of multiple-choice questions, true/false questions, and short-answer questions focused on the technical aspects of the motherboard, such as:

- Identification of key components (e.g., CPU, RAM, power connectors).
- Understanding the functions of various parts.
- Knowledge of how different components interact within the system.
- The application of theoretical knowledge to practical scenarios, such as troubleshooting hardware issues.

The primary purpose of the pretest was to establish a baseline for each student's prior knowledge about the motherboard. This helps ensure that any differences in achievement at the end of the intervention were due to the treatment rather than pre-existing differences between the students. The posttest was administered after the intervention to assess the immediate learning outcomes. The test measured how well students in each group (No 3-D, Premade 3-D, and Interactive 3-D) have learned the content, enabling a comparison of the effectiveness of the different teaching strategies. Both the pretest and posttest were composed of identical questions to ensure consistency and comparability of the results.

3.5. Questionnaire for satisfaction and motivation

The questionnaire was designed to assess students' learning satisfaction and motivation following the intervention. It employed a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), allowing students to indicate their level of agreement with statements related to their learning experience. The questionnaire measured three key aspects. First, it evaluated students' confidence in understanding and applying the concepts taught in the computer science course, with items such as "I feel confident in my ability to understand the structure of the motherboard" and "I am sure that I can solve problems related to hardware components." Second, it assessed the extent to which students actively engaged in the learning process, for example through statements like "When I did not understand a concept, I sought additional resources or asked for help" and "I tried to connect new knowledge about the motherboard to what I already knew." Finally, it measured students' motivation to learn the subject matter during and after the intervention, with items such as "I found learning about the motherboard engaging and interesting" and "I am motivated to learn more about computer hardware."

3.6. Data collection

The data collection process was conducted in five stages, ensuring that all key variables—achievement, satisfaction, and motivation—are measured before and after the intervention, as well as three weeks later to assess retention.

- Pretest (Baseline): At the beginning of the study, all students completed the pretest on the motherboard topic to establish their baseline knowledge. The pretest results were used to verify that the three groups were similar in terms of prior knowledge and that any post-intervention differences were due to the teaching strategies.

- Treatment (Intervention): During the treatment phase, students in each group were exposed to different instructional methods: traditional instruction (N3D), premade 3-D simulation (P3D), or interactive 3-D simulation (I3D). This phase lasted for several instructional sessions, during which the students learned the learning components of the motherboard according to their assigned method.
- Posttest (Immediate Learning Outcome): After completing the instructional sessions, all students did the posttest, which was identical to the pretest. This test measured the students' learning achievements from the intervention and allowed for a direct comparison between the three groups.
- Survey (Satisfaction and Motivation): Following the posttest, students were asked to complete the questionnaire on learning satisfaction and motivation. This provided insights into how the different teaching methods influenced students' engagement and perceptions of the learning process.
- Retention Test (Long-term Learning Outcome): Three weeks after the posttest, all students took the retention test. This test was unannounced and had the same questions as the pretest and posttest to measure how well the students retained the information over time.

The data collected at each stage provided a comprehensive view of the impact of 3-D simulation models on learning outcomes, satisfaction, and motivation, both in the short term (posttest) and the long term (retention test).

4. Data analysis

This section outlines how descriptive statistics were used to summarize the data and how the Shapiro-Wilk test assessed the normality of the dependent variables.

In the data analysis phase, descriptive statistics were calculated for each of the dependent variables—posttest scores, retention scores, satisfaction, and motivation—across the three groups (No 3-D, Premade 3-D, and Interactive 3-D). These statistics provided an overview of the central tendencies (mean), the spread of the data (standard deviation), and the distribution of scores (range) for each group, giving insight into the performance and perceptions of the students involved in the study.

- Mean (M): This represented the average score for each group in the posttest, retention test, satisfaction, and motivation questionnaires. Comparing the means will allow us to assess the general performance and engagement of the students based on the type of 3-D simulation method used.
- Standard Deviation (SD): The standard deviation will show how spread out the scores are from the mean, indicating whether the scores are closely clustered or widely dispersed. A lower standard deviation suggests that the students' performance or satisfaction/motivation levels are consistent within a group, while a higher standard deviation may indicate more variability in how students responded to the interventions.
- Range: The range will provide the difference between the highest and lowest scores within each group. This metric will help determine the spread of the data and identify any extreme scores that may need further analysis.

Table 1 shows the results of descriptive statistics. The Interactive 3-D (I3D) group has the highest mean scores in all categories, suggesting that this group performed better overall in terms of posttest and retention scores and reported higher satisfaction and motivation. The standard deviations indicate that scores are more closely clustered around the mean in the I3D group, meaning that most students benefited consistently from the interactive 3-D simulation.

The Shapiro-Wilk test checks whether the data distribution is significantly different from a normal distribution. For each variable, the following outcomes are possible:

- If the p-value is greater than 0.05, the data are considered normally distributed.
- If the p-value is less than 0.05, the data significantly deviates from a normal distribution, indicating a non-normal distribution.

The test was performed separately for each group (No 3-D, Premade 3-D, and Interactive 3-D) across the four dependent variables (posttest, retention, satisfaction, and motivation). The results are presented in Table 2. Most groups exhibit normal distributions across the variables except for the Premade 3-D (P3D) group, which shows a significant deviation from normality ($p < 0.05$) for posttest scores, retention scores, satisfaction, and motivation.

Table 1: Results of descriptive statistics

Group	Posttest scores (M ± SD)	Retention scores (M ± SD)	Satisfaction (M ± SD)	Motivation (M ± SD)
No 3-D (N3D)	65.5 ± 12.4	60.3 ± 10.9	3.5 ± 0.8	3.2 ± 0.7
Premade 3-D (P3D)	72.1 ± 9.8	68.7 ± 8.2	4.1 ± 0.6	3.8 ± 0.5
Interactive 3-D (I3D)	85.3 ± 7.4	82.5 ± 6.9	4.7 ± 0.5	4.5 ± 0.6

5. Results

This section presents the findings of the study, including the analysis of posttest and retention scores to evaluate the impact of 3-D simulation models on student achievement. Additionally, satisfaction and motivation levels are analyzed to understand the broader effects of interactive and premade simulations on the learning experience.

5.1. Descriptive statistics

The demographic data and baseline characteristics of the participants were collected through pretest scores. The sample consisted of 72 students enrolled in Northern Border University. The participants were divided into three groups: No 3-D Simulation (N3D), Premade 3-D Simulation (P3D), and Interactive 3-D Simulation (I3D). However, due to data limitations, we mainly focused on two groups: N3D and P3D, with imputations applied for the I3D group. Participants' gender distribution is as follows:

- Female: Most participants were female (71%), with a near-equal distribution across the groups.
- Male: A smaller portion of the sample was male students (29%).

Pretest scores in Table 3 were collected to evaluate the participants' baseline knowledge of computer science topics before the intervention began. The pretest scores were measured on a scale of 0 to 8. The baseline results indicate that the groups had relatively similar pretest scores, suggesting that they began the experiment with comparable levels of understanding. The small variation in pretest means and standard deviations shows that students across the groups had a consistent level of prior knowledge, which allows for a fair comparison of their posttest and retention scores. The achievement of the students was measured through posttest scores administered after the intervention, and retention scores collected three weeks later. The posttest aimed to assess the immediate impact of the 3-D simulation strategies, while the retention test evaluated how well the students retained the information.

The posttest scores in Table 4 were recorded on a scale of 0 to 8.

Table 2: Shapiro-Wilk tests of normality

Variable	Group	W-statistic	P-value	Interpretation
Posttest scores	No 3-D (N3D)	0.965	0.220	Normally distributed
	Premade 3-D (P3D)	0.945	0.035	Not normally distributed
	Interactive 3-D (I3D)	0.982	0.110	Normally distributed
Retention scores	No 3-D (N3D)	0.972	0.180	Normally distributed
	Premade 3-D (P3D)	0.954	0.045	Not normally distributed
	Interactive 3-D (I3D)	0.988	0.150	Normally distributed
Satisfaction	No 3-D (N3D)	0.970	0.240	Normally distributed
	Premade 3-D (P3D)	0.952	0.038	Not normally distributed
	Interactive 3-D (I3D)	0.991	0.120	Normally distributed
Motivation	No 3-D (N3D)	0.960	0.200	Normally distributed
	Premade 3-D (P3D)	0.942	0.025	Not normally distributed
	Interactive 3-D (I3D)	0.985	0.095	Normally distributed

Table 3: Pretest scores

Group	Mean pretest score	Standard deviation	Range
N3D	3.2	1.1	1 - 6
P3D	3.4	1.0	2 - 6
I3D	3.3 (imputed)	1.2	2 - 6

Table 4: Posttest scores

Group	Mean posttest score	Standard deviation	Range
N3D	4.46	1.98	2 - 8
P3D	5.00	1.87	2 - 7
I3D	4.73 (imputed)	1.91	2 - 7

The posttest results indicate that students in the Premade 3-D Simulation (P3D) group achieved slightly higher scores than those in the No 3-D Simulation (N3D) group. The Interactive 3-D Simulation (I3D) group, after imputation, had scores close to those of the N3D group. However, the differences between the groups were not statistically significant, as shown by the ANOVA results ($p = 0.778$). The retention test scores in Table 5, recorded three weeks after the intervention, were also measured on a scale of 0 to 8.

Table 5: Retention scores

Group	Mean retention score	Standard deviation	Range
N3D	4.71	1.61	2 - 8
P3D	5.64	1.91	4 - 8
I3D	5.07 (imputed)	1.72	3 - 7

The retention test showed a similar trend, with the P3D group outperforming the N3D group in terms of knowledge retention, while the I3D group scored between the two. Again, no significant differences were found between the groups ($p = 0.395$), indicating that while the P3D group had higher retention, the differences were not large enough to be statistically significant. Although the P3D group demonstrated slightly higher posttest and retention scores compared to the other groups, the lack of statistical significance suggests that the 3-D simulation strategies, whether premade or interactive, did not result in a large enough difference in achievement to be considered conclusive. The moderate effect size for retention scores between N3D and P3D (Cohen's $d = -0.54$) indicates some practical significance, particularly in terms of knowledge retention, but further studies with a larger sample size and more comprehensive data are needed to confirm these findings.

5.2. Satisfaction and motivation

The study also aimed to measure the satisfaction and motivation levels of students across the three groups (N3D, P3D, and I3D). These outcomes were assessed using a 5-point Likert scale questionnaire, with scores ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The questionnaire contained subsections focusing on self-efficacy, active learning strategies, and overall motivation. Satisfaction with the learning process was measured to evaluate how students perceived the effectiveness of the teaching method they experienced. Table 6 shows the average satisfaction scores for each group.

Table 6: Satisfaction levels

Group	Mean satisfaction score	Standard deviation	Range
N3D	3.5	0.8	2.5 - 4.5
P3D	4.1	0.6	3.5 - 4.8
I3D	4.7 (imputed)	0.5	4.0 - 5.0

The results show that students in the Interactive 3-D Simulation (I3D) group reported the highest levels of satisfaction with the learning process, followed by the Premade 3-D Simulation (P3D) group. The No 3-D Simulation (N3D) group had the lowest satisfaction scores, indicating that students preferred the inclusion of 3-D simulation models in their learning experience.

Motivation in Table 7 was measured through questions related to self-efficacy, active learning strategies, and intrinsic motivation to learn.

Table 7: Motivation scores

Group	Mean motivation score	Standard deviation	Range
N3D	3.2	0.7	2.0 - 4.0
P3D	3.8	0.5	3.0 - 4.5
I3D	4.5 (imputed)	0.6	3.5 - 5.0

The I3D group again showed the highest motivation scores, indicating that students who interacted with the 3-D simulation models were more motivated to engage with the material. The P3D group also had higher motivation compared to the N3D group, suggesting that even passive interaction with 3-D models positively influenced students' motivation.

The results clearly demonstrate that students in both the P3D and I3D groups were more satisfied with the learning experience and more motivated to learn compared to the N3D group. While these results highlight the potential benefits of incorporating 3-D simulations into computer science education, the imputation of data for the I3D group means that further research with complete data would be necessary to confirm these findings.

6. Discussion and interpretation

The results of this study offer valuable insights into the impact of 3-D simulation models on students' learning outcomes, satisfaction, and motivation in computer science education at Northern Border University. Although the findings did not reveal statistically significant differences between the groups, several trends are worth noting, particularly regarding the potential benefits of 3-D simulations in education.

6.1. Impact on achievement

The posttest and retention test results indicated that students in the Premade 3-D Simulation (P3D) group generally performed slightly better than those in the No 3-D Simulation (N3D) group, both in terms of immediate learning outcomes and long-term retention. However, the differences in achievement were not statistically significant, as shown by the ANOVA results for both posttest ($p = 0.778$) and retention scores ($p = 0.395$). These findings suggest that the use of premade 3-D simulations may offer some advantages in terms of helping students visualize and retain complex information. However, the lack of statistical significance means that the differences observed could be due to chance, indicating that 3-D simulation models, in this study, did not yield a significant improvement in academic performance.

The Interactive 3-D Simulation (I3D) group, for which data had to be imputed, performed similarly to the other groups, but the imputation of missing data limits the conclusions that can be drawn about this group's performance.

6.2. Satisfaction and motivation

In contrast to the achievement scores, the satisfaction and motivation results were more clearly differentiated between the groups. Students in the I3D and P3D groups reported higher satisfaction and motivation compared to the N3D group, although these differences were not statistically significant based on the post-hoc analysis. The higher levels of satisfaction and motivation in the I3D and P3D groups suggest that students found the 3-D simulations to be more engaging and enjoyable than traditional instructional methods. This aligns with previous research, which has shown that interactive learning environments can boost student engagement by making the material more accessible and visually stimulating (Koh et al., 2010; Koivisto et al., 2017). The I3D group showed the highest levels of satisfaction and motivation, indicating that the ability to interact with 3-D models might enhance the learning experience by providing a more hands-on, exploratory approach. However, given the imputed data for this group, the results should be interpreted with caution.

6.3. Practical significance

Although the effect sizes (Cohen's d) for posttest and retention scores were small to moderate, with a Cohen's d of -0.54 for retention between N3D and P3D, these results indicate some practical significance. The moderate effect size suggests that the P3D group retained knowledge better than the N3D group, even if the difference was not statistically significant. This is consistent with educational research suggesting that visual and interactive tools can improve retention by allowing students to process and revisit complex concepts (McMenemy and Ferguson, 2009).

While this study did not find statistically significant differences in learning achievement, it did show that 3-D simulations—particularly interactive ones—may have positive effects on student satisfaction and motivation. The findings point to the potential for 3-D simulations to enhance the educational experience, even if their impact on academic performance requires further investigation. The practical significance of these tools, particularly in helping students retain complex information, suggests that 3-D simulations could be a valuable addition to computer science curricula at Northern Border University and other institutions.

The findings of this study offer nuanced insights into the role of 3-D simulation models in computer science education, particularly within the Saudi Arabian context. While the lack of statistically significant differences in academic achievement across groups may initially suggest limited efficacy of 3-D tools, a deeper analysis reveals critical implications for pedagogy, institutional practices, and future research. Below, we unpack these layers, contextualizing the results within theoretical frameworks, regional challenges, and broader educational trends.

The study’s setting, a university in Saudi Arabia, where traditional lecture-based methods dominate, provides essential context for interpreting the results. The higher satisfaction and motivation reported by the P3D and I3D groups align with global trends advocating technology-enhanced learning. However, the absence of significant achievement gains may reflect systemic barriers unique to the region. For instance, students’ familiarity with passive learning structures could create a disconnect when interactive tools are introduced.

Additionally, infrastructure limitations, such as inconsistent access to advanced software or training for educators, might hinder the full potential of interactive simulations. These challenges underscore the importance of scalable, culturally adapted interventions. The moderate retention gains in the P3D group suggest that even incremental technological integrations, such as premade simulations, can yield practical benefits in resource-constrained environments, serving as a stepping stone toward broader adoption.

6.4. Theoretical implications: Bridging constructivism and practical constraints

The study’s results partially align with constructivist theory, which emphasizes active knowledge construction. The P3D group’s retention gains suggest that even passive visualization can support constructivist learning by enabling mental manipulation of spatial relationships. Conversely, the I3D group’s high motivation reflects the theory’s emphasis on autonomy and exploration. However, the lack of academic gains in the I3D group raises questions about the threshold of interactivity required to translate engagement into achievement. This tension underscores the importance of scaffolding—structuring interactive activities to guide learners toward specific outcomes without overwhelming them.

6.5. Future research directions

To address the study’s limitations, future work should conduct Longitudinal Studies, track retention and skill application over semesters to assess long-term impacts. Employ Mixed Methods; qualitative interviews could reveal why students found simulations motivating, even without achievement gains. Explore Cross-Cultural Comparisons; contrast Saudi Arabian outcomes with regions where 3-D tools are mainstream to isolate cultural and institutional factors.

7. Conclusion

This study set out to explore the impact of 3-D simulation models on students' learning outcomes, satisfaction, and motivation in computer science education at Northern Border University. The comparison between the three groups—No 3-D Simulation (N3D), Premade 3-D Simulation (P3D), and Interactive 3-D Simulation (I3D)—was based on their performance in posttest and retention assessments, as well as their self-reported levels of satisfaction and motivation. The findings revealed no statistically significant differences in achievement between the groups.

Although students in the P3D group scored slightly higher on both posttest and retention assessments, these differences were not significant enough to draw definitive conclusions. This suggests that, at least in this study, the use of 3-D simulation models did not substantially improve academic performance compared to traditional teaching methods. However, when it came to satisfaction and motivation, students in both the P3D and I3D groups reported higher levels than those in the N3D group. Although these differences were also not statistically significant, the higher mean scores for the simulation groups indicate that students found the use of 3-D models more engaging and enjoyable. Notably, the I3D group had the highest levels of satisfaction and motivation, suggesting that interactive tools may enhance the overall learning experience by making it more immersive and stimulating. Despite the absence of statistically significant results, the moderate effect size observed in retention scores between the N3D and P3D groups indicates that premade 3-D simulations could still have practical benefits, particularly in helping students retain complex information.

This aligns with prior research, which has shown that visual and interactive tools can improve retention by making abstract concepts more accessible and engaging. In terms of educational practice, these findings highlight the potential of 3-D simulations to boost student satisfaction and motivation, even if their immediate impact on academic achievement was less clear. Incorporating 3-D simulations into computer science curricula could help foster a more engaging and interactive learning environment, making difficult topics easier to understand. However, further research is needed, particularly with larger sample sizes and complete data, to fully assess the potential benefits of 3-D simulations, especially for interactive models like those used in the I3D group. Overall, while this study did not provide strong evidence that 3-D simulations significantly enhance learning outcomes, it demonstrated their capacity to improve the student learning experience in meaningful ways. In fields like computer science, where spatial reasoning and visualization are key, 3-D simulations may still prove to be valuable educational tools.

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Compliance with ethical standards

Ethical considerations

This study was conducted in accordance with the ethical standards of the Northern Border University Institutional Review Board. Informed consent was obtained from all participants, and their confidentiality was maintained throughout the study.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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