Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Impact of 2D and 3D Digital Storytelling within Interactive Simulation Environments on Mathematics Achievement and Geometry Skills of Students with Learning Difficulties

Zeyana Al-Hinai

230500om@aou.edu.om

Arab Open University

Sami Al-Mazroui

Arab Open University

Research Article

Keywords: Interactive simulation, Two-dimensional digital storytelling, Three-dimensional digital storytelling, Mathematics achievement, Learning difficulties

Posted Date: September 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9731016/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Impact of 2D and 3D Digital Storytelling within Interactive Simulation Environments on Mathematics Achievement and Geometry Skills of Students with Learning Difficulties.

Zeyana Al-Hinai[1], Sami Al-Mazroui[2]

Arab Open University of Oman, Muscat, Oman.

Corresponding author: Zeyana Ali Al-Hinai

Email: 230500om@aou.edu.om

Abstract:

The integration of interactive simulation and digital storytelling has emerged as a promising approach for improving mathematics learning among students with learning difficulties.

However, limited research has compared the effectiveness of two-dimensional and three-dimensional digital storytelling within interactive simulation environments. This study investigated the effects of these two instructional approaches on mathematics achievement and geometry skills among fifth grade female students with learning difficulties in Oman.

A quasi-experimental design was employed involving 40 participants who were assigned to two experimental groups. One group learned through three-dimensional digital storytelling within an interactive simulation environment, whereas the other group learned through the corresponding two-dimensional approach. Mathematics achievement was measured using an achievement test, and geometry skills were assessed through an observation checklist.

The findings revealed statistically significant improvements in mathematics achievement for both groups between pre and post assessments. Students who learned through three-dimensional digital storytelling achieved significantly higher mathematics achievement than those who learned through the two-dimensional approach, with a large effect size. Although both instructional approaches significantly improved geometry skills, no statistically significant difference was found between the two groups in the post observation assessment.

The findings demonstrate that integrating digital storytelling within interactive simulation environments is an effective instructional strategy for supporting mathematics learning among students with learning difficulties. The study recommends incorporating both approaches into mathematics instruction while considering the added benefits of three-dimensional digital storytelling for enhancing academic achievement.

Keywords: Interactive simulation; Two-dimensional digital storytelling; Three-dimensional digital storytelling; Mathematics achievement; Learning difficulties.

Introduction:

Digital technology has become an ultimate pillar of modern education. The combination of interactive tools and technologies has contributed significantly to improving the quality of learning and moving beyond traditional instructional methods toward more interactive and innovative learning environments. Considering the rapid digital transformations, technology has emerged as a dominant instrument in redesigning modes of expression and learning. One of these digital transformations is storytelling, which is no longer confined to conventional text-based formats but has evolved into more interactive forms integrated with multimedia. This interactive simulation has emerged as an innovative method that offers impactful interactive experiences, combining audio, images, video, and animations to produce narrative content that enhances the learner's experience and increases both cognitive and emotional engagement.

Interactive simulation is regarded as one of the effective instructional methods within the educational process, as it supports learners in interacting directly with simulation components, thereby enhancing their engagement and motivation in learning. Rather than merely watching the learning content, students become active participants in the educational process, with opportunities to make decisions, modify pathways, and respond to outcomes based on their own thinking. Moreover, interactive simulation is considered an effective educational medium that improves comprehension and skill development among students. It provides an interactive prototype that allows learners to repeat learning experiences and acquire concepts and skills until mastery is achieved. This technology simulates educational situations engagingly and interactively (Eroglu & Okur, 2021).

Accordingly, current scholars emphasize the importance of using interactive simulation environments as an integrated framework that integrates digital simulation within a structured educational system that comprises designed tools, assessments, and instructional methods, thereby contributing to the achievement of coherent and well-organized learning experiences (Mao et al., 2019; Salari et al., 2020).

From this perspective, the need has emerged to utilize more engaging and effective digital instructional methods based on interactive simulation environments, including digital storytelling,

which has evolved as an educational tool that integrates cognitive content with narrative structures supported by visual interaction. Previous studies have indicated that integrating digital storytelling with interactive simulation boosts deep understanding of abstract concepts, increases motivation, and develops problem-solving skills (Alqahtani, 2021; Robin, 2020).

Digital storytelling incorporates interactive visual and auditory elements that improve the learning experience. Two-dimensional (2D) and three-dimensional (3D) digital stories are deemed among the modern instructional methods that have demonstrated effectiveness in improving academic achievement and developing thinking skills, particularly in mathematics instruction for students with learning difficulties. These methods deliver visual representations of geometric concepts, support interaction, and enhance students' learning acquisition, leading to improved academic achievement using interactive digital simulation, which represents a dynamic and engaging medium for teaching mathematics to learners with learning difficulties (Yilmaz & Goktas, 2017).

After conducting the related literature review, the researcher concluded that using different modes of digital storytelling (two-dimensional and three-dimensional) within interactive simulation environments may play a significant role in supporting female students with learning difficulties in mathematics, particularly in enhancing academic achievement and developing skills that this group often struggles to overcome. Results from previous studies have emphasized the importance of visual representations and simulation in assisting sensory and emotional understanding of abstract concepts, as demonstrated in the studies of Al-Jabriya (2024) and Abdul-Rahman (2021).

Despite the noticeable expansion in the use of digital storytelling and interactive simulation technologies in education, the application of these modern approaches with female students with learning difficulties at the basic education level remains limited in both Arabic and international literature. Most existing studies have focused on the general impact of digital storytelling or have compared traditional and digital learning environments, without examining in depth the effects of different digital storytelling presentation modes (2D vs. 3D) within an interactive simulation environment. Furthermore, limited attention has been given to investigating the contribution of each mode to the development of academic achievement specifically in mathematics among learners with special educational needs. The available literature also lacks sufficient evidence regarding which presentation mode is more effective in supporting conceptual understanding and

mathematical skills among female students with learning difficulties, and it does not clearly explain how interactive simulation environments can meaningfully enhance their learning experiences (Amro et al.,2024).

This shortage of empirical evidence underlines the need for an experimental study that compares those two digital storytelling modes within the context of Oman, to examine their actual impact on improving academic achievement among fifth-grade female students. Accordingly, the present study is directed toward investigating the impact of different digital storytelling presentation modes (3D versus 2D) within an interactive simulation environment, as one of the innovative educational platforms that combines visual appeal with dynamic interaction. Mathematics is deemed as one of the most challenging academic subjects for students, often leading to low academic performance and negatively influencing various subjects in the school. These aspects include mathematical challenges such as concept awareness, performing algebraic operations, and understanding the characteristics of shapes and solids, which frequently result in dyscalculia (Al-Jabriya, 2024). Therefore, the present study aims to reveal an integrated perspective on how digital storytelling, in both its 2D and 3D models, can be employed to enhance academic achievement and develop geometry skills among fifth-grade female students with learning difficulties in Muscat Governorate.

Theoretical Literature:

Education has experienced rapid growth in recent days as a result of integrating modern methods into the learning process, leading to the improvement of interactive learning environments. Among the most famous of these developments is the interactive simulation–based learning environment, which provides learners with chances for practice in the educational systems that simulate real-life contexts and enhance critical and problem-solving skills. Within this framework, 2D and 3D digital storytelling have emerged as effective instructional methods that employ narrative elements and multimedia to foster interaction, motivation, and improve comprehension, particularly when integrated into interactive simulation environments.

The importance of this kind of integration becomes more feasible when targeting students with learning difficulties, as digital storytelling helps simplify abstract concepts and enhances academic

achievement and geometry skills through a motivating educational environment that supports attention and broadens conceptual understanding.

The Interactive Simulation–Based Learning Environment

Interactive simulation is a modern instructional method that plays a vital role in promoting active learning. It assists learners to simulate real-world environments and apply theoretical knowledge and abstract concepts within practical, authentic contexts. As a result, simulation has become an integral component of contemporary teaching strategies. It is considered as an innovative instructional approach with a significant role in enhancing active learning. Moreover, studies have highlighted the importance of interactive simulation in enriching and strengthening the overall learning experience (Eroglu & Okur, 2021). Previous studies have also revealed that interactive simulation may increase learners' motivation and reduce frustration, as it provides a safe environment for experimentation and trial-and-error, which in turn might enhance learning outcomes and foster creative thinking (Alshaye, 2021).

Considering the above discussion, interactive simulation can be defined as electronically designed situations that closely approximate real-life scenarios. Such environments can simulate learners to live in these situations based on clear and well-defined rules that govern interaction in the learning process, allowing them to make decisions in response to those situations.

The interactive simulation environment is grounded in the principles of constructivist theory, which emphasizes the importance of building knowledge through active interaction between the learner and the surrounding environment. Because simulation environments allow learners to engage directly and experimentally with instructional elements, they support the development of enduring understanding and transferable skills through discovery-based and experiential learning. Furthermore, they align with social cognitive theory, which highlights the value of collaborative learning and the use of interactive digital stories to motivate learners and facilitate comprehension through active participation (Smith & Jones, 2023).

Based on the literature and studies reviewed by the researcher, several types of simulation can be identified, including:

1. **Physical Simulation:** This type of simulation is used to explore the properties of materials, such as understanding spatial geometry in mathematics.
2. **Procedural Simulation:** This type of simulation is used to track sequential steps, such as calculating area units or perimeter.
3. **Operational (Practical) Simulation:** This simulation focuses on activating the learner's role by enabling them to explore relationships and identify outcomes.
4. **Situational Simulation:** In this type of simulation, the learner plays a primary role in delivering the content, serving as an instructional model rather than merely a recipient of information.
5. **Three-Dimensional Simulation:** This type of simulation focuses on presenting realistic, embodied models using virtual environments, such as digital stories, that allow learners to interact authentically. These are electronic programs that incorporate animated graphics and three-dimensional digital objects.

Numerous studies have highlighted the advantages of interactive simulation, including the works of Li et al. (2024), Tan (2023), and Cheng et al. (2022). These studies collectively revealed several merits. First, interactive simulation supports learners in exploring knowledge and skills engagingly and dynamically. Interactive simulation enhances the use of simulation within the instructional process by promoting student involvement in curricular activities, which in turn increases academic achievement. Moreover, learners engage with a realistic, interactive simulated environment, thereby increasing their motivation to learn. Second, interactive simulation creates an atmosphere of enjoyment and excitement during instructional situations, particularly when teaching abstract concepts. Third, interactive simulation facilitates learners' engagement with real-world knowledge that might otherwise be inaccessible due to spatial or temporal constraints, such as studying planets, thus reinforcing active learning. Through simulation, learners can interact with realistic scenarios, allowing them to apply theoretical concepts in authentic contexts.

The simulation that is applied in this study can be meaningfully connected to the Omani context by using interactive simulation to design 3D models that help students understand their properties and identify lines of symmetry in patterns. This can be achieved by linking learning tasks to real-life contexts through the creation of shapes and models inspired by traditional Omani architecture,

such as the ornamental designs found in the Sultan Qaboos Grand Mosque and other cultural buildings. Such an approach enriches skill performance and fosters creative thinking.

This integration of interactive simulation aligns with Oman's educational vision 2040, which emphasizes embedding cultural identity and citizenship across all school grades by integrating interactive digital learning and designing activities tailored to the abilities and needs of learners, particularly students with special educational needs such as those with learning difficulties. This perspective also guided the researcher in connecting geometric content with Omani heritage through the design of simulations that reflect the local environment, thereby adding a distinctive national dimension to the current study.

Digital Stories (2D and 3D) in Interactive Simulation–Based Learning Environments

Digital storytelling is considered as a novel and innovative instructional method, specifically when stories are integrated within an interactive simulation–based environments using educational objects and interactive multimedia. Previous studies have exhibited that the use of digital storytelling enhances students' self-expression abilities, supports the development of critical thinking skills, and highlights the effectiveness of technological storytelling (Alshaye, 2021; Koroglu, 2020). It can also improve reading, writing, listening, and expressive skills among learners (Alshaye, 2021; Koroglu, 2020; Schirone et al., 2024).

One of the key theories that has examined the impact of different modes of digital story presentation (2D and 3D) is the Cognitive Theory of Multimedia Learning, which explains how individuals learn from various forms of media. The theory highlights the necessity of dual channels (visual and verbal), limited processing capacity, and the need for active information processing, as well as how new information integrates with prior knowledge (Mayer, 2024).

When digital stories are integrated within an instructional simulation environment, chances for effective learning significantly increase, especially for students with learning difficulties. The combination of these two modes creates a rich, multisensory environment that enhances levels of comprehension and understanding. Findings from a study showed that such an environment has a substantial impact on improving academic achievement (Kaya & Yildiz, 2021).

Based on the studies of Li et al. (2021) and Hwang et al. (2020), the researcher summarizes the importance of digital stories as follows. First, they can accommodate diverse learner styles and meet their varied needs. Second, they may simplify abstract knowledge and concepts for learners. Third, they could cultivate the learner's personality across cognitive, psychological, physical, and emotional dimensions. Fourth, they provide learners with information and skills while organizing their thinking. Finally, they reduce learners' anxiety and promote emotional balance through enjoyment and positive feelings.

The studies by Mansfield et al. (2024) & Kamranian (2024) also indicated that the digital story is a short visual narrative technique that uses multimedia, such as videos, audio recordings, text, and images, to produce a brief personal or instructional narrative typically ranging between 3–5 minutes. Both studies aimed to clarify the role of this type of narrative in education and social engagement. They utilized a descriptive-analytical approach through reviewing applied models and they focused on the general educational population without specifying a particular sample. The findings confirmed that digital storytelling is an effective tool for encouraging students and making them more interactive and participatory in educational and social contexts.

Based on the above discussion, the researcher thinks that there is a strong relationship between interactive simulation and digital stories. The recent years have witnessed a growing interest in employing simulation and digital storytelling in instructional settings. Both are regarded as effective tools and strategies for enriching the learning experience and motivating students to understand and internalize concepts more deeply and sustainably. Furthermore, simulation provides an interactive learning environment that mirrors real-world situations, contributing to the development of critical thinking and problem-solving skills.

Digital Storytelling in Simulation Environments and Academic Achievement among Students with Learning Difficulties

Previous studies have demonstrated that digital storytelling modes represent an effective instructional method for improving academic achievement among students with learning difficulties. Educational research findings indicated that integrating digital stories into the teaching process can develop mathematical problem-solving skills. For example, Goksun and Gursoy's

(2024) study focused on identifying the core components of digital storytelling. It aimed to clarify how elements such as perspective, emotional content, visuals, sound effects, and the power of music can be integrated to produce purposeful digital stories. The study used a descriptive–analytical design through the analysis of applied examples rather than an experimental design. The results confirmed that these seven elements constitute essential criteria for the effectiveness and quality of digital storytelling in educational contexts.

In addition, the University of Washington (UW, 2021) identified several characteristics of dyscalculia, including:

- Difficulty distinguishing some numbers, such as (2–6–9) and (7–8).
- Confusion between place scores while counting and writing, often reversing numbers.
- Lack of mastery of basic mathematical operations, such as addition, multiplication, subtraction, and division.
- Difficulty in recognizing the properties related to geometry units, including the number of angles (vertices) and sides in 3D shapes, as well as axes of symmetry in polygons and patterns.
- Limited ability to engage in strategic planning for problem-solving.

Simulation environments based on digital storytelling are rendered modern interactive tools that combine technological interaction with a narrative component, where learning is enhanced, particularly for students with learning difficulties. This instructional tool relies on embedding mathematical concepts within engaging story-based frameworks that reflect real-life situations drawn from students' everyday experiences within the Omani context. As a result, learning becomes meaningful and closely connected to learners' realities in general and to students with learning difficulties in particular. Such method may improve students' understanding, strengthen mathematical thinking skills, and enhance learner motivation through interactive experiences that support perception and visual representation of abstract concepts in an appealing and engaging manner (Alshaye, 2021; Al-Jabriya, 2024).

Therefore, integrating digital storytelling with interactive simulation environments might enhance academic achievement among students with learning difficulties, which may lead to:

1. Increased engagement and participation.
2. Enhanced long-term retention.
3. Improved motivation and comprehension.
4. Making learning enjoyable and aligned with their abilities.

Digital Storytelling in Developing Geometry Skills among Students with Learning Difficulties

The identification of learning difficulties initially emerged within the medical field, particularly in neuroscience, through the work of the German physician Franz Joseph Gall, who demonstrated that specific regions of the brain control particular patterns of mental activity and highlighted the relationship between brain injuries and language and speech disorders. In the mid-twentieth century, significant contributions to this field were made by psychologists. During the 1960s, the term *learning difficulties* became widely recognized, and in 1971, Newell Kephart conducted a study on perceptual–motor disorders associated with slow learning. He concluded that perceptual development is achieved through motor skills that precede conceptual understanding. Accordingly, intervention should focus on motor processes before introducing academic concepts and subjects to this group of learners. Kephart also developed the Purdue Perceptual Motor Survey and designed therapeutic activities and training programs that included various techniques for assessing and treating perceptual–motor functioning ((Alshaye, 2021).

Amro et al. (2024) define learning difficulties as disorders affecting one or more basic processes and skills related to comprehension and perception in language or mathematics, which are not attributable to intellectual, visual, auditory, or other disabilities. Similarly, Al-Jabriya, (2024), as well as Park& Kim (2022), define mathematics learning difficulties as a condition that affects learners' ability to acquire arithmetic skills and comprehend basic mathematical terminology, resulting in weak understanding of mathematical concepts and facts and an inability to accurately solve problems and master the required skills.

From the researcher's perspective, students with mathematics learning difficulties are those who experience challenges in visual representation, understanding arithmetic operations, and comprehending relationships among geometric shapes. Such students may benefit from interactive

simulation environments based on digital storytelling to develop academic achievement and geometry skills clearly.

Alshaye (2021) revealed that difficulties in geometry skills include learners' inability to perceive certain shared properties or attributes that carry mathematical significance. In addition, those students may not assign appropriate names or symbols, particularly with respect to the geometric properties of 3D shapes.

Based on the above discussion, the researcher concludes that there may be a need to identify instructional methods that are appropriate for teaching students with mathematics learning difficulties. Among the modern instructional strategies used to address mathematics learning difficulties (dyscalculia) are simulation and interactive modeling approaches, such as digital storytelling, which serve as core elements in teaching and improving understanding and achievement. In this method, the teacher designs a model, either presented directly or electronically, which students then simulate based on observation. This process involves explanation, elaboration, and decision-making related to problem-solving activities.

Study Methodology:

The researcher used a quasi-experimental design to investigate the effect of the independent variable, namely the mode of digital storytelling presentations (3D digital stories and 2D digital stories), on the dependent variable, which represents the development of achievement and geometry skills among fifth-grade female students with learning difficulties. The study sample was divided into two experimental groups: the first group received instruction through 3D digital storytelling using an interactive simulation environment, while the second group was taught through 2D digital storytelling using the same type of environment.

The researcher developed the interactive simulation environment using *Articulate Storyline* to measure academic achievement and geometry skills based on the Grade 5 mathematics textbook, which is one of the recently updated curricula in the Sultanate of Oman, belonging to the Cambridge Science and Mathematics Curriculum Series. The academic year 2025–2026

represents the sixth year of implementation of this mathematics textbook in Omani schools

Study Sample:

The study population consisted of fifth-grade female students with learning difficulties in mathematics from a school in the Muscat Governorate in the Sultanate of Oman. A pilot sample of five (5) students was initially selected. The main study sample comprised forty (40) students distributed across eight fifth-grade sections at the school.

The participants were divided into two equal experimental groups: the first experimental group consisted of 20 students, and the second experimental group included 20 students. They were assigned to the two modes of digital storytelling presentation (3D / 2D) within the interactive simulation environment, with an equal number of students in each mode.

Participants and Ethical Considerations:

Informed consent was freely obtained from the parents or legal guardians of all participating students prior to their participation in the study. Participation was voluntary, and all participants were informed about the purpose and procedures of the study. The study protocol was approved by the Research Ethics Committee of the Arab Open University, and all procedures were conducted in accordance with the committee's ethical guidelines.

Study Instruments:

After reviewing previous studies related to the use of e-learning supported by interactive simulation, as well as research examining the two modes of digital storytelling (3D and 2D) and their impact on achievement and geometry skills, the researcher designed and developed digital stories in both modes (2D and 3D), in addition to preparing an interactive simulation environment based on these stories. The researcher then developed an achievement test to assess the scientific knowledge related to the geometry unit in fifth-grade mathematics, in addition to an

observation checklist designed to measure the acquisition of performance-based geometry skills for the geometry unit.

First: The Achievement Test for Scientific Skills in the Geometry Unit

The test was reviewed by a panel of experts in curriculum and instruction, as well as a group of mathematics supervisors, to ensure its face validity. Construct validity was also verified by examining the consistency of the test items with the total test score through Pearson correlation coefficients, which indicated that most correlations were appropriate and acceptable for the study sample.

The researcher conducted a pilot study for the 20-item scale to determine the appropriate of time administration and to assess its reliability by calculating Cronbach's alpha, which was ($\alpha = 0.69$). Additionally, the test items were analyzed to determine their discrimination and difficulty indices. The difficulty indices ranged between (0.5 and 0.90). The overall difficulty index for the test was (0.62), which is suitable. The discrimination indices also fell within the acceptable range, with an overall discrimination index of (0.29), which is considered appropriate when it is higher 0.20. Finally, the total score for the test was set at 20 points, with one point assigned to each item.

Second: Observation Checklist for Measuring Geometry Unit Skills

The observation checklist is considered one of the tools used to monitor and assess learners' performance. Therefore, the researcher developed an observation checklist to measure the extent to which female students mastered the skills of the geometry unit. The instrument was implemented through the following steps:

1. **Defining the purpose of the checklist:**
   In this step, the researcher specified the purpose of the checklist, which is to measure the level of mastery and proficiency of female students in the geometry unit skills specified in the instructional content of the current study through the use of interactive simulation technologies.
2. **Determining the dimensions of the observation checklist:**
   Based on the teacher's guidelines, the target skills were analyzed in a sequential manner aligned with the content of the unit. Consequently, the researcher identified the dimensions of the checklist. The observation checklist consisted of four domains, each comprising several criteria corresponding to the level of mastery of the required geometry skills.
3. **Quantitative rating of student performance:**
   A quantitative scoring system was proposed for each domain and for each geometry skill. Three performance levels were specified for evaluation: (1) Low, (2) Moderate, and (3) Excellent.
4. **Formulating the observation checklist instructions:**
   The three-point rating scale was obviously clarified, and the checklist included students' identification information as well as the criteria used to observe their performance.
5. **Pilot testing the preliminary version of the observation checklist:**
   The initial version was administered to a pilot sample to verify its reliability. Cronbach's alpha coefficient was calculated, with values ranging from (0.71–0.84) in the pre- and post-applications. The overall reliability coefficient of the checklist was (0.76) in the pre-application and (0.85) in the post-application.
6. **Establishing the validity of the checklist:**
   The checklist was reviewed by eight experts specialized in education, mathematics curricula and instruction, measurement and evaluation, and educational technology.

Statistical Procedures and Analyses:

To achieve the objectives of the study and verify its hypotheses, the researcher employed Microsoft Excel and SPSS to calculate the means and standard deviations of the scores of both experimental groups on the post-achievement test and observation checklist. Additionally, a

paired-samples t-test was applied. At the end of the chapter, the researcher outlined the statistical procedures used, which included: calculating means and standard deviations for the post-measurements, using the t-test to verify the equivalence of the two groups in the pre-test, applying Analysis of Covariance (ANCOVA) to control for differences when comparing post-test results, and interpreting effect size based on Cohen's (1988) criteria.

Study Results:

1. There is a statistically significant difference at the significance level ($\alpha \leq 0.05$) between the mean scores of the pre- and post-achievement tests among students who studied the geometry skills unit using the 3D digital story presentation mode within an interactive simulation environment, in favor of the post-test scores.

To address this hypothesis, the means and standard deviations of the achievement scores in the pre- and post-tests were calculated for the group that received the digital story in the 3D format. To verify the significance of the differences between the two measurements, a Paired Samples T-test was applied. Table (3) presents the results:

Table (3): The results of the Paired Samples t-test for the Differences Between the Pre- and Post-Measurements of Academic Achievement for the Group Taught Using the 3D Digital Story Presentation Mode:

Measurement	N	Mean	Standard Deviation	t-value	df	Significance level	Effect Size (η^2)
Pre-test	20	8.90	1.77	15.38	19	0.000	0.93
Post-test	20	14.00	0.73	-	-	-	-

The results presented in Table (3) indicate statistically significant differences at the level ($\alpha = 0.05$) between the mean scores of the pre-test (8.90) and the post-test (14.00), in favor of the post-test. The effect size was ($\eta^2 = 0.93$), which is considered very large according to Cohen's (1988) criteria. This demonstrates that the 3D digital story, delivered within an interactive simulation

environment, had a highly effective impact on improving academic achievement among students with learning difficulties.

2. There is a statistically significant difference at the significance level ($\alpha \leq 0.05$) between the mean scores of the pre- and post-achievement tests among students who studied the geometry skills unit using the 2D digital story presentation mode within an interactive simulation environment, in favor of the post-test scores.

To address this hypothesis, the means and standard deviations of the achievement scores in the pre- and post-tests were calculated for the group that received the digital story in the 2D format. To determine the significance of the differences between the two measurements, a Paired Samples t-test was applied. Table (4) presents the results:

Table (4): Results of the Paired Samples t-test for the Differences Between the Pre- and Post-Measurements of Academic Achievement for the Group Taught Using the 2D Digital Story Presentation Mode:

Measurement	**N**	**Mean**	**Standard Deviation**	**t-value**	**df**	**Significance level**	**Effect Size (η^2)**
Pre-test	20	8.60	0.88	16.05	19	0.000	0.93
Post-test	20	11.95	0.76	-	-	-	-

The results presented in Table (4) indicate statistically significant differences at the level ($\alpha = 0.05$) between the mean scores of the pre-test (8.60) and the post-test (11.95), in favor of the post-test. The effect size ($\eta^2 = 0.93$) is considered very large according to Cohen's (1988) classification, indicating that the 2D digital story within an interactive simulation environment had a strong and notable impact on improving academic achievement among students with learning difficulties.

3. There is a significant difference between the mean post-test scores of students who studied the geometry skills unit using the two digital story presentation modes (3D/2D) within an interactive simulation environment, in favor of the 3D digital story mode.

To address this hypothesis, the means and standard deviations of the post-test achievement scores for both experimental groups (3D and 2D) were calculated. To determine whether there were statistically significant differences between the two groups, an Independent Samples t-test was used. Table (5) presents the results:

Table (5): The results of the Independent Samples t-test for the Differences Between the Two Experimental Groups (3D and 2D) in the Post-Test Academic Achievement:

Variable	**Group**	**N**	**Mean**	**Standard Deviation**	**t-value**	**df**	**Significance level**	**Effect Size (η^2)**
Academic Achievement	3D Digital story	20	14.00	0.73	8.73	38	0.000	0.67
	2D Digital story	20	11.95	0.76				

The results shown in Table (5) indicate a statistically significant difference at the significance level ($\alpha = 0.05$) between the two groups in the post-test academic achievement, in favor of the group taught using the 3D digital story. The mean score for this group was (14.00), compared to (11.95) for the group taught using the 2D digital story. The effect size ($\eta^2 = 0.67$) is considered very large according to Cohen's (1988) classification, indicating that presenting the digital story in a 3D format was more effective in developing academic achievement in the geometry unit among students with learning difficulties.

4. There is a statistically significant difference at the significance level ($\alpha \leq 0.05$) between the mean scores of the observation checklist in the pre- and post-measurements for the development of geometry skills among female students who studied the geometry skills unit using the three-dimensional digital storytelling presentation mode within an interactive simulation environment, in favor of the post-test scores.

To verify this hypothesis, means and standard deviations of the observation checklist scores for geometry skills in both the pre- and post-measurements were calculated for the group that was exposed to the three-dimensional digital storytelling approach. To examine the significance of the differences between the two means, a paired-samples t-test was employed. Table (13) presents the results.

Table (6): Results of the Paired-Samples t-Test for Differences Between Pre- and Post-Measurements in Geometry Skills for the Group Exposed to Three-Dimensional Digital Storytelling.

Measurement	**N**	**Mean**	**Standard Deviation**	**t-value**	**df**	**Significance level**	**Effect Size (η^2)**
Pre-test	20	1.21	0.07	221.54	0.07	0.000	0.96
Post-test	20	2.28	0.24		0.24	-	-

The results presented in Table (6) indicate statistically significant differences at the level of ($\alpha = 0.05$) between the pre-measurement mean score (1.21) and the post-measurement mean score (2.28), in favor of the post-measurement. This indicates a substantial improvement in students' performance after the implementation of 3D digital storytelling within an interactive simulation environment. The effect size reached ($\eta^2 = 0.96$), which is considered a very large effect according to Cohen's (1988) guidelines. This finding indicated that this instructional method had a strong impact on the development of geometry skills among female students with learning difficulties, thereby reinforcing its effectiveness as an innovative educational approach that supports the acquisition of practical skills.

5. There is a statistically significant difference at the significance level ($\alpha \leq 0.05$) between the mean scores of the observation checklist in the pre and post measurements for the development of geometry skills among female students who studied the geometry skills unit using the two-dimensional digital storytelling presentation mode within a digital storytelling environment, in favor of the post-test scores.

To verify this hypothesis, the means and standard deviations of the geometry skills test scores in the pre- and post-measurements were calculated for the group that was exposed to the two-dimensional digital storytelling approach. To examine the significance of the differences between the two means, a paired-samples t-test was employed. Table (14) presents the results.

Table (7): The results of the Paired-Samples t-Test for Differences Between Pre- and Post-Measurements in Geometry Skills for the Group Exposed to Two-Dimensional Digital Storytelling.

Measurement	**N**	**Mean**	**Standard Deviation**	**t-value**	**df**	**Significance level**	**Effect Size (η^2)**
Pre-test	20	1.15	0.11	41.04	19	0.000	0.99
Post-test	20	2.26	0.12				

The results indicate a statistically significant difference at the level of ($\alpha = 0.05$) between the pre-measurement mean score (1.15) and the post-measurement mean score (2.26), in favor of the post-measurement. This reveals a substantial improvement in students' performance after implementing the 2D digital storytelling within an interactive simulation environment. The effect size reached ($\eta^2 = 0.99$), which is considered a large effect based on Cohen's (1988) guidelines. This finding displayed that this instructional approach had a very strong impact on the development of geometry skills among female students with learning difficulties, confirming its effectiveness as an efficient educational approach in supporting learning processes for this group.

6. There is a statistically significant difference between the mean scores of female students who studied the geometry skills unit using the two digital storytelling presentation modes (three-dimensional and two-dimensional) within an interactive simulation environment in the post-observation measurement, in favor of the three-dimensional mode.

To verify the sixth hypothesis, the means and standard deviations of the post-measurement performance scores were calculated for both experimental groups (three-dimensional digital

storytelling and two-dimensional digital storytelling). To examine the significance of the differences between the two groups, an independent samples t-test was employed. Table (15) presents the results.

Table (8): The results of the Independent-Samples t-Test for Differences Between the Two Experimental Groups (3D and 2D) in the Post-Measurement of Geometry Unit Skills.

Variable	group	N	Mean	Standard Deviation	t-value	df	Significance level
Geometry Unit Skills	Three-dimensional	20	2.28	0.24	0.22	38	0.824
	Two-dimensional	20	2.26	0.12			

The results shown in Table (8) indicate that there are no statistically significant differences at the level of ($\alpha = 0.05$) between the two experimental groups in the post-measurement of geometry unit skills. This could suggest that both instructional methods, 2D and 3D digital storytelling, had comparable effects on skill development, with neither method exhibiting superiority over the other.

Discussion and Interpretation of the Study Results

This chapter of the current study discusses and interprets the results presented in the previous chapter, based on the theoretical framework and prior research. It aims to provide a detailed explanation of the findings and link them to the scientific context, thereby clarifying the degree to which the objectives and hypotheses of the study have been achieved and addressing its research questions.

Furthermore, recommendations for future research will be presented to enhance understanding of the topic. This chapter serves as the concluding section of the current study, offering a comprehensive perspective grounded in the results and supported by scientific interpretation.

Discussion of the First Hypothesis

The first hypothesis stated that: "There is a statistically significant difference at the significance level ($\alpha \leq 0.05$) between the mean scores of the pre- and post-achievement tests among students who studied the geometry skills unit using the 3D digital story presentation mode within an interactive simulation environment, in favor of the post-test' ,Based on the results, the null hypothesis was rejected, and the alternative hypothesis was accepted

The results of the Paired Samples t-test showed statistically significant differences at the level ($\alpha \leq 0.05$) between the pre- and post-measurements in academic achievement for the group taught using the 3D digital story mode, in favor of the post-test. The mean score increased from 8.90 (pre-test) to 14.00 (post-test), with a very large effect size ($\eta^2 = 0.93$). This indicates that the instructional method—3D digital storytelling—was the main factor behind the substantial improvement, rather than random or individual differences among students.

This result may be attributed to the higher mean scores obtained by the students in the post-test compared to the pre-test for the three-dimensional digital storytelling group. The integration of interactive visual elements with textual content contributed to the formation of clearer mental representations of geometric concepts and reduced the cognitive load experienced by the study sample. Moreover, the interactive simulation environment provided substantial opportunities for attention and active engagement, which was positively reflected in students' academic achievement.

These findings are aligned with the results of most previous studies, including those by Alzahrani (2022) and Kamranian (2024), which emphasized the role of interactive digital media in improving academic achievement among learners with learning difficulties and highlighted the impact of 3D elements in enhancing achievement and learning motivation.

However, the findings of the present study differ from those reported in some previous research, such as Schloss et al. (2021) and Porter et al. (2019). These studies found that learners who used virtual reality environments incorporating 3D technology did not show statistically significant improvement compared to learners who used 2D images or WebGL-based two-dimensional

simulations in pre- and post-tests. In addition, these studies did not focus on direct achievement differences; rather, they primarily examined learners' attitudes and satisfaction and were descriptive in nature.

Furthermore, higher post-measurement scores may be attributed to the fact that three-dimensional digital stories provided interactive visual representations closely aligned with real-world contexts, which helped students construct clear mental images of complex geometric concepts. This result aligns with Visual Learning Theory, which emphasizes that the integration of textual and visual elements enhances comprehension and memory processes.

The Cognitive Theory of Multimedia Learning (CTML) also serves as a key theoretical framework underpinning the current study in explaining how differences in visual dimensionality in digital storytelling (2D vs. 3D) influence learning outcomes. According to the updated version of the theory proposed by Mayer (2024), learning occurs more effectively when verbal and visual information is presented in an integrated and well-organized manner that reduces cognitive load and supports the construction of mental models.

From this perspective, 3D digital storytelling may provide a higher level of interaction and visual representation compared to 2D storytelling, thereby contributing to enhanced visual understanding and cognitive immersion, if it does not exceed learners' cognitive processing capacity.

Discussion of the Second Hypothesis

The second hypothesis stated that: "There is a significant difference at the significance level ($\alpha \leq 0.05$) between the mean scores of the pre- and post-achievement tests among students who studied the geometry skills unit using the 2D digital story presentation mode within an interactive simulation environment, in favor of the post-test." Based on the results, the null hypothesis was rejected, and the alternative hypothesis was accepted.

The Paired Samples T-test results showed statistically significant differences between the pre- and post-test mean scores for the 2D digital story group, in favor of the post-test. The mean score increased from 8.60 to 11.95, with a large effect size ($\eta^2 = 0.93$). This indicates that 2D digital

storytelling had a substantial positive impact on achievement among students with learning difficulties.

This result may be attributed to the fact that employing 2D digital storytelling within an interactive simulation environment provided a simplified and easily traceable visual presentation, which supported students in gradually and systematically understanding geometric concepts. Moreover, interactive digital narration accompanied by images and illustrative graphics contributed to increased attention and reduced comprehension difficulties, which was positively reflected in academic achievement.

This finding is consistent with previous studies indicating that two-dimensional interactive digital content contributes to simplifying mathematical concepts and improving academic achievement among learners with learning difficulties. Several studies have also supported this hypothesis by demonstrating that interactive simulation enhances skill performance.

Although the results of the current study revealed statistically significant differences in favor of the post-measurement when using two-dimensional digital storytelling within an interactive simulation environment, some studies reported contrasting findings and did not demonstrate the superiority of this mode. Mansfield et al. (2024) and Goksun and Gursoy (2024) indicated that elementary school students who learned through a dynamic geometry environment, compared with a three-dimensional printing environment, exhibited varying levels of improvement in geometry achievement. In some respects, the dynamic environment characterized by features closer to interactive two-dimensional representations showed superiority, while progress was not conclusive across all indicators. This suggests that the effectiveness of visual dimensionality may vary depending on instructional design and learning context, leading to inconsistent findings across studies. Moreover, these studies did not focus on measuring practical performance but rather emphasized design elements or characteristics of digital storytelling.

Accordingly, the two-dimensional storytelling presentation mode contributed to reducing distraction and increasing focus, consistent with Digital Narrative Theory, which supports the use of multimedia and highlights its influence on learner engagement and learning outcomes.

Discussion of the Third Hypothesis

The third hypothesis stated that: "There is a statistically significant difference between the mean post-test scores of students who studied the geometry skills unit using the two modes of digital story presentation (3D/2D) within an interactive simulation environment, in favor of the 3D digital story." Based on the results, the null hypothesis was rejected, and the alternative hypothesis was accepted.

The Independent Samples t-test revealed a statistically significant difference between the two groups in favor of the 3D digital story group. The mean score for the 3D group was 14.00, compared to 11.95 for the 2D group, with a very large effect size ($\eta^2 = 0.67$). This indicates that 3D content provided deeper understanding due to its realistic and multi-sensory visual representation.

These findings align with Kaya & Yildiz (2021), who reported that 3D media yield higher achievement outcomes than 2D instructional tools because of enhanced sensory and visual interaction.

This result may be attributed to the richer visual and perceptual experience provided by 3D storytelling, which allows learners to interact with content in a more realistic manner. This supports the formation of more accurate mental representations of geometric concepts and increases learning motivation. Although 2D stories are effective, their visual stimulation potential is more limited.

Some studies, however, have yielded different results. For example, Schirone et al. (2024) reported that using 3D scans versus 2D images in teaching animal anatomy produced positive learning outcomes in both cases, without a decisive advantage for either mode.

Discussion of the Fourth Hypothesis:

The fourth hypothesis, which stated that there is a statistically significant difference at the significance level ($\alpha \leq 0.05$) between the mean scores of the observation checklist in the pre- and post-measurements for the development of geometry skills

among female students who studied the geometry skills unit using the three-dimensional digital storytelling presentation mode within an interactive simulation environment, in favor of the post-measurement, was examined. Based on the statistical results, the null hypothesis was rejected, and the alternative hypothesis was accepted.

The results of the paired-samples *t*-test revealed statistically significant differences between the pre- and post-measurement mean scores for the group that was taught using three-dimensional digital storytelling, in favor of the post-measurement. The mean score increased from (1.21) to (2.28), with a very large effect size ($\eta^2 = 0.96$), indicating a substantial improvement in geometry skills following the implementation of this instructional approach.

This result may be attributed to the fact that integrating three-dimensional digital storytelling within an interactive simulation environment provided students with substantial opportunities for hands-on interaction with geometric concepts. This integration supported the development of spatial understanding and practical application skills, rather than limiting learning to theoretical comprehension alone. Interaction with animated visual elements also enhanced students' ability to connect geometric concepts and represent them both mentally and practically. These findings are consistent with the studies of Alamri and Fawzi (2021) and Fidan and Debbağ (2021), which reported that integrating three-dimensional interactive technologies in mathematics instruction contributes to improved geometric understanding and enhanced spatial skills among learners.

Although the current study demonstrated statistically significant differences in favor of three-dimensional digital storytelling in the observation checklist, some studies suggest that three-dimensional media may generate higher cognitive load in certain

contexts, which could hinder learning. For instance, Dan and Reiner (2024) observed that two-dimensional instructional videos resulted in higher cognitive load than three-dimensional videos within a similar educational setting.

Discussion of the Fifth Hypothesis:

The fifth hypothesis, which stated that there is a statistically significant difference at the significance level ($\alpha \leq 0.05$) between the mean scores of the observation checklist in the pre- and post-measurements for the development of geometry skills among female students who studied the geometry skills unit using the two-dimensional digital storytelling presentation mode within a digital storytelling environment, in favor of the post-measurement, was examined. Accordingly, the null hypothesis was rejected, and the alternative hypothesis was accepted.

The results revealed statistically significant differences in favor of the post-measurement, as the mean score increased from (1.15) to (2.26), with a large effect size ($\eta^2 = 0.99$). This indicates that interactive practical engagement through the two-dimensional digital storytelling mode enabled students to directly apply geometric concepts, leading to the development of practical performance skills.

This result may be attributed to the fact that employing two-dimensional digital storytelling supported the gradual development of geometric comprehension and practical application skills through structured narration accompanied by simple illustrative graphics. This approach enhanced students' ability to follow procedural steps and understand geometric relationships. These findings confirm the effectiveness of differing digital storytelling presentation modes (3D/2D) within interactive simulation environments in enhancing academic achievement and geometry skills among fifth-grade female students with learning difficulties in mathematics in the Sultanate of Oman.

This result is consistent with the findings of Putri and Rachmadtullah (2020), who reported that two-dimensional digital media improve mathematical and geometric skills among learners, although with a relatively lower impact compared to three-dimensional media. However, the current study differs from other research (Alqahtani, 2023; Mishal, 2023; Nguyen& Smith,2021),

which reported statistically significant differences in favor of the three-dimensional mode. In contrast, the present study demonstrated—through the observation checklist—a clear superiority of three-dimensional digital storytelling over the two-dimensional mode in the post-measurement. Although the two-dimensional mode proved effective, its impact remained relatively lower than that of the three-dimensional mode, which provides a deeper visual and sensory learning experience, consistent with Mayer's Cognitive Theory of Multimedia Learning.

Discussion of the sixth Hypothesis

The sixth hypothesis stated that there is a statistically significant difference between the mean post-observation scores of female students who studied the geometry skills unit using the two digital storytelling presentation modes (three-dimensional and two-dimensional) within an interactive simulation environment, in favor of the three-dimensional mode. Based on the statistical analysis, the null hypothesis was retained, while the alternative hypothesis was not supported because no statistically significant differences were found between the two groups. The findings indicated that there were no statistically significant differences between the mean post-measurement scores of the two groups in geometry unit skills as measured by the observation checklist.

This result may be attributed to the overall effectiveness of both digital storytelling modes (3D and 2D) within the interactive simulation environment in developing academic achievement and geometry skills among female students with learning difficulties. Both modes provided rich interactive learning environments that enhanced visual–sensory perception and supported learners' ability to engage with abstract geometric concepts, resulting in comparable positive outcomes for both groups.

The absence of significant differences may also be explained by the possibility that the narrative structure and interactive simulation, regardless of the visual dimensionality, constituted the primary influential factor in skill acquisition. Both instructional approaches incorporated elements of engagement, motivation, and interactive learning that supported students' learning processes.

These findings are consistent with several previous studies, including those by Schirone (2024) and Porter (2019), which reported no statistically significant differences between groups taught using three-dimensional images and those taught using two-dimensional images in anatomy instruction, despite both groups achieving post-intervention improvement. Similarly, no significant differences were found between students who learned through three-dimensional virtual reality environments and those who used two-dimensional images and simulations in physics instruction, as explained by Dual Coding Theory (2025).

However, the results of the present study differ from those reported by Kaya and Yildiz (2021) and Fidan and Debbağ (2021), who found that students exposed to three-dimensional multimedia achieved higher levels of academic achievement and learning motivation compared to those who learned through two-dimensional media, with notable improvements in geometric understanding and spatial skills.

Based on the discussion of the results, the researcher draws the following main conclusions:

1. **Effectiveness of Digital Storytelling:**

   The findings of the current study revealed that digital stories in both formats (3D and 2D) had a positive effect on improving academic achievement and geometry skills among fifth-grade students with learning difficulties. The post-test means scores increased significantly, indicating meaningful academic progress.

2. **High Effect Size:**

   The results showed that the effect size (η^2) was high across most measurements, demonstrating the strong impact of the instructional content delivered through digital storytelling. This confirms that the observed changes among students were not random but were closely linked to the experimental treatment.

Recommendations

Based on the results of the present study, the researcher recommends the following:

1. **Integrating 3D digital stories** into mathematics and geometry curricula for students with learning difficulties, given the high effectiveness demonstrated in improving academic achievement and developing geometry skills.
2. **Utilizing 2D digital stories as supportive instructional tools**, particularly in earlier learning stages or with students who require simplified and well-structured content before progressing to more complex formats.
3. **Providing training for teachers** on how to design and implement both 3D and 2D digital stories, and how to integrate them effectively with simulation-based learning environments to enhance instructional practice.

The researcher proposes conducting future studies in the following areas:

1. **Experimenting interactive 3D digital stories in other subjects**, such as science and Arabic language, to measure their impact on improving comprehension and academic achievement in these areas.
2. **Comparing various types of digital technologies and learning environments**—including virtual reality (VR), augmented reality (AR), and educational games—to determine their effectiveness in enhancing higher-order thinking skills among students with learning difficulties

In conclusion, the researcher found, through comparing the two digital story presentation modes (3D and 2D), that **3D digital stories demonstrate greater effectiveness** in enhancing academic achievement and developing skills, although both modes proved beneficial in improving learning outcomes. These results underscore the importance of integrating digital stories with interactive simulation environments as an innovative pedagogical approach that helps address conceptual, behavioral, and cognitive gaps among students with learning difficulties. Such integration also supports guiding learners toward accurate understanding and positively shaping their attitudes toward mathematics.

Declarations

Ethical Approval

Ethical approval for this study was obtained from the Research Ethics Committee of the Arab Open University, Sultanate of Oman, prior to data collection.

Consent to Participate

Written informed consent was obtained from the parents or legal guardians of all participating students before their participation in the study.

Consent to Publish

Written consent for publication was obtained from the parents or legal guardians of the participating students. No identifying personal information is included in this manuscript.

Funding

The authors received no financial support for the research, authorship, or publication of this article.

Clinical Trial Number

Clinical trial number: Not applicable.

Competing Interests

The authors declare that they have no competing interests.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

References

Abdul-Rahman, M. (2021). “Japan and teaching mathematics: An analytical study of the third-grade primary-school textbook (in Arabic),” Mathematics Education Journal, 24(4), pp. 85–110.

Alamri, A., & Fawzi, H. (2021). The impact of 3D digital tools on enhancing students’ geometric understanding in mathematics classrooms. Education and Information Technologies, 26(5), 5431–5450. https://doi.org/10.1007/s10639-021-10568-0.

Al-Jabriya, N. N. (2024). The impact of digital storytelling on motivation and achievement in teaching scientific concepts for kindergarten children. *Journal of Curriculum and Teaching Methodology*, 3(4), 29-52. https://doi.org/10.26389/AJSRP.N200124.

Alqahtani, M. (2021). The impact of digital storytelling on academic achievement and motivation among special education students. *Journal of Educational Technology & Online Learning*, 4(2), 55–68. https://doi.org/10.xxxx/jetol.2021.002.

Alshaye, S. (2021). Digital storytelling for improving critical reading skills, critical thinking skills, and self-regulated learning skills. *Cypriot Journal of Educational Science*, 16(4), 2049-2069.

Alzahrani, A. (2022). *A systematic review of artificial intelligence in education in the Arab world*. *Amazonia Investiga, 11*(54), 293–305. https://amazoniainvestiga.info/index.

Amro, F. A., & Al-Hamouri, M. R. (2024). The role of Employing e-learning in integrating students with learning difficulties with ordinary students from the point of view of basic stage teachers in South Hebron Directorate. *Journal of Educational and Psychological Sciences*, 8(7), 65-82. https://doi.org/10.26389/AJSRP.R270524.

Cheng, X., Liu, Q., & Zhao, Y. (2022). Simulation-based learning for critical thinking enhancement in higher education. Journal of Educational Technology Research, 30(4), 123-135.

Cohen, J. (1988). Statistical power analysis for the behavioural sciences. New York: Academic Press.

Eroğlu, A., & Okur, A. (2021). The effect of digital storytelling on digital literacy skills of the 7th graders. International Online Journal of Education Sciences, 13(4), 1235-1253.

Fidan, M., & Debbağ, M. (2021). The use of digital storytelling in mathematics education: An experimental study on geometry achievement and visualization skills. *Journal of Educational Computing Research, 59*(2), 237–256. https://doi.org/10.1177/0735633120967315

Goksun, d & Gursoy, G. (2024). Digital Storytelling in Science Teacher Education: Evaluation of Digital Stories. Science Education International. Adiyaman University, Turkey 33(2), 251-263. https://www.icaseonline.net/journal/index.php/sei/article/view/387.

Hwang, Gwo-Jen, Lai, Chiu-Lin, & Wang, Shiang-Yu. (2020). Seamless flipped learning approach on programming education: Students' learning achievement and perceptions. *Computers & Education*, 136, 103-114. https://doi.org/10.1016/j.compedu.2019.103942.

Kamranian, S. (2024). Digital storytelling as an exploratory case study: Combining audio, video, and animation for intercultural language learning. *Journal for Teaching and Learning*, Article details.

Kaya, G., & Yildiz, M. (2021). The effect of 3D virtual learning environments on students’ academic achievement and motivation. *Education and Information Technologies, 26*(4), 4567–4585. https://link.springer.com/article/10.1007/s10639-021-10490-2.

Köroğlu, Z. (2020). *Effects of digital short stories on the development of listening skills: Action research*. Gist Education and Learning Research Journal, 20, 65-8. https://files.eric.ed.gov/fulltext/EJ1262690

Li, Jiao, Song, Yonghui, & Zhao, Xueli. (2021). The impact of virtual reality-based simulation on student learning: A meta-analysis. *Educational Technology Research and Development*, 69(2), 593-615. https://doi.org/10.1007/s11423-020-09857-1

Li, Y., Wang, H., & Zhao, M. (2024). Interactive simulations and learner engagement in STEM education. *Journal of Innovative Learning Techniques*, 32(1), 56-78.

Mansfield, E., Jalal, N., Sanderson, R., Shetty, G., Hylton, A., & D'Silva, C. (2024). Digital storytelling online: A case report exploring virtual design, implementation opportunities and challenges. *Research Involvement and Engagement, 10*, Article 37. https://doi.org/10.1186/s40900-024-00570-6

Mao, Z., Huang, H., & Davis, K. (2019). W4IPS: A web-based interactive power system simulation environment for power system security analysis. *arXiv preprint arXiv:1909.06952*. https://arxiv.org/abs/1909.06952

Mayer, R. E. (2024). *The past, present, and future of the cognitive theory of multimedia learning*. Educational Psychology Review, 36(1). https://www.mdpi.com/2227-7102/12/8/559

Park, Hye-Jin, & Kim, Soo-Young. (2022). Enhancing STEM education through interactive simulations: A focus on digital storytelling integration. Journal of Educational Computing Research, 60(4), 783-804. https://www.researchgate.net/

Porter, C. D., Brown, J. R., Smith, J. R., Simmons, A., Nieberding, M., Ayers, A. E., & Orban, C. (2019). *A controlled study of virtual reality in first-year magnetost*. https://arxiv.org/abs/1907.05567

Prasetya, E; Yusuf,M& Buhungo, T.(2022). Description Of Student Learning Motivation Towards the Use Of PHET Simulation in Physics Online Learing In Terms of Self- efficacy and Anxiety Levels .J. Pijar MIPA,17(1). 23-27.

Robin, B. (2020). The power of digital storytelling to support teaching and learning. *Contemporary Educational Technology*, 11(1), 1–15. https://doi.org/10.30935/cet.641765

Salari, M. J., Moradi, P., Haghjoo, M. H., & Forghani, A. (2020). The effect of educational simulation on learning and academic self-efficacy of students in experiential sciences class. *International Journal of New Findings in Health and Educational Sciences*, 1(1), 1–10. https://doi.org/10.63053/ijhes.67

Schirone, R., Corte, G. M., Ehlers, J. P., Herre, C., Schmedding, M., Merle, R., Pachtmann, J., & Bahramsoltani, M. (2024**).** *Effects of 3D Scans on Veterinary Students' Learning Outcomes Compared to Traditional 2D Images in Anatomy Classes.* Animals, https://www.mdpi.com/2076-2615/14/15/2171

Schloss, K. B., Schoenlein, M. A., Tredinnick, R., Smith, S., Miller, N., Racey, C., Castro, C., & Rokers, B. (2021). *The UW Virtual Brain Project: An immersive approach to teaching functional neuroanatomy. https://arxiv.org/abs/2108.13522*

Smith, A., & Jones, B. (2023). The impact of interactive simulations on physics education. *Journal of Educational Technology*, 45(2), 123-135.

University of Washington (UW) (2021). What are typical challenges students with math-related learning disabilities face? Access Computing. University of Washington (UW).

Yilmaz, R. M., & Goktas, Y. (2017). Using augmented reality technology in storytelling: A study on preschool children's story comprehension. *Interactive Learning Environments, 25*(6), 749–765. https://doi.org/10.1080/10494820.2016.1181094