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“Using 3D modeling to develop the creative abilities of learners”

THESIS

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Using 3D modeling to develop the creative abilities of learners

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Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

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Dedication

This thesis is dedicated to my family, whose unwavering support, encouragement and love have been my guiding light throughout this journey. To my parents for their endless patience and faith in my abilities, as well as to my brothers and sisters for their constant support and understanding. I also dedicate this work to my friends, whose camaraderie and support have made this experience meaningful and memorable. Your friendship has been a source of strength and joy.

Abstract

This paper examines new possibilities for using 3D modeling technologies and explores the development of spatial thinking, imagination and creativity of learners through 3D modeling. The research material was the work of various authors in the field of creativity and creativity development, as well as materials from researchers in the field of three-dimensional modeling. Their use made it possible to study the ideas and outline the prospects for the development of the creative abilities and interests of students. The experimental group was trained using the free 3D modeling program Blender and further experiments and surveys were conducted. The results and analysis of the experiment provide valuable insights into the effectiveness of 3D modeling in creative abilities among learners.

Аңдатпа

Бұл жұмыс 3D модельдеу технологияларын қолданудың жаңа мүмкіндіктерін зерттейді және 3d модельдеу арқылы оқушылардың кеңістіктік ойлауын, қиялын және шығармашылығын дамытуды зерттейді. Зерттеу материалы шығармашылық және шығармашылықты дамыту саласындағы әртүрлі авторлардың жұмыстары, сондай-ақ үш өлшемді модельдеу саласындағы зерттеушілердің материалдары болды. Оларды қолдану идеяларды зерделеуге және оқушылардың шығармашылық қабілеттері мен қызығушылықтарын дамыту перспективаларын анықтауға мүмкіндік берді. Эксперименттік топ Blender тегін 3d модельдеу бағдарламасы арқылы оқытылды және одан әрі эксперименттер мен сауалнамалар жүргізілді. Эксперименттің нәтижелері мен талдауы оқушылардың шығармашылық қабілеттеріндегі 3D модельдеудің тиімділігі туралы құнды түсінік береді.

Аннотация

В данной статье рассматриваются новые возможности использования технологий 3D-моделирования и исследуется развитие пространственного мышления, воображения и творческих способностей учащихся с помощью 3D-моделирования. Материалом для исследования послужили работы различных авторов в области креативности и развития творческих способностей, а также материалы исследователей в области трехмерного моделирования. Их использование позволило изучить идеи и наметить перспективы развития творческих способностей и интересов учащихся. Экспериментальная группа прошла обучение с использованием бесплатной программы 3D-моделирования Blender, после чего были проведены дальнейшие эксперименты и опросы. Результаты и анализ эксперимента дают ценную информацию об эффективности 3D-моделирования для развития творческих способностей учащихся.

Abbreviations

ICT - Information and Communication Technology

CAD - Computer-Aided Design

VR - Virtual Reality

AR - Augmented Reality

STEM - Science, Technology, Engineering, and Mathematics

AI - Artificial Intelligence

MR - Mixed Reality

SPSS - Statistical Package for the Social Sciences

GUI - Graphical User Interface

UV - Ultraviolet (in the context of texturing in 3D modeling)

API - Application Programming Interface

OS - Operating System

VRML - Virtual Reality Modeling Language

PDF - Portable Document Format

3DS - 3D Studio (a file format for 3D models)

CGI - Computer-Generated Imagery

PBL - Project-Based Learning

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Chapter 1

Background and motivations

1.1 Introduction

Nowadays, when technological progress is rapidly developing, changing the educational landscape, the integration of innovative tools and methodologies to ensure the intellectual growth and creative potential of students has become of paramount importance. Education plays a key role in shaping the individual, society and the world as a whole. Its importance covers various aspects - from personal development to social progress. Personal development: Education is fundamental for personal growth and self-realization. It gives people the necessary knowledge, skills and competence that allow them to achieve their goals, realize their potential and lead a fulfilling life. Education develops critical thinking, creativity, problem solving and communication skills, enabling people to cope with difficulties, make informed decisions and adapt to changing circumstances. Economic empowerment: Education is a path to economic opportunities and social mobility. It provides people with the qualifications and authority necessary to gain access to high-paying jobs, secure stable employment and achieve financial security. In addition, education promotes entrepreneurship and innovation, contributing to economic growth and prosperity at both the individual and societal levels. Social cohesion: Education plays a crucial role in strengthening social cohesion and building inclusive communities. By promoting mutual understanding, tolerance and respect for diversity, education develops empathy and compassion, eliminating cultural, ethnic and socio-economic differences. In addition, education instills civic values and democratic principles, allowing people to actively participate in public life and contribute to the common good. Health and well-being: Education is inextricably linked to indicators of health and well-being. It provides people with the knowledge and skills necessary to choose a healthy lifestyle, access to medical services and prevent diseases. In addition, education strengthens mental health by increasing resilience, self-esteem and emotional intelligence, thereby reducing the prevalence of mental disorders and improving overall well-being. Sustainable development: Education is the cornerstone of sustainable development, serving as a catalyst for respect for the environment, social justice and economic prosperity. By increasing environmental awareness, sustainable development literacy and responsible citizenship, education empowers people to address pressing global issues such as climate change, biodiversity loss and social inequality. Cultural preservation: Education plays a crucial role in preserving cultural heritage and facilitating the transfer of knowledge, traditions and values from generation to generation. By instilling cultural literacy and promoting recognition of the diversity of cultural expressions, education enriches collective identity and promotes intercultural dialogue and mutual understanding. In fact, education is not just a means of acquiring knowledge or skills; it is a fundamental human right and a powerful force for positive change. By investing in education, individuals, communities and nations can reach their full potential and build a brighter and fairer future for future generations. Creativity, in turn, which is often called the cornerstone of innovation and problem solving, occupies a central place in modern education. Creativity is of great importance in education because it promotes innovation, develops problem-solving skills, encourages critical thinking, promotes self-expression, develops adaptability, and stimulates curiosity and engagement.[1] By developing creativity in education, students develop the ability to generate new ideas, approach problem solving from different perspectives, and express themselves truly. Creativity helps students navigate complex issues, adapt to changes and make a meaningful contribution to the development of society. Moreover, creative activity develops internal motivation, which leads to deeper involvement and consolidation of knowledge in various subject areas. Thus, the integration of creativity into education is necessary to prepare students for success in the 21st century, where the ability to think critically, innovatively solve problems and communicate effectively is of paramount importance. As teachers strive to teach students the skills they need to thrive in an increasingly complex and interconnected world, developing creativity has become a major challenge. By encouraging divergent thinking, instilling originality, and encouraging research, educational institutions aim to empower students to navigate uncertainty and find new solutions to real-world problems.

However, traditional educational paradigms often fail to effectively develop and evaluate creativity, which forces educators to look for alternative approaches. Modern education is in urgent need of innovative development. Due to the development of high–tech industries all over the world, the need for scientific and engineering personnel in our country is becoming increasingly acute.

The result of education should be not only the assimilation of knowledge and skills by students, but also their adaptation to constantly changing living conditions and readiness in the future to acquire new professions, including engineering. As a result, there is an obvious need to search for and use new pedagogical technologies and methods that could ensure the achievement of this result. The training of competent, creative, highly qualified, and most importantly in–demand specialists who are oriented in rapidly changing conditions and are able to apply modern information technologies is one of the main tasks of the educational system. Education faces many challenges, from involving students in meaningful learning to preparing them for an increasingly complex and technological world. One of the key challenges in education is the struggle for effective student engagement. Many students find the traditional classroom environment and teaching methods boring, which leads to detachment and lack of motivation. Another challenge in education is the need to prepare students for a rapidly changing technology-driven world. The traditional approach to education often lags behind technological advances, as a result of which students are poorly prepared for the demands of modern society.

One of the ways to solve these problems is to study 3D modeling. In recent years, the advent of 3D modeling technology has revolutionized industries ranging from architecture and engineering to entertainment and healthcare. Working with 3D modeling is one of the most "popular areas of use of information and communication, multimedia technologies, and not only professionals, but also novice users are engaged in this work. No modern multimedia program can do without computer graphics. At the same time, teachers realized the potential of 3D modeling as a tool that can improve the quality of teaching and learning. Unlike traditional two-dimensional representations, 3D models offer exciting interactive platforms through which students can visualize abstract concepts, manipulate objects, and experiment with design principles. By using digital tools such as computer-aided design (CAD) software and virtual reality (VR) environments, teachers can facilitate hands-on learning and experience acquisition, thereby overcoming the limitations of traditional teaching methods. Among these tools, 3D modeling stands out as a dynamic and versatile environment capable of revolutionizing the educational process.[2] One of the innovative solutions to these problems is the integration of 3D modeling into educational practice. This technology provides a unique opportunity to transform traditional teaching methods, making learning more interactive, fun and relevant to the real world. With the help of 3D modeling software, students can create, manipulate and explore three-dimensional objects, making abstract concepts more tangible and attractive. This not only improves their understanding of complex topics, but also develops creativity and problem-solving skills.

Three-dimensional modeling technology can be used in various educational subjects:

- **Mathematics**- Students can use 3D modeling software to create and manipulate geometric shapes by learning concepts such as volume, surface area, and spatial relationships. It helps to visualize complex mathematical functions and equations, allowing students to intuitively understand mathematical concepts.[3] Moreover, students can use three-dimensional graphs and diagrams to represent and analyze data, which makes statistical concepts more accessible and exciting.
- **Science** - Students can create 3D models of biological structures such as cells, organs and organisms, which allows them to study anatomy, physiology and genetics in practice. 3D modeling can be used to visualize molecular structures and chemical reactions, helping students understand the behavior and properties of various substances.[4] It is also possible to simulate physical phenomena and experiments using 3D models, studying concepts such as motion, forces, energy and waves.

- **Social Studies** - Students can use 3D modeling to recreate historical events, monuments, and artifacts, bringing history to life and allowing them to explore different time periods and cultures.[5] 3D models can be used to visualize geographical features such as mountains, rivers, and ecosystems, making it easier to study physical geography and population geography.
- **Art and Design** - Students can use 3D modeling to create multimedia presentations, animations, and digital storytelling projects, combining visual, auditory, and textual elements to effectively convey ideas. [6] 3D modeling software provides students with a platform to explore sculpture, digital art, and design, allowing them to create three-dimensional works of art and designs. Students can use 3D modeling to design and visualize architectural structures, learning the principles of design, scaling, proportions, and spatial planning. 3D modeling can be used to create prototypes and repeat product designs, allowing students to explore shape, function, and usability in product development projects.

Interest in these types of technical creativity[7], which serves as the basis for further orientation of students to engineering specialties and inventive activities, must be formed from elementary school and later at the university. Research by many foreign scientists confirms that 3D modeling contributes to the formation of interest in technical creativity. In them, 3D modeling is considered as the most important discipline in engineering education of students. In the process of technical creativity, students learn the basics of design and modeling. The formation of cognitive interest in any field of knowledge, including interest in technical creativity, allows you to evoke positive emotions towards this area, which in turn encourages the student to practice innovative activities in the technical field in the future. Nevertheless, in the modern pedagogical system, the possibilities of 3D modeling technology in shaping the interest and development of students' creativity have not been sufficiently explored. There are several reasons why the full potential of 3D modeling technology in education[8], especially its impact on the formation of student interest and the development of creative abilities, remains relatively unexplored in many educational institutions:

1. Limited awareness and training: Many teachers may not be fully aware of the possibilities and applications of 3D modeling technology in education or may not have the necessary training to effectively integrate it into their teaching practice. Without adequate opportunities for professional development and support, educators may be hesitant or insufficiently prepared to explore new pedagogical approaches related to 3D modeling.
2. Limited infrastructure and resources. The introduction of 3D modeling technology in education often requires access to appropriate hardware, software, and technical support. However, not all educational institutions have the necessary infrastructure or resources to support the integration of 3D modeling into their curricula. Limited funding, outdated equipment and logistical problems can create obstacles to implementation.
3. Curriculum Alignment: Integrating 3D modeling technology into the curriculum requires careful alignment with educational standards, learning objectives,

and assessment methods. Teachers may find it difficult to find ways to seamlessly integrate 3D modeling into existing curricula without disrupting established learning procedures and sacrificing study time devoted to other subjects and activities.
4. A change in the pedagogical paradigm: The introduction of 3D modeling technology into education often entails a change in pedagogical paradigms — from teacher-oriented learning to a student-oriented approach to research-based learning. This shift may require teachers to rethink their role as learning facilitators, empower students as active participants in the learning process, and create opportunities for research, experimentation, and collaboration.
5. Evaluation and accountability. Educational institutions are often under pressure to demonstrate measurable results and accountability for student achievement. However, it can be difficult to assess the impact of 3D modeling technology on the formation of students' interest and creative development using traditional assessment methods and standardized tests. Teachers may need to develop new assessment strategies and criteria that reflect the multifaceted nature of student creativity and engagement.
6. Cultural and institutional resistance: Resistance to change, fear of the unknown, and entrenched institutional culture can hinder the introduction and adoption of innovative technologies such as 3D modeling in education. Educators, administrators, parents, and other stakeholders may be skeptical or unwilling to embrace new technologies and pedagogical approaches, preferring to adhere to familiar practices and traditions. In the process of analyzing these problems, a contradiction was revealed between the use of 3D as an opportunity to develop creative abilities and the lack of knowledge of the possibilities of 3D modeling that contribute to solving this problem.

Based on the contradictions found, the **research problem** is determined: what are the possibilities of using 3D modeling in generating interest in learning and developing creative abilities? As part of the relevance of this problem, the **research topic** was formulated: "Using 3D modeling to develop the creative abilities of learners and increase their interest in education" The **relevance** of this problem lies in the fact that the currently available training system does not fully rely on modern computer technologies, including 3D modeling, do not fully ensure the training of future specialists for future professional activities in modern conditions of computerization of society, as well as insufficient information and research on improving creativity and creative abilities. The purpose of the study is to theoretically substantiate, analyze and experimentally test the possibility of developing creative abilities and interest in learning through 3D modeling in the system of additional education.

The object of research: the process of developing students' creative abilities and forming their interest in learning **Subject of research:** 3D modeling as an opportunity to develop students' creative abilities and their interest in learning. The **hypothesis of the study:** 3D modeling has been effectively integrated into teaching and learning practices; the structure and essence of the concept of creative abilities are revealed; the development of creative abilities through 3D modeling in the system of additional education has been consistently implemented a set of additional 3D modeling classes has been developed, focused on the development of indicators. . Criteria and indicators for the development of creative abilities and interest in learning have been defined, which are characterized by: the focus of interest, the presence of knowledge and the need to engage in technical creativity in the future, the presence of positive emotions from activity, perseverance in mastering modeling skills. [9] In accordance with the purpose and hypothesis, the following **research objectives** are formulated: 1) To analyze the pedagogical, psychological, methodological literature on the problem of developing creative abilities through 3D modeling and to identify the degree of its development in theory and practice; 2) To identify the level of development of creative abilities of the subjects 3) To analyze the methodological and practical experience of teaching 3D modeling. 4) Conduct a comparative analysis and selection of software for 3D modeling training.

This paper examines the multifaceted impact of using 3D modeling as a pedagogical tool for developing students' creative abilities and increasing interest in education. The tasks facing students are interesting and often difficult to solve, which makes it possible to increase the educational motivation of students, develop their spatial imagination, as well as their abilities in computer science and determine the relationship with mathematics"

Chapter 2

Literature Review

2.1 3d modeling in education: teaching methods and practice

School methodologists note a general decrease in the level of motivation and interest in learning among modern schoolchildren. Some teachers explain this fact by the technical backwardness of schools, in which some students stopped considering educational literature as the only true source of knowledge and switched to searching for information on the Internet using electronic gadgets, computers, mobile phones, tablets, etc. Modern information technologies make it possible to display various visual information in three-dimensional space. Most of the information about the world around us is perceived through the organs of vision. [10] In order to achieve maximum accuracy in the perception of information, it is necessary to provide visual perception as close as possible to reality. Modeling training is of great importance both for the formation of ICT competence and for achieving personal results, including the development of creative abilities. Children are exposed to 3D from a very young age through models and special effects used in films and TV shows using computer graphics. And recreating your characters in 3D is an exciting creative process for children, limited only by their imagination. The use of 3D modeling and animation in education provides teachers with new learning tools. These tools help students to perceive learning material more easily, increase their motivation and accelerate the assimilation of large amounts of knowledge. 3D technologies can change the approach of educational institutions to learning, allowing them to combine and apply modern approaches to learning. [11] 3D technologies will allow you to diversify your training sessions, and make the learning process effective and visually voluminous.

Jean Piaget, a well-known Swiss psychologist, proposed a theory of cognitive development, which assumes that people go through four stages of mental development as they acquire knowledge and understanding of the world around them. These stages are:

- Sensorimotor stage: This stage is characterized by sensory experiences and motor actions. For example, infants explore the world through their senses (sight, hearing, touch, taste, smell) and their movements. The educational material at this stage should stimulate the senses and encourage research. For example, colorful and textured objects, toys that make sounds, and actions that encourage grabbing and manipulating objects help children better understand the world around them.

- The preparatory stage: At this stage, children begin to use symbols (such as words and images) to represent objects and ideas. They participate in pretend games and develop basic language skills. The educational material should be aimed at the development of speech, imagination and symbolic thinking. Storybooks, educational games and activities that encourage creative play help children make connections between symbols and concepts of the real world.

- The specific stage of operation: At this stage, children become more capable of logical thinking and can perform mental operations with specific objects. They begin to understand concepts such as environmental conservation and can take part in solving basic tasks. The educational material should contribute to the development of logical thinking and problem-solving skills. Practical exercises, experiments and puzzles that require logical thinking and understanding of cause-and-effect relationships help children develop their logical abilities.

- The formal operational stage: At this final stage, people develop the ability to think abstractly and hypothetically. They can participate in solving complex problems, consider different points of view and reflect on the possible results of their actions. The educational material at this stage should encourage students to think critically and analytically. Complex texts, debates, research projects, and discussions that require students to analyze, evaluate, and summarize information help develop their linguistic and cognitive abilities

According to Piaget's theory[12], as people progress through these stages, they develop increasingly complex mental structures and the ability to assimilate new information in accordance with their existing understanding of the world. Each stage builds on the previous one, which leads to more advanced forms of thinking and understanding. By understanding these stages, educators can develop age-appropriate materials and activities that promote learning and cognitive development of students. One of the reasons for the difficulty of perceiving information is that most of the educational material is presented at the lexical level. In order to achieve maximum accuracy in the perception of information, it is necessary to provide visual perception as close as possible to reality. Observing the natural order of perception and processing of information leads to time savings in the learning process. When educational material is presented with the help of visual images, various channels are involved in the process of perception: hearing, vision, etc. An imaginative visual representation of an object can be obtained by studying the object itself or its physical model, as well as their display obtained by multimedia means (electronic posters, video clips, animation, etc.), including computer (virtual) 3D images. [13] An important feature of three-dimensional models is the ability to change the properties of both the component elements of the model and the entire model as a whole, depending on the needs of the developer. Thanks to this, you can change the location of individual elements in space, change their appearance, use additional objects, and so on. You can show not only static graphics, but also complex spatial animation, as well as processes (including hidden ones) occurring both with and inside the object. And this leads not only to a significant increase in the visibility of the material, but also to significant time savings during training. In addition, modern technologies make it possible to obtain photorealistic graphics based on a model that is not inferior in quality to photo and video materials. The advantages of learning using information technology in the form of using 3D models are obvious. Unlike flat static images, such models are interactive: you can select any viewing point, make any transformations with a minimum of effort. Computer 3D models in the process of studying can either be disassembled into separate elements, or assembled into a single product. The interactivity of 3D computer models means that students and teachers are given the opportunity to actively interact with these tools. Interactivity means that there are conditions for educational dialogue-interaction, one of the participants of which is a computer model.

3D laboratories are specialized facilities equipped with advanced tools and technologies for creating, manipulating and visualizing three-dimensional objects and the environment. Such premises often include:

- 3D printers: Devices that create physical objects layer by layer based on digital drawings.
- 3D scanners: Devices that capture the geometry and texture of physical objects to create digital 3D models.
- Computer-aided design (CAD) software: Programs used to design and model objects in three dimensions.
- Virtual Reality (VR) and Augmented reality (AR) equipment: systems that immerse users in a virtual environment or overlay digital content on the real world.

The active introduction of 3D laboratories in education is due to several factors:

- Industry requirements: Many industries such as mechanical engineering, architecture, and healthcare are increasingly relying on 3D technology. Educational institutions strive to prepare students for careers in these fields by providing them with hands-on experience with 3D tools.
- Pedagogical advantages: 3D technologies improve the quality of learning by making abstract concepts tangible and providing an interactive experience. They engage students and improve their understanding and memorization of difficult topics.

- Technological advances: Advances in 3D printing, scanning, and modeling have made these technologies more accessible, making it easier to integrate them into educational institutions.

Examples of 3D technology applications [14] in education:

- Physics: Students can use simulators to visualize and experiment with concepts such as gravity, motion, and electromagnetic fields. Virtual laboratories allow you to conduct safe and cost-effective experiments.
- Mathematics: 3D modeling software allows students to study geometric shapes, spatial relationships, and mathematical functions in three dimensions.
- Biology: Virtual anatomical research provides a realistic and ethical alternative to traditional animal research. Interactive models help students understand complex biological structures and processes. History: Augmented and virtual reality applications allow students to explore historical sites and artifacts in an immersive virtual environment. Digital reconstructions bring ancient civilizations and events to life.
- Geography: 3D maps and globes allow students to explore geographical features, terrain and ecosystems in an interactive way. They can virtually visit different parts of the world, analyze landscapes and understand geographical phenomena such as erosion and plate tectonics.
- Architecture and Engineering: Students can use 3D modeling software to design structures, buildings and machines. This hands-on approach allows them to understand architectural principles, structural integrity, and engineering concepts by creating and manipulating virtual prototypes.
- Language Learning: Immersive virtual reality environments can simulate real language situations, allowing students to practice speaking and listening in a safe and controlled environment. They can communicate with virtual characters, explore a foreign environment and improve their language skills through interactive activities.
- Art and Design: 3D modeling and sculpture tools allow students to unleash their creativity by creating digital sculptures, characters and environments. They can explore shape, texture, and composition by experimenting with various artistic techniques in a digital environment.
- Medicine and Healthcare: Virtual simulators and anatomical models help medical students understand human anatomy, physiology, and medical procedures. They can practice surgical techniques, diagnose diseases and learn about the inner workings of the human body in a realistic virtual environment

Advantages of using a 3d laboratory:

- Improves understanding and memorization of complex concepts.
- Promotes hands-on learning and engagement.
- Prepares students for careers in technology-related fields.

Disadvantages of using a 3D laboratory :

- Expensive to install and maintain.
- It requires special teacher training.
- Accessibility issues for schools with limited resources or infrastructure.

Advantages for students and teachers in using a 3d laboratory :

Students:

- Improved understanding of abstract concepts.
- Increase motivation and engagement.
- Developing critical thinking and problem solving skills.

Teachers:

- Improving learning efficiency through interactive demonstrations.
- Adaptation of educational materials to the needs of students.
- Opportunities for professional development and professional development.

There are many examples of how 3D labs are used in education in the United States. For example:

- Medical education: Many medical schools in the United States are introducing 3D printing technology into their curricula. For example: University of Michigan Medical School: They use 3D printing to create anatomical models for surgical training and patient education. Medical students can study complex anatomical structures and practice surgical procedures on realistic models before operating on real patients.
- STEM education at universities: Massachusetts Institute of Technology (MIT): The MIT laboratory provides students with access to advanced tools for manufacturing products, including 3D printers and laser cutters. Students use these resources to create prototypes, experiments and research in various disciplines, from engineering to architecture.
- Libraries and workshops: New York Public Library (NYPL): NYPL's TechConnect program provides access to 3D printing technologies in some branches. They conduct seminars and trainings for visitors to learn how to create and print their own objects using 3D printers. This initiative promotes STEM education and digital literacy in the community.

- K-12 Education: Johns Hopkins University Center for Talented Youth (CTY): CTY offers summer programs for academically gifted students, including courses in 3D design and printing. Students learn to use CAD software to create their own 3D models, which are then printed on 3D printers. Such practical experience contributes to the development of creative abilities and problem-solving skills among young students.
- Schools of Art and Design: Rhode Island School of Design (RISD): RISD's Department of Digital Technology and Media is introducing 3D technology into its curriculum. Students study digital fabrication techniques, including 3D printing and CNC milling, to create interactive installations, sculptures and other works of art. This interdisciplinary approach combines traditional artistic practices with advanced digital tools.

It is necessary to start forming students' ideas and competencies related to 3D modeling from elementary school. Introducing primary school students to 3D modeling is important because it promotes the development of critical skills and competencies at an early stage, preparing them for life in a world that is becoming increasingly digital and technologically oriented. At this stage of formation, children are very receptive to learning and developing spatial thinking, creativity and problem-solving abilities. By engaging in 3D modeling, students not only deepen their understanding of abstract concepts in subjects such as mathematics and natural sciences, but also develop digital literacy and fluency in technologies that are fundamental to success in the workplace in the 21st century. In addition, familiarity with 3D modeling promotes interdisciplinary learning, stimulates curiosity and innovation in various fields, and lays the foundation for lifelong learning and adaptation to an ever-changing technological landscape. Various articles raise the issue of the importance of 3d in the field. In one of them[15] previous research covering a wide range of educational disciplines is summarized by posing two questions: Where is 3D used in the education system?
How is 3D used in the education system?(see Uses of 3DP in different educational settings)

Table 2.1 - Uses of 3DP in different educational settings

How is 3D being used in the education system?	Schools	Universities	Libraries
Teaching students about 3D	3DP and 3D modelling are introduced to students during design and prototyping projects in class	The fundamentals of 3DP and 3D modelling are introduced to engineering and design students, who apply their skills during in-class projects	Improving access to 3DP equipment and services enables self-directed learning by students outside class
Teaching educators about 3D	3DP and 3D modelling are being introduced to in-service teachers	3DP and 3D modelling are being introduced to pre-service and in-service teachers	Training librarians enables them to operate and maintain 3DP equipment, and troubleshoot 3D modelling problems
Using 3D during teaching	Using 3D during class projects to improve student engagement and understanding of STEM subjects	Using 3D during class projects to improve student engagement and understanding of STEM subjects	Using 3D during class projects to improve student engagement and understanding of STEM subjects
Using 3D to produce artefacts that aid learning	-	3D models enable hands-on learning in lectures and lab sessions, particularly in anatomy and chemistry teaching	-
Using 3D to create assistive technologies	-	-	-

Table "Uses of 3DP in different educational settings" explains where 3d technologies were used To answer these questions, a review of the scientific literature was conducted, which explores the application of 3d technologies in teaching and education. The use of digital manufacturing technologies such as 3D to support education is far from new. Disciplines such as architecture and engineering were the first to use rapid prototyping technologies and many advantages associated with the introduction of these technologies into teaching have been identified. For example, they can facilitate learning, develop skills and increase student engagement; inspire creativity, improve attitudes towards STEM subjects and careers, and increase teacher interest and engagement. This literature review expands our understanding of 3D in the education system by describing the benefits and challenges of using 3D.

Research shows that strong spatial thinking, a skill necessary to create three-dimensional objects, is directly related to success in science, technology, engineering and mathematics, which are collectively called STEM disciplines[16]. STEM stands for Science, Technology, Engineering and Mathematics - science, technology, engineering and mathematics. It is a broad term used to combine these academic disciplines. Also, this term usually refers to an approach to the educational process, according to which the basis for acquiring knowledge is simple and accessible visualization. scientific phenomena, which makes it easy to grasp and gain knowledge based on practice and a deep understanding of processes. The integration of 3D modeling and printing into the STEAM education system is gaining momentum due to its potential to improve learning outcomes in various subjects[17]. Research has shown numerous benefits of using 3D technologies in learning, including increased student engagement, better visualization of concepts, and improved mathematical and technical skills.[18] However, successful implementation depends on the preparedness of teachers and their training in the effective use of these tools. Teachers must have a basic understanding of mathematical concepts such as geometry, algebra, and fractions in order to take full advantage of 3D modeling and printing capabilities. In addition, teachers of various STEAM disciplines face unique challenges when implementing 3D technologies into their curricula.[19] For example, it may be difficult for teachers of engineering and computer science to associate 3D printing with other subjects, while it may be difficult for teachers of mathematics, biology, chemistry, physics and fine arts due to the technical aspects of using 3D printers. Despite these difficulties, STEAM teachers generally believe that 3D modeling and printing can make a significant contribution to the principles of learning on STEAM, provided they have the necessary support and resources. Based on the analysis of the literature and the education plan, it was concluded that the topic of 3d modeling and prototyping is considered superficially in the school computer science course and a fairly small amount of time is devoted to this. It is possible to identify a common approach for most of them, and as an object of research, modeling is not given as much attention. Basically, this topic boils down to the introduction of basic concepts and consideration of models of various types and types.

2.2 Software Analysis

There is a wide variety of 3D graphics software that is suitable for different skill levels, preferences, and goals. Mastering and choosing the right 3D modeling software is a very important step. It is important to choose the one based on your goals, since some programs are not very simple tools for learning, even for adults. Also an important element is that many programs are paid, and in the field of education and for many students this is an important factor in choosing.

Blender is a comprehensive package for creating 3D images, which includes modeling, animation, rendering, compositing, video editing and simulation capabilities. It is an open source software supported by the Blender Foundation, making it available to users worldwide. Here is a brief description of its key aspects: It supports various file formats and has an active community providing add-ons and plugins that extend its functionality. Blender's interface may initially seem complicated due to its extensive feature set, but it offers customizable layouts and extensive documentation to help users learn and master its tools. Blender can be downloaded and used for free, regardless of commercial or non-commercial purposes. This makes it an attractive option for artists, hobbyists, independent developers and even professionals who are looking for reliable 3D software without financial constraints.

Advantages: Cost-effective: Blender is available to any open source user and is free. Multifunctional: Blender offers a complete set of tools for creating 3D images, including modeling, animation, rendering and more, competing with many commercial software packages. An active community: Blender has a large and active community that publishes tutorials, add-ons, and support forums, making it easier for users to learn and troubleshoot. Regular updates: The Blender Foundation regularly releases updates and new features, ensuring that Blender remains competitive and meets industry standards. Cross-platform compatibility: Blender runs on Windows, macOS and Linux, allowing users to work seamlessly on different operating systems.

Disadvantages: Interface complexity: The Blender interface can be difficult for new users due to the multitude of panels, buttons and menus. However, it is highly customizable and users can create their own layouts to optimize the workflow. Resource-intensive: Blender's advanced features, especially in rendering and modeling, can be resource-intensive, requiring powerful hardware to run smoothly, especially in complex projects.

3ds Max is a professional 3D computer graphics software developed and produced by Autodesk, a leading design and entertainment software company. It is widely used in various industries such as architecture, games, film, television and advertising to create high-quality 3D content. It allows users to create complex 3D models, animations, visual effects and architectural visualizations. With features such as parametric modeling, procedural animation, and particle systems, it provides versatility when creating a wide range of visual content. It is also commercial software, so a paid license is required to use it. Autodesk offers a variety of subscription plans, including monthly, annual and multi-year, tailored to the needs of users and their budgets. In addition, students, teachers and educational institutions are provided with educational licenses at discounted prices, and sometimes even free of charge.

Advantages: Full range of features: 3ds Max offers a wide range of tools for modeling, animation, rendering and visual effects, allowing users to perform various projects within a single software environment. Integration with other Autodesk Software: As part of the Autodesk ecosystem, 3ds Max seamlessly integrates with other Autodesk programs such as Maya, AutoCAD and Revit, ensuring compatibility and workflow efficiency. Industry-standard rendering: 3ds Max includes powerful rendering engines such as Arnold and V-Ray, allowing users to create photorealistic images with enhanced lighting, materials and effects. Extensive user base and Support: 3ds Max has a large and active user community with numerous guides, forums, and resources available online for learning, troubleshooting, and knowledge sharing. Extensive plugin support: 3ds Max supports a wide range of third-party plugins and scripts, allowing users to extend functionality and customize their workflows according to their specific needs.

Disadvantages: Cost: It requires a significant investment compared to free alternatives or open source programs such as Blender. Learning process: Mastering its extensive set of functions and complex workflows can take time and dedication. Resource-intensive: Rendering complex scenes and animations in 3ds Max can be a resource-intensive process that requires powerful hardware to achieve optimal performance. License management: Managing licenses and subscription plans, especially in large-scale production environments, can be challenging and require additional administrative costs.

SketchUp is a 3D modeling software developed by Trimble Inc. It is known for its intuitive interface and ease of use, which makes it popular among architects, interior designers, engineers and hobbyists to create 3D models of buildings, interiors, furniture and other objects. SketchUp offers a simple approach to 3D modeling, allowing users to create models by drawing lines and shapes in a familiar way, similar to a sketch. The program has a simple and intuitive interface with tools for drawing, extruding, rotating and scaling geometry. SketchUp uses push-pull modeling technology, with which users can easily create and manipulate 3D shapes by pressing and pulling on surfaces. SketchUp is available in several versions, including SketchUp Free (web version), SketchUp Shop (web version), SketchUp Pro (desktop application) and SketchUp Studio (subscription package). SketchUp Free and SketchUp Shop offer basic functionality and are available for free, while SketchUp Pro and SketchUp Studio include additional features and require a paid license or subscription.

Advantages: Ease of use: SketchUp's intuitive interface and simple tools allow users to quickly create 3D models even without prior 3D modeling experience. Versatility: SketchUp can be used for a wide range of applications, including architectural design, interior design, woodworking, urban planning and more. Large 3D Warehouse: SketchUp has an extensive online storage facility called 3D Warehouse, where users can find and download thousands of ready-made 3D models created by other users. This makes it easier to fill projects with ready-made content and speeds up the modeling process. Community and Support: SketchUp has a large and active user community with forums, tutorials, and resources that help users learn, troubleshoot, and share knowledge. Disadvantages: Limited Accuracy: SketchUp's commitment to ease of use can lead to limitations when it comes to accurate modeling and detail, especially when compared to more advanced 3D modeling software. Workflow Limitations: Although SketchUp does an excellent job of creating conceptual models and preliminary designs, it may not be suitable for complex or highly detailed projects that require advanced modeling and rendering capabilities. Export Capabilities: SketchUp's export capabilities are somewhat limited compared to other 3D modeling programs, especially when it comes to exporting to industry standard file formats or integrating with certain software and workflows.

Tinkercad is a user-friendly Internet-based 3D modeling software developed by Autodesk. It is designed to be intuitive and accessible, making it an excellent choice for beginners, teachers, and hobbyists who are new to 3D design and modeling. Tinkercad offers a simplified approach to 3D modeling, allowing users to create and manipulate 3D shapes using basic geometric primitives such as cubes, cylinders and spheres. It features an intuitive drag-and-drop interface where users can easily place, resize and combine shapes to create more complex models. Tinkercad also provides basic tools for adding text, colors, and simple shapes to enhance the appearance of models. Tinkercad is available for free to anyone with an internet connection and a web browser. There are no subscription fees and no upfront costs, making it accessible to a wide audience, including students, teachers, and hobbyists.

Advantages: Ease of use: Tinkercad's user-friendly interface and intuitive tools make it easy for beginners to start creating 3D models without prior experience or technical knowledge. Accessibility: Since Tinkercad works over the Internet, it can be accessed from any device connected to the Internet and having a web browser, which eliminates the need to install or update software. Educational Resources: Tinkercad offers a variety of educational resources, including tutorials, projects, and lesson plans, making it a popular choice for teachers looking to introduce 3D design concepts in the classroom. Integration with other Autodesk software: Tinkercad seamlessly integrates with other Autodesk programs such as Fusion 360 and AutoCAD, allowing users to easily migrate and refine their projects with more advanced tools as their skills develop. Community and Information Sharing: Tinkercad has a community platform where users can share their developments, collaborate on projects and leave feedback, fostering creativity and collaboration between users.

Disadvantages: Limited functionality: Although Tinkercad is great for solving simple 3D modeling tasks, it lacks the advanced features and capabilities inherent in more professional 3D modeling programs such as Blender or 3ds Max. As users develop their skills and projects, they may find themselves limited in their basic tools and capabilities. Limitation: Since Tinkercad is a web application, users need a reliable internet connection to access and use it. Offline functionality is not available, which may be a limitation in certain situations or environments. Export Capabilities: Tinkercad offers limited export capabilities compared to more advanced 3D modeling software. Although users can export projects as STL files for 3D printing, exporting to other file formats or integrating with other software can be more difficult. Advanced features and capabilities, you may need to explore other software options as you develop your skills and projects.

Table 2.2 - Comparison of different 3D softwares

3D softwares	OS	Price	Complexity	Format support	Browser	Drawing
Blender	Linux, Windows	free	medium	OBJ, FBX, STL, 3DS, DXF, DAE, X3D, VRML, PLY.	-	+
3ds max	Windows	From 235 $ to 1 875 $	high	OBJ, FBX, 3DS, DWG, DXF, STL	-	-
Sketchup	Windows macOS	from 119 $ to 749 $	elementary	KP, DWG, DXF, 3DS, OBJ, STL	-	+
Tinkercad	Android, iOS, Windows, MacOS	free	elementary	STL	+	+

The selection of software for three-dimensional modeling was made according to the following criteria: paid / free service; speed of operation, range of tools; availability of materials and help; the ability to create your own shapes and models; support for printing on a 3D printer. We have reviewed some 3D modeling programs.

2.3 Development of spatial imagination

Spatial imagination is the ability to mentally manipulate objects and spatial relationships in three-dimensional space and visualize them. It includes various cognitive processes that allow people to perceive, interpret and interact with spatial information, which allows them to effectively understand and navigate their physical environment. Here are some characteristics of spatial imagination:

Mental Rotation: Spatial imagination involves the ability to mentally rotate objects in front of your mind's eye. People with strong spatial imagination can mentally manipulate objects to represent them from different points of view, angles and orientations. In 3D modeling, people should be able to mentally rotate objects not only horizontally and vertically, but also in depth. This involves visualizing how objects will look from different angles and perspectives, which is crucial for creating accurate and realistic models.

Spatial visualization: Spatial imagination includes the ability to visualize complex spatial relationships and configurations. In 3D modeling, people must be able to mentally create and manipulate objects in virtual space, understanding how different elements interact and relate to each other in three dimensions.

Perception of perspective: Spatial imagination allows people to perceive different angles and points of view when interpreting spatial information. They can visualize scenes or objects from different points of view and understand how spatial elements look from different angles. Working with 3D modeling software requires the ability to use different points of view in a virtual environment.

Spatial perception: Spatial imagination involves increased awareness of the spatial environment and the ability to navigate effectively in physical space. People with a strong spatial imagination have a keen sense of direction, distance and spatial relationships, which allows them to navigate in an unfamiliar environment. Users need to understand the layout of the virtual space, including the position, scale, and orientation of objects relative to each other, in order to effectively manipulate and arrange elements in the scene.

Spatial thinking: Spatial imagination involves the ability to reason and solve problems using spatial information. People can analyze spatial structures, make spatial judgments, and derive spatial relationships to solve spatial problems or tasks. Users should analyze spatial relationships, make informed design decisions, and anticipate how changes will affect the overall structure of the model.

Spatial memory: Spatial imagination involves the ability to store and retrieve spatial information in memory. People can mentally imagine and recall spatial patterns, configurations, and routes, which makes it easier to navigate and solve spatial thinking problems. Users need to remember the location, dimensions, and properties of objects in the scene, which makes it easier to navigate, edit, and organize the model efficiently.

Spatial Creativity: Spatial imagination promotes creativity and innovation in spatial design and problem solving. Individuals can generate new spatial solutions, present alternative placement options, and explore creative possibilities in spatial contexts. 3D modeling encourages spatial creativity and innovation by allowing users to explore creative possibilities and express their ideas in three dimensions. Spatial imagination allows users to experiment with various design concepts, textures, lighting effects and compositions to create visually appealing and aesthetically pleasing models.

Spatial Communication: Spatial imagination allows people to effectively communicate spatial concepts and ideas. They can use visual representations, diagrams, and models to communicate spatial information to others, which promotes collaboration and mutual understanding in solving spatial problems. Users can communicate spatial information through visual representations, renderings, animations, or virtual step-by-step instructions, which facilitates collaboration, feedback, and mutual understanding between stakeholders involved in the design process. Spatial imagination encompasses a range of cognitive abilities that contribute to the perception, interpretation, and manipulation of spatial information. [20] It plays a crucial role in various fields, including STEM disciplines, architecture, design and art, and is necessary for the development of creativity, problem solving skills and spatial thinking.

2.4 Direct connection between spatial imagination and creativity

The connection between spatial imagination and creativity lies in the fundamental role that spatial thinking plays in the creative process.[21] Spatial imagination, which includes the ability to mentally manipulate objects and visualize spatial relationships in three-dimensional space, provides a cognitive foundation for creative self-expression and problem solving in various fields.

- Spatial imagination allows people to visualize abstract ideas and concepts in three-dimensional space. This ability allows creatively minded people to create mental images of potential solutions, explore alternative perspectives, and conceptualize innovative projects or compositions.

- Spatial imagination promotes the generation and exploration of ideas, providing a mental platform for experimentation and research. Creative individuals can mentally manipulate objects, rearrange elements, and explore hypothetical scenarios to create new ideas, solutions, or designs.

- Spatial imagination includes spatial thinking skills that are necessary for problem solving and creative thinking. Creative individuals can analyze spatial structures, identify relationships between elements, and develop new strategies to overcome spatial constraints or problems.

- Spatial Creativity and Artistic Expression: Spatial imagination fuels artistic creativity by allowing people to translate their creative ideas into tangible forms and expressions. Artists, designers and architects use spatial imagination to create visually appealing works of art, innovative designs and immersive environments that evoke an emotional response and inspire the audience.

- Spatial Collaboration and Communication: Spatial imagination facilitates collaboration and communication by providing a common language for expressing and sharing ideas. Creative individuals can use visual representations, sketches, diagrams, or prototypes to convey spatial concepts and projects to employees, stakeholders, or an audience, fostering mutual understanding and feedback.

- Spatial Exploration and Innovation: Spatial imagination encourages exploration and innovation by encouraging people to push the boundaries of what is possible in three-dimensional space. Creatively minded people can experiment with unconventional ideas, non-standard shapes and materials to create innovative designs, inventions or experiences that challenge norms and stimulate innovation.

In general, spatial imagination is an essential component of creativity, allowing people to visualize, conceptualize and express ideas in three-dimensional space. Using spatial thinking skills, creative thinkers can unleash their imagination, solve complex problems and bring innovative ideas to life in a wide range of disciplines, from art and design to science and engineering.

Chapter 3

Methods and Methodology

3.1 The development of spatial thinking, imagination and creativity in students

The study developed instructions and laboratory work for students of the 9th grade of the 66th lyceum school on 3D modeling. To achieve this goal, the Blender program was chosen, which is free. Students of the basic school perform basic level tasks to build a simple model. All the tools, functions and interface are first explained, and then, according to detailed instructions, students model objects themselves, consolidating the theoretical material.

Participants: Twenty-four high school students between the ages of 14 and 16 were selected from a city school to participate in the experiment. They were divided into two groups: either the experimental group (n=12) or the control group (n=12). All participants had basic computer literacy skills. An important component was not having experience working with 3D modeling programs.

Procedure: The experimental group underwent structured 3D modeling training using standard software for eight weeks. The curriculum shown in the table **The Curriculum Outline** included training programs and practical exercises aimed at developing spatial thinking, imagination and creativity.

Table 3.1 - The Curriculum Outline

Section and Topics	**Time (hours)**			**Description**
	Theory	**Practice**	**Overall**	
Week 1: Introduction to Blender				
Introduction	1		1	Held acquaintance session, described tasks and goals.
Introduction with Blender	1	1	2	Overview of Blender interface, navigation, and main 3D modeling tools and techniques.
Week 2: Basic exercises				
Operations with objects	1	1	2	Creating simple geometric shapes (cube, sphere, cylinder), transforming objects (moving, rotating, zooming), and combining/editing objects.
Advanced modeling tools	1	1	2	Introduction to advanced modeling tools such as extrusion, chamfering, and loop cutting, and modeling complex objects/environments.
Week 3: Complex exercises				
Modifiers	1	2	3	Introduction to modifiers and their application in workflow modeling.
Week 4: Complex exercises 2				
Generating modifiers		1	1	Learn modifiers like Mirror, Array and Solidify.
Deforming modifiers		1	1	Learn modifiers like Subdivision Surface and Curve
Week 5: Topology				
Topology	1	1	2	Understanding the importance of clean and efficient topology.
Retopology	1	1	2	Introduction to retopology tools and workflows. Retopologizing high-poly meshes to create optimized low-poly models.
Week 6: Modeling				
Free modeling 1	2	2	4	Modeling according to drawings and by eye.
Week 7: Modeling 2				
Free modeling 2	2	2	4	Modeling according to drawings and by eye.
Week 8: Light and texture				
Work with light	1	1	2	Understanding light in 3D, control of light and shadow, parameters of light sources.
Work with texture	1	1	2	Understanding texture in 3D.

Unlike the experimental group, the second, control group did not undergo additional lectures on 3D modeling. They followed the standard curriculum prescribed by the educational institution.

Evaluation criteria:

Both groups underwent preliminary and post-test tests to assess the development of spatial thinking, imagination and creativity. The assessments included standardized tests such as the Purdue Spatial Visualization Test (PSVT), Torrance Creative Thinking Tests (TTCT), and the Spatial Imagination task:

- The Purdue Spatial Visualization Test (PSVT) is a widely used assessment tool designed to measure spatial visualization ability. This test was developed by researchers at Purdue University and has been widely used in educational and professional institutions to assess a person's spatial thinking skills. PSVT elements often include tasks such as mentally rotating objects, identifying objects from different points of view, or predicting how an object will look when rotated or transformed. PSVT provides valuable information about a person's spatial abilities and can be used to identify strengths and weaknesses in this area. The results of the PSVT test can help teachers and employers make informed decisions about employment, career counseling, and training programs. In addition, researchers use the test to study the development of spatial skills and their relationship to other cognitive abilities
- Torrance Creative Thinking Tests (TTCT) are a widely used tool for evaluating the creativity of individuals. It consists of various tasks that evaluate various aspects of creativity. Participants are offered open-ended tasks or problems and are asked to generate as many creative solutions or ideas as possible over a period of time. TTCT assessment is based on fluency, flexibility, originality and thoroughness of answers. These dimensions cover various aspects of creative thinking, including the ability to generate a large number of ideas (fluency), to think in a variety of ways (flexibility), to generate unique and innovative ideas (originality), and to develop and expand ideas (detail). The TTCT test has been used in educational institutions to identify creatively gifted students, in research on the nature of creativity and its development, as well as in various other contexts to assess and develop creative potential. The artistic level of execution is not taken into account in the drawings.
- The task of developing spatial imagination usually involves presenting participants with verbal or visual descriptions of spatial arrangements, such as geometric shapes or spatial relationships, and asking them to mentally visualize these objects or manipulate them in their minds. Participants may be asked to imagine objects rotating in space, mentally assemble complex shapes, or visualize three-dimensional scenes from different points of view.

3.2 Survey of learners

In addition, data was collected through participant observation, survey, and written reflections to gain insight into the participants' experiences, perceptions, and learning outcomes. Those 12 students from the experimental group participated in the survey. Accordingly, with the selected indicators and criteria, a diagnostic map of the experiment was created, which you can see in the table Diagnostic map.

Table 3.2 - Diagnostic map

Criteria	**Description**
Motivational	Interest, desire and willingness to engage in technological creativity.
Cognitive	Initiative in learning and the need to acquire and apply knowledge on the topic.
Emotional	The presence of positive emotions in connection with the activity, the brightness of emotional reactions, Emotional involvement and activity in the activity
Strong-willed	Perseverance in learning modeling skills, classroom activities.

The main purpose of this is to identify the level of interest in creativity among students and to receive prompt feedback. In the theoretical part of the work, a number of criteria and indicators were identified, thanks to which it is possible to determine the level of interest in technical creativity. Each of the criteria is evaluated using a questionnaire, which consists of 5 questions.

Motivational Criterion:

Q1. Would you like to continue practicing 3D modeling after completing this course?
a) Yes
b) Neutral
c) No
Q2. To what extent are you interested in exploring advanced techniques in 3D modeling?
a) Interested
b) Neutral
c) Not interested
Q3. How motivated are you to learn more about the applications of 3D modeling in different fields?
a) Motivated
b) Neutral
c) Not motivated
Q4. Do you find 3D modeling challenging and rewarding?
a) Challenging and rewarding
b) Neutral
c) Not challenging and rewarding

Q5.How important do you consider mastering 3D modeling skills for your future endeavors?
a) Important
b) Neutral
c) Not important

Cognitive Criterion:

Q1. How confident do you feel in your ability to create 3D models?
a) Confident
b) Neutral
c) Not confident
Q2. Do you feel a sense of accomplishment when completing a 3D modeling task?
a) Yes
b) Neutral
c) No
Q3. How important is it for you to understand the principles behind 3D modeling software?
a) Important
b) Neutral
c) Not important
Q4. Do you enjoy problem-solving and experimentation in 3D modeling?
a) Yes, I love it
b) Neutral
c) No, I find it frustrating
Q5. How do you rate your ability to learn new 3D modeling techniques quickly?
a) Quick learner
b) Average learner
c) Slow learner

Emotional Criterion:

Q1.Describe your emotional experience when engaging in 3D modeling activities.
a) Excited and enthusiastic
b) Neutral
c) Frustrated and bored
Q2. Do you feel excited about the creative possibilities offered by 3D modeling?
a) Yes, excited
b) Neutral
c) Not excited
Q3. How do you feel when facing challenges or setbacks in 3D modeling tasks?
a) Motivated to overcome them
b) Neutral
c) Discouraged and demotivated
Q4. Do you enjoy the process of experimenting with different design ideas in 3D modeling?

a) Yes, it's fun
b) Neutral
c) No, it's tedious
Q5. How do you feel about your progress in 3D modeling compared to your initial expectations?
a) Met/Exceeded expectations
b) Neutral
c) Did not meet expectations

Strong-Willed Criterion:

Q1. How determined are you to improve your skills in 3D modeling?
a) Highly determined
b) Moderately determined
c) Not determined
Q2. Are you willing to invest time and effort into practicing 3D modeling outside of class?
a) Yes
b) Maybe
c) No, I prefer not to
Q3. How do you handle frustration or difficulties encountered during 3D modeling tasks?
a) Persevere until resolved
b) Take breaks and try again
c) Give up easily
Q4. How important is it for you to excel in 3D modeling compared to other activities or interests?
a) Important
b) Somewhat important
c) Not important
Q5. How would you describe your overall level of enthusiasm for learning and practicing 3D modeling?
a) Very enthusiastic
b) Moderately enthusiastic
c) Not enthusiastic

Based on the above criteria and indicators, we have identified the following levels of interest in technical creativity:
- a high level is characterized by the desire to engage in technical creativity, expressed interest in technical creativity, initiative, the need for knowledge on the subject, the presence of positive emotions from activities, emotional involvement in activities, activity in the classroom, perseverance in mastering modeling skills;
- the average level is characterized by an unstable interest in technical creativity, passivity in the classroom, the presence of positive or neutral emotions from activity, restraint of emotional reactions, a weak desire to master modeling skills;
- the low level is characterized by a lack of directed interest in technical creativity,

unwillingness to engage in technical creativity, lack of creative intent, passivity in the classroom, lack of positive emotions from activity, unwillingness to master modeling skills;
To find out at what level the students are, it is necessary to consider the results obtained during the diagnostic techniques. In a questionnaire consisting of five questions, students are asked to mark one of three options. By choosing one or another option, students demonstrate their interest in a particular activity.

3.3 Data Collection

Data were collected during interviews and surveys as a qualitative data collection tool and a structured experiment that was conducted with the participation of 24 high school students from the 66th Lyceum school. The first dataset known as the Student Preferences Dataset is a structured dataset capturing information about participants in a survey related to design education or training of 3D modeling. Each participant is assigned a unique identifier (Participant ID) and their characteristics and preferences related to learning and design are recorded across various columns. The data was gathered through the use of survey questionnaires. The dataset has a total of 213 records and 20 attributes. Table Student Preferences Dataset has a description of the characteristics.

Collection Purpose:

- Marketing research: This data may be useful to get an idea of user preferences and concerns. This can help us improve our product and services in the future to better meet the needs of the target audience.
- Educational research: This data is useful for studying the effectiveness of various teaching methods, learning environments, and materials in design education. Understanding the preferences and concerns of participants can help adapt learning strategies to better meet the needs of students.
- Curriculum and Course development: This data can be used to develop training courses and curricula.
- User Experience Design (UX): Data is needed to understand how users prefer to study and interact with educational materials related to software and design tools. This can serve as a basis for the development of user-friendly learning platforms and resources.

The second dataset known as List Of Students is a structured dataset capturing information about students who participated in an experiment related to the improvement of creative abilities after 3d modeling lessons. The dataset has a total of 24 records and 6 attributes. In this experiment there are 2 groups: both the experimental group (n=12) and the control group (n=12) participated in the experiment. Standardized tests such as the spatial visualization test, creative thinking tests, and the spatial imagination task were used to measure spatial thinking, imagination, and creativity before and after the experiment. Statistical analysis of the collected data was carried out using standard procedures. The average scores and

Table 3.3 - Student Preferences Dataset

Attribute	Description
Participant ID	A unique identifier for each participant.
Learning Style	Describes the preferred learning style, categorized into auditory, visual, reading/writing, or kinesthetic.
Learning Environment	Specifies the preferred learning environment such as collaborative workspace, classroom, or anywhere with internet access.
Learning Method	Indicates the preferred learning materials like video tutorials, written instructions, interactive online modules, etc.
Feedback Preference	Reflects the preferred type of feedback (verbal, written, visual) received by each participant.
Learning Time Allocation	Indicates the preferred duration of learning sessions categorized into short, moderate, or extended sessions.
Learning Location	Specifies the location where the participant prefers to learn.
Software	Lists the preferred software tools for design-related activities.
Proficiency Level	Indicates the participant's skill level in using the specified software tools, categorized into beginner, intermediate, or advanced.
Motivation	Describes the reason or purpose behind the participant's learning, such as personal interest, academic requirement, career advancement, etc.
Learning Approach	Specifies the preferred learning approach like structured online courses, trial and error, instructor-led workshops, etc.
Importance of 3D Modeling	Describes their opinion on the importance of 3D modeling
Challenges	Lists the challenges or obstacles that can be faced during their learning journey
Support Preference	Indicates the sources of support or assistance utilized such as instructor guidance, peer collaboration, industry publications, etc.
Stay Updated Methods	Describes how participants stay updated on new trends and advancements in 3D modeling technology
Collaboration Experience	Describes if participants ever collaborated with other people on a 3D modeling project
Career Benefits	Describes how participants believe 3D modeling skills can benefit their future career or academic pursuits
Role of Creativity	Describes the role of creativity in succeeding in 3D modeling
Learning Priority	Describes the importance of learning 3D modeling in education
Interest Areas	Specifies the areas of interest or specialization such as animation, product design, architectural visualization, etc.

standard deviations for each assessment indicator were calculated and hypothesis testing was performed to determine the significance of the observed results. The p-values obtained as a result of the analysis were used to assess the significance of the differences between the experimental and control groups. Ethical principles were strictly observed throughout the entire research process. Informed consent was received from all participants. The study was conducted in accordance with ethical standards and regulations governing research involving humans.

Limitations: Although the study has produced promising results, it is important to recognize its shortcomings. These include a relatively small sample size and the specific context of the experiment, which may limit the possibility of spreading the results to other population groups or living conditions.

Table 3.4 - List of students

Name	**Gender**	**Age**	**Nationality**	**Experience**	**Group**
pupil 1	female	14 years old	kazakh	no	experimental
pupil 2	male	15 years old	kazakh	no	experimental
pupil 3	male	14 years old	kazakh	no	experimental
pupil 4	female	14 years old	kazakh	no	experimental
pupil 5	female	14 years old	kazakh	no	experimental
pupil 6	female	14 years old	kazakh	no	experimental
pupil 7	female	14 years old	kazakh	no	experimental
pupil 8	male	14 years old	kazakh	no	experimental
pupil 9	female	14 years old	kazakh	no	experimental
pupil 10	male	15 years old	kazakh	no	experimental
pupil 11	female	14 years old	kazakh	no	experimental
pupil 12	female	14 years old	kazakh	no	experimental
pupil 13	male	14 years old	kazakh	no	control
pupil 14	female	15 years old	kazakh	no	control
pupil 15	female	14 years old	kazakh	no	control
pupil 16	female	15 years old	kazakh	no	control
pupil 17	male	15 years old	kazakh	no	control
pupil 18	female	14 years old	kazakh	no	control
pupil 19	male	14 years old	kazakh	no	control
pupil 20	male	14 years old	kazakh	no	control
pupil 21	female	15 years old	kazakh	no	control
pupil 22	female	15 years old	kazakh	no	control
pupil 23	female	14 years old	kazakh	no	control
pupil 24	male	14 years old	kazakh	no	control

Chapter 4

Results and analysis

4.1 Detailed market overview

The first thing to do was to find out the opinion of the survey participants about the applications that they think are the most in demand. In the Left Graph of Figure "Software Usage and Preferred Learning Styles" you can see the rating of applications. Blender turned out to be the most popular among the participants (97 out of 212), which may be due to its free availability and powerful features suitable for both beginners and professionals. 3DS Max is also used significantly (49 participants), probably due to its widespread use in professional environments and educational programs. SketchUp and Tinkercad are less popular, which may reflect their narrower specialization or limited capabilities compared to Blender and 3DS Max. In the Right Graph of Figure "Software Usage and Preferred Learning Styles" you can see that the majority of participants prefer a kinesthetic learning style (112 out of 212), indicating that participants are actively involved in learning through practical activities and physical experience. Visual style is also popular (79 participants), which may reflect the importance of visualization in the learning process, especially in areas such as 3D modeling. Fewer participants prefer the auditory (15 participants) and textual methods (6 participants), which may indicate relatively lower effectiveness of these methods in the context of studying 3D technologies, where visualization and practice are more important.

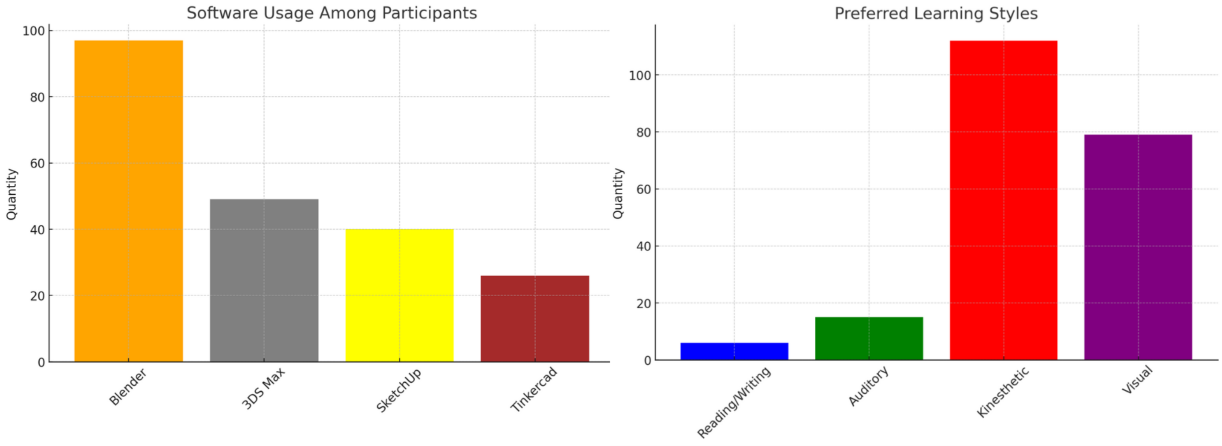

Figure 4.1 - Software Usage and Preferred Learning Styles

In the Left Graph of the Figure "Interest Area and Motivational in Learning 3D" you can see that interests in various fields demonstrate the wide possibilities of using 3D technologies and reflect the individual preferences of students. The areas of interest are distributed in a highly variable way, reflecting the diversity of 3D technology applications. Character and environment modeling (86) is the most popular field, which may be due to the high demand for this specialization in the entertainment and video game industries. Animation (68) is also in high demand, emphasizing the importance of dynamic and visually appealing 3D scenarios in cinema and advertising. Architectural visualization (24) and product design (34) are less represented, but still important in their respective sectors, especially in construction and industrial design, where precision and visualization of the final product are critical to the success of the project. In the Right Graph of Figure "Interest Area and Motivational in Learning 3D" you can see that Personal interest (109) is the main motivator for learning 3D, which reflects the desire of participants to develop their skills and capabilities in their field of interest. Career growth (80) is also important, emphasizing the importance of 3D skills in the labor market. Academic requirements (23) are the least significant, which may indicate that many participants are already outside the traditional educational system or seek self-education.

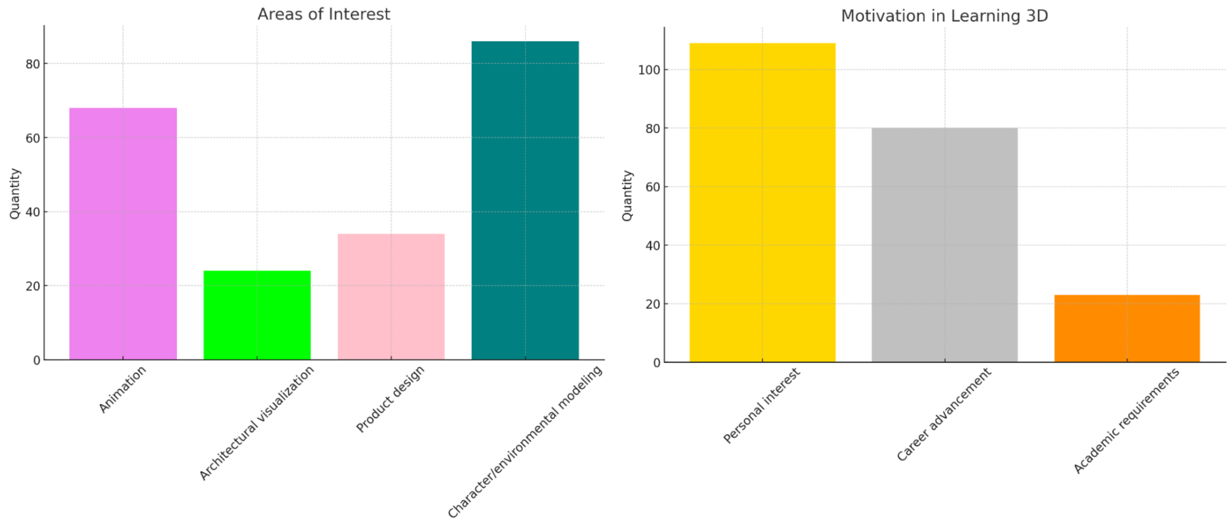

Figure 4.2 - Interest Area and Motivational in Learning 3D

In the Right Graph of Figure "Learning methods and Role of Creativity" you can see that most of the participants (89) consider creativity essential for the successful development and application of 3D technologies, which emphasizes the importance of an innovative approach and original thinking in this area. Also, many (74) recognize creativity as important, but not critical, which may indicate a pragmatic approach to learning, where not only creative ideas are important, but also technical skills. Some participants (49) consider creativity relatively important, which may reflect their views that technical mastery of tools is sometimes more important than the creative process. In the Left Graph of Figure "Learning methods and Role of Creativity " you can see Illustration of the number of participants who prefer different learning methods. Live demonstrations (106) are the most preferred teaching method, which emphasizes the importance of direct interaction and the ability to ask questions in real time. Interactive online modules (45) and video tutorials (56) are also popular, highlighting the trend towards distance learning and flexibility in choosing the time and place to study. Written instructions (5) are less popular, perhaps because of the difficulty of perceiving complex material without visual or verbal support.

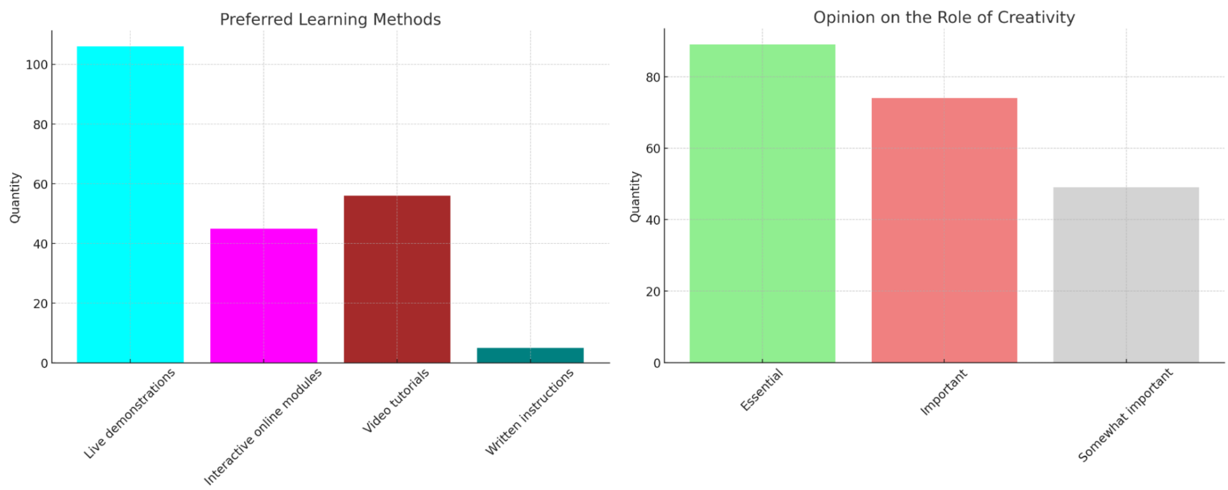

Figure 4.3 - Learning methods and Role of Creativity

4.2 The results of the experiment

These assessments were conducted using standardized assessment procedures and criteria. In the presented results, the figures represent the average scores (mean) and standard deviations (SD) for the experimental (exp) and control (ctrl) groups according to the corresponding estimates.

The results of the preliminary tests did not reveal significant differences between the experimental and control groups in spatial thinking, imagination or creativity ($p > 0.05$). However, post-test analysis revealed significant improvements in all three areas in the experimental group compared with the control group ($p < 0.001$). In statistical analysis, the p-value (probability value) is an indicator that helps determine the significance of the observed results. When performing hypothesis testing, such as comparing averages between two groups, the p value indicates the probability of obtaining observed results (or more extreme results) if the null hypothesis is correct. When testing hypotheses, the commonly used significance level is 0.05, which corresponds to a 5 percent probability of obtaining results if there is no true difference between the groups. Therefore, if the p value is greater than 0.05 ($p > 0.05$), this indicates that there is insufficient evidence to reject the null hypothesis, which usually states that there are no differences between groups. In other words, a p value greater than 0.05 indicates that the observed differences between the groups are not statistically significant at the selected significance level, and any observed differences may be due to chance rather than a true effect.

For example, in the Purdue Spatial Imaging Test (PSVT), the average score for the experimental group was 23.8 with a standard deviation of 3.1, while the average score for the control group was 19.4 with a standard deviation of 3.5. These figures indicate the average performance of the participants in each group in the field of spatial visualization. a visualization task, with higher scores indicating better spatial visualization abilities. Statistical analysis ($p < 0.001$) shows that the difference in average scores between the experimental and control groups is statistically significant, which suggests that the experimental intervention had a positive effect on the participants' spatial visualization abilities. They also demonstrated higher creative thinking skills by scoring higher on the Torrance Creative Thinking tests. In addition, the participants of the experimental group demonstrated a developed spatial imagination, as evidenced by their performance of the spatial imagination task.

Table 4.1 - Results of the test

Assessment Measure	**Exp Group (n=12)**	**Control Group (n=12)**	**p-value (Pre-test)**	**p-value (Post-test)**
Purdue Spatial Visualization Test	Mean: 23.8, SD: 3.1	Mean: 19.4, SD: 3.5	$p > 0.05$	$p < 0.001$
Torrance Tests of Creative Thinking	Mean: 72.1, SD: 8.5	Mean: 59.3, SD: 6.8	$p > 0.05$	$p < 0.001$
Spatial Imagination Task	Mean: 85.1 percent, SD: 5.7	Mean: 68.3 percent, SD: 7.1	$p > 0.05$	$p < 0.001$

The results of the experiment revealed a significant improvement in spatial visualization abilities, creative thinking skills and spatial imagination among the participants of the experimental group compared with the control group. In particular, the participants of the experimental group demonstrated higher results on the Purdue Spatial Visualization Test (PSVT), the Torrance Creative Thinking Test (TTCT) and the spatial imagination task, which indicates an increase in academic performance in all assessed areas. These results highlight the potential of 3D modeling training as an effective pedagogical tool for developing active learning, problem-solving skills and creative expression in educational institutions. By involving students in hands-on design assignments and providing opportunities for research and experimentation, 3D modeling training promotes a deeper understanding of spatial concepts and encourages creative thinking and innovation. The results of the experiment indicate that structured 3D modeling training can effectively develop spatial thinking, imagination and creativity in high school students. By involving students in practical design tasks, 3D modeling training promotes active learning and problem-solving skills, providing opportunities for creative expression and research. These results highlight the potential of 3D modeling technology as a valuable tool for improving learning outcomes and developing creativity in educational institutions.

4.3 Survey results

A qualitative analysis of the participants' observations, interviews and written reflections allowed for a deeper understanding of the impact of 3D modeling training on their learning experience. The participants of the experimental group expressed enthusiasm for the practical nature of the lessons and reported that they felt more confident in their spatial abilities. They also described the process of creating 3D models as exciting and enjoyable, evoking a sense of achievement and satisfaction.

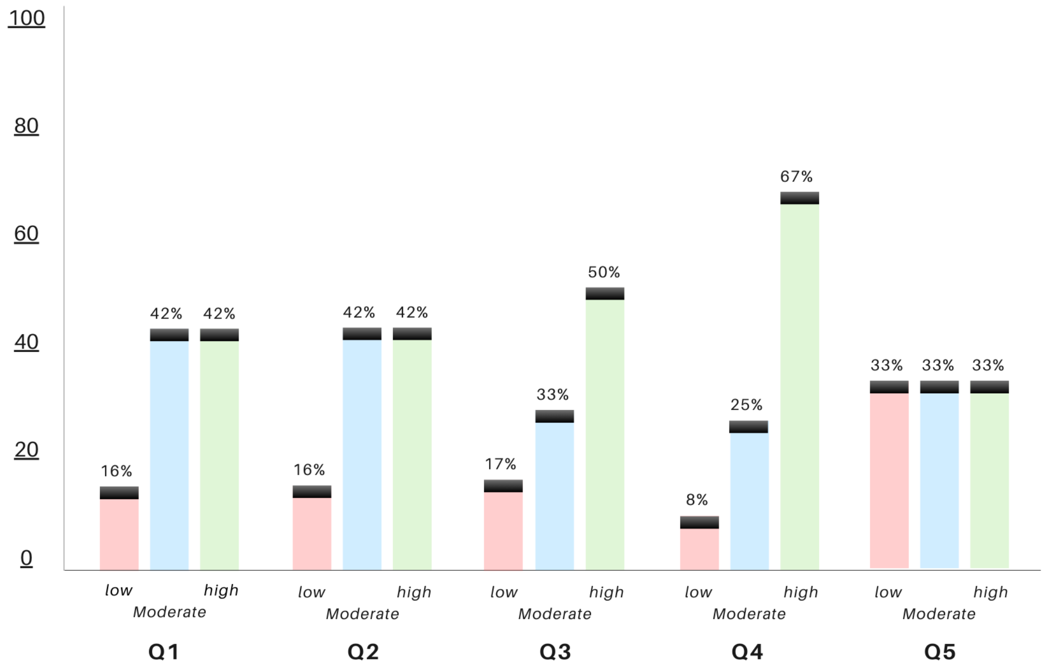

Figure 4.4: Motivational Criterion: survey analysis

The answers to this question have a fairly even distribution between high and moderate interest, with a smaller number indicating low interest. The majority of participants demonstrated a high level of motivation in the answers to questions 3 and 4, with more than 50 percent consistently choosing the option indicating high motivation. Question 3 shows a slight bias towards high interest. Question 4 indicates a clear preference for high interest. Question 5 showed a more even distribution of responses across the three options, indicating a more diverse level of motivation among participants for this particular question (see figure Motivational Criterion)

General analysis:

Approximately 46.67 percent. of the participants demonstrated a high level of motivation on all five issues. About 35 percent of the participants demonstrated a moderate level of motivation. About 18.33 percent of the participants demonstrated a low level of motivation. This analysis provides an overview of the distribution of motivation levels among participants based on their responses to the questionnaire. This analysis shows that a significant proportion of respondents show a high level of interest in the topics under study, while a smaller percentage of respondents show a low level of interest. Moderate interest lies between these two extremes and is the second most common level of interest among respondents.

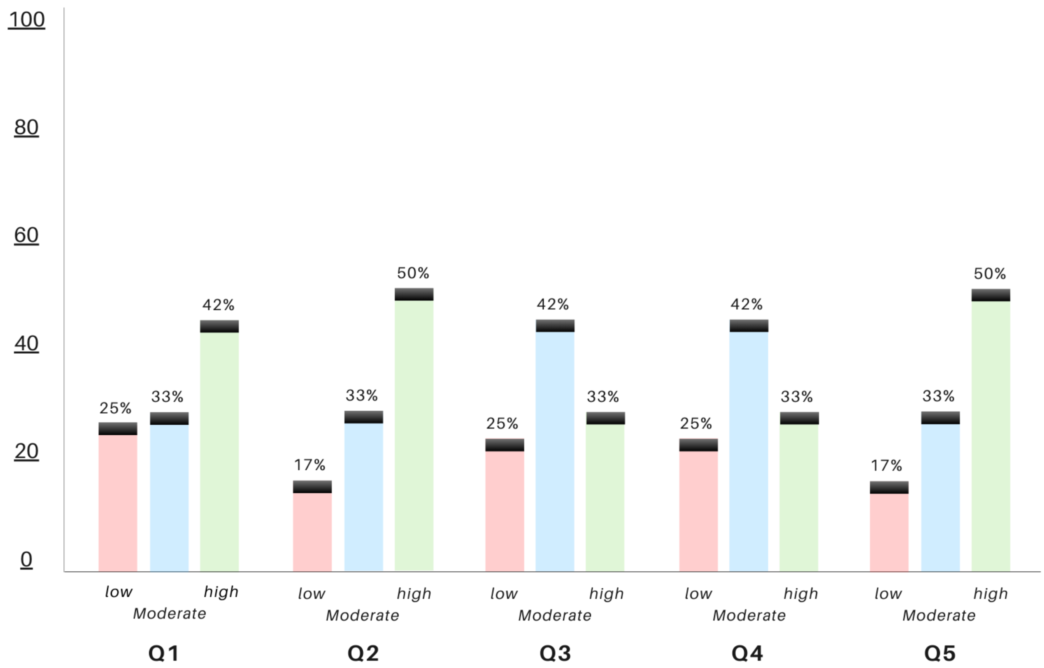

Figure 4.5 - Cognitive Criterion: survey analysis

In the Cognitive Criterion section, high, medium and low levels of interest can be distinguished for all issues. Questions 2 and 5 show that the majority of respondents indicate high cognitive abilities. Questions 3 and 4 show a fairly balanced distribution between moderate and low cognitive abilities. Question 1 is distributed differently across all three levels of cognitive abilities, with a slightly small amount of high interest. In general, respondents demonstrate different cognitive abilities for all the questions considered, with answers to some questions being more consistent than others(see figure Cognitive Criterion.).

General analysis:

Approximately 41.67 percent of respondents demonstrate a high level on all issues. About 36.67 percent of respondents demonstrate a moderate level. Approximately 21.67 percent of respondents indicate a low level. This analysis shows that a significant proportion of respondents have a high level of interest, followed by those with a moderate level. However, there is still a percentage of respondents indicating a low level of interest.

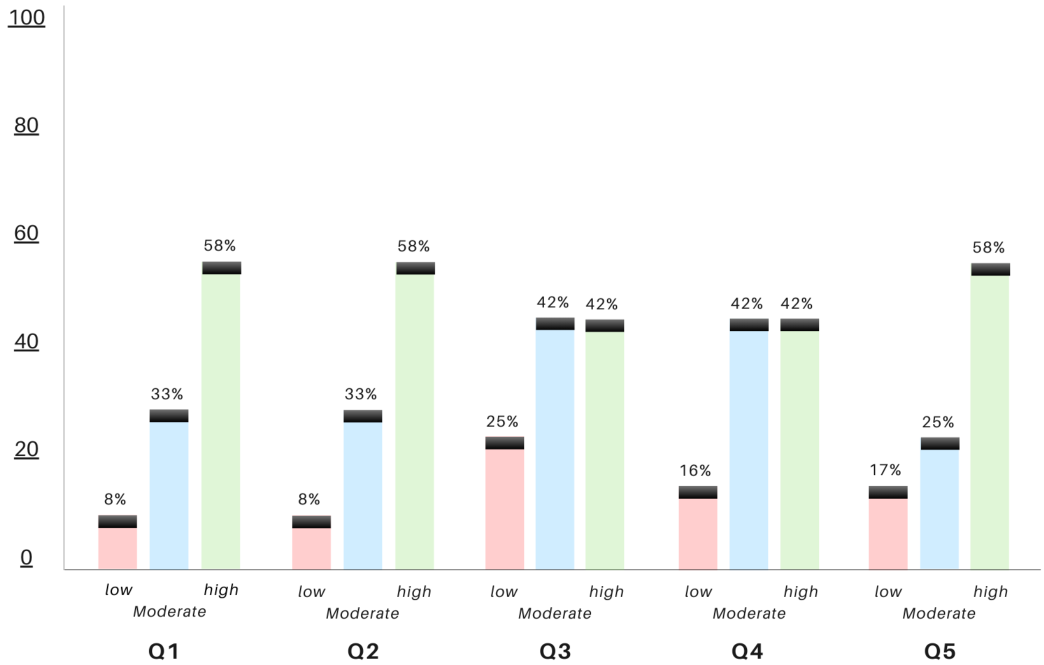

Figure 4.6 - Emotional Criterion: survey analysis

In the Emotional Criterion section, respondents indicating high emotional intelligence predominate on all questions. Questions 3 and 4 demonstrate a balanced distribution between average and high emotional intelligence. Questions 1, 2 and 5 show that the majority of respondents indicate a high emotional interest. In general, respondents tend to show a high level of emotional interaction with all the questions considered, with some questions being distributed more balanced than others. This can be explained by the fact that the modeling process brought very positive emotions. (see figure Emotional Criterion)

General analysis:

Approximately 51.67 percent of respondents demonstrate a high level of emotional intelligence on all issues. About 35 percent of respondents demonstrate a moderate level of emotional intelligence. Approximately 13.33 percent of respondents indicate a low level of emotional intelligence. This analysis shows that the majority of respondents have a high level of emotional intelligence, followed by those with moderate intelligence. However, there is still a small percentage of respondents indicating a low level of emotional interest.

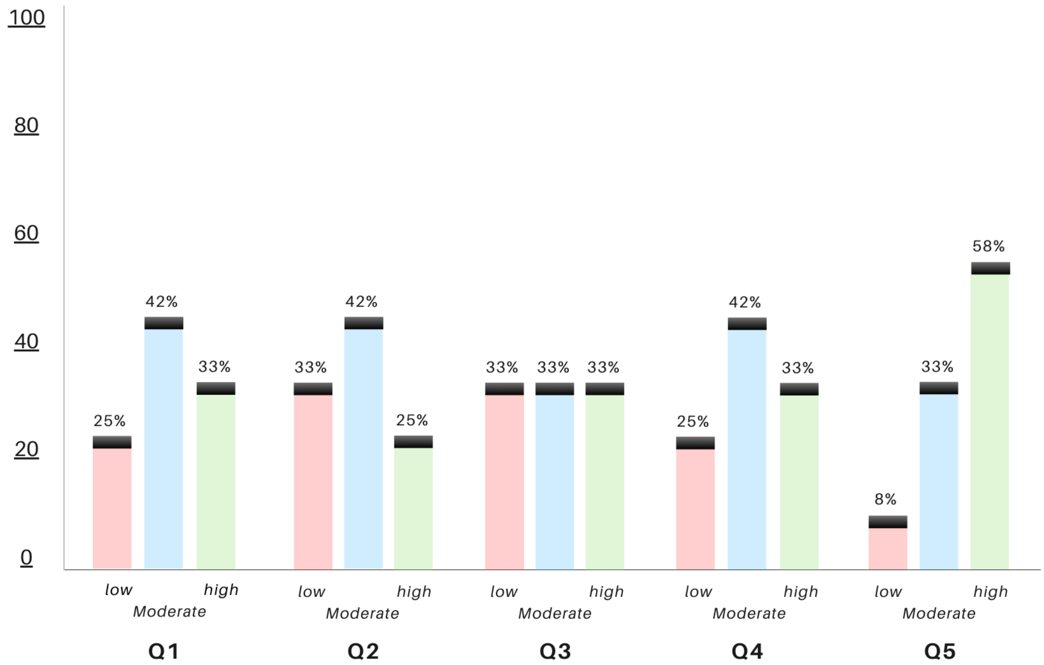

Figure 4.7 - Strong-Willed Criterion: survey analysis

In the last section, in all questions there is a combination of strong-willed, moderate-willed and weak-willed characteristics. Questions 3 and 5 demonstrate a more even distribution between the three levels of volitional characteristics. Questions 2 and 4 show that the majority of respondents indicate moderate-volitional characteristics. Question 1 shows a more diverse distribution of volitional characteristics across three levels. In general, respondents demonstrate varying degrees of volitional qualities on all the issues considered, and they give more consistent answers to some questions than others(see Figure Strong-Willed Criterion).

General analysis:

Approximately 36.67 percent of respondents demonstrated a high level of willpower on all issues. About 38.33 percent of respondents demonstrated a moderate level of willpower. Approximately 25 percent of respondents indicated a low level of willpower. This analysis shows that respondents demonstrate a relatively balanced distribution across three levels of strong will, with a moderate level somewhat more common than a high or low one.

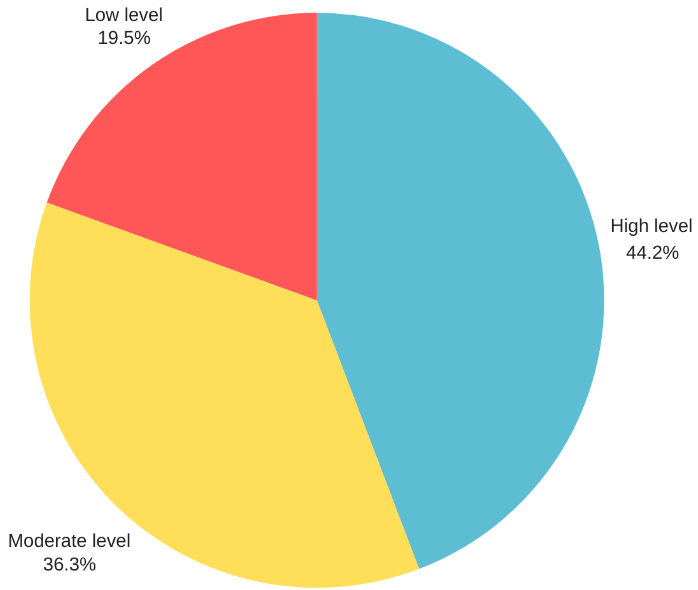

Figure 4.8 - General distribution of interest levels

The following analysis provides an idea of the overall distribution of high, medium and low levels across all four criteria, helping to identify a common trend in the levels of interest, cognitive abilities, emotional intelligence and strong will of respondents. 48.63 percent of respondents demonstrate a high overall level across all criteria. About 39.95 percent of respondents demonstrate an average overall level. Approximately 21.42 percent of respondents indicate a low overall level.

Based on the data obtained, it can be noted that especially the motivational and emotional components of interest are formed a little better than the cognitive and volitional components.

This was revealed thanks to the responses of the students:

- **High Level Analysis:**
  Motivational Criterion : 28 respondents
  Cognitive Criterion: 25 respondents
  Emotional Criterion: 31 respondents
  Strong-will Criterion: 22 respondents

- **Moderate Level Analysis:**
  Motivational Criterion : 21 respondents
  Cognitive Criterion: 22 respondents
  Emotional Criterion: 21 respondents
  Strong-will Criterion: 23 respondents

- **Low Level Analysis:**
  Motivational Criterion : 11 respondents
  Cognitive Criterion: 13 respondents
  Emotional Criterion: 8 respondents
  Strong-will Criterion: 15 respondents

Chapter 5

Disscussion

The results of this study convincingly prove the effectiveness of teaching structured 3D modeling in the development of spatial thinking, imagination and creativity in high school students. Through a comprehensive Blender program, participants demonstrated significant improvements in spatial visualization abilities, creative thinking skills, and spatial imagination compared to their peers who did not receive additional training. One of the key findings of this study is a significant increase in participants' scores on standardized tests measuring spatial visualization abilities, such as the Purdue Spatial Visualization Test (PSVT). The participants of the experimental group showed higher average scores on the PSVT post-test, which indicates an improvement in spatial thinking skills after learning 3D modeling. This suggests that the practical experience of manipulating three-dimensional objects in a digital environment contributed to the development of the participants' spatial visualization abilities. Similarly, the experimental group demonstrated excellent results in the Torrance Creative Thinking Test (TTCT), which evaluates various aspects of creativity, including fluency, flexibility, originality and elaboration. By participating in open-ended design tasks and problem-solving exercises during the 3D modeling training, participants were able to generate more diverse and innovative solutions reflecting enhanced creative thinking skills. In addition, the participants of the experimental group demonstrated great efficiency in performing a spatial imagination task, which required mental visualization of spatial arrangements and manipulation of them. This indicates that learning 3D modeling not only improves spatial thinking in a practical context, but also develops the ability of participants to mentally manipulate geometric shapes and visualize three-dimensional scenes — an essential skill in various STEM disciplines (science, technology, engineering and mathematics). A qualitative analysis of the participants' observations and answers to the questionnaire questions further clarified the impact of 3D modeling training on the learning process of students. The participants expressed enthusiasm for the practical nature of the classes and reported that after the 3D modeling classes they felt more confident in their spatial abilities. The process of creating 3D models was described as exciting and enjoyable, causing participants to feel a sense of achievement and satisfaction. These results highlight the potential of 3D modeling technology as a valuable tool for the development of active learning, problem-solving skills and creative expression in educational institutions. By including structured 3D modeling training in the curriculum, teachers can provide students with the opportunity to develop the necessary spatial and creative skills that are becoming increasingly relevant in today's technology-based world. However, it is important to recognize some limitations of this study. The sample size was relatively small and consisted of high school students from the same educational institution. In addition, the duration of the study was limited to five weeks, which may have limited the depth of learning and skill development. Future research could explore the long-term impact of 3D modeling training on the spatial abilities and creativity of students in different populations and educational contexts.

Chapter 6

Conclusion

6.1 Conclusions

The findings of this study underscore the significant impact of structured 3D modeling training on the development of spatial thinking, imagination, and creativity in high school students. Through an eight-week program using Blender, students demonstrated notable improvements in spatial visualization abilities, creative thinking skills, and spatial imagination compared to their peers who followed the standard curriculum. The post-test assessments revealed statistically significant differences between the experimental and control groups, indicating that the experimental intervention effectively enhanced students' spatial abilities and creative potential. Moreover, qualitative analysis of participant observations and surveys provided valuable insights into the students' experiences and perceptions, highlighting increased enthusiasm, confidence, and motivation among those who underwent 3D modeling training. These findings have important implications for educational practice. Integrating structured 3D modeling training into the curriculum offers a dynamic approach to teaching and learning, fostering active engagement, problem-solving skills, and creative expression. By providing hands-on design tasks and opportunities for experimentation, educators can cultivate students' spatial understanding and encourage innovative thinking across various subject areas. Furthermore, this research contributes to the broader literature on educational technology and pedagogy by showcasing the potential of 3D modeling technology as a powerful tool for enhancing learning outcomes and nurturing creativity in high school students. As technology continues to evolve, incorporating innovative approaches like 3D modeling training can empower students to thrive in a rapidly changing world. In conclusion, the results of this study underscore the importance of integrating 3D modeling training into educational practices to promote spatial thinking, imagination, and creativity among high school students. By harnessing the potential of technology-enhanced learning experiences, educators can inspire the next generation of innovators and problem solvers, preparing them for success in the digital age.

6.2 Future work

The current study has demonstrated the potential of 3D modeling technologies to develop students' creative abilities and interests. However, some areas require further study and development in order to fully realize the benefits of 3D modeling in education. Future research could focus on conducting extended longitudinal studies to observe the sustained impact of 3D modeling on students' creativity and interest in STEM disciplines over several academic years, as well as evaluating the long-term retention of skills and knowledge acquired during 3D modeling classes. In addition, the introduction of 3D modeling programs in various educational environments, including elementary schools, secondary schools and universities, will help to assess adaptability and effectiveness in different age groups and at different levels of education.

It is also important to investigate the impact of 3D modeling in various socio-economic and cultural contexts in order to determine its universal applicability and determine the necessary adjustments for different groups of students. Exploring the use of 3D modeling in non-STEM subjects such as literature, history, and art can foster creative thinking and engagement in these areas, while developing interdisciplinary curricula that combine 3D modeling with traditional subjects can provide a more holistic educational experience. In addition, the integration of advanced technologies such as virtual reality (VR), augmented reality (AR) and artificial intelligence (AI) with 3D modeling can further enhance the learning process, and it is important to evaluate the effectiveness of these combined technologies in improving spatial thinking, problem solving skills and creativity. The development of comprehensive training programs for teachers to effectively integrate 3D modeling into their teaching practices and the assessment of the impact of teacher training on the successful implementation and results of 3D modeling programs in the classroom are also crucial. Promising areas for future work are the creation of adaptive learning platforms using 3D modeling to adapt educational content to individual needs and learning styles, as well as the study of the effectiveness of personalized 3D modeling to increase student engagement and academic achievement.

Future research should also focus on improving data collection methods and improving their quality. This includes developing more robust tools to account for various aspects of student engagement, creativity, and learning outcomes related to 3D modeling. Exploring innovative data collection techniques such as real-time analytics, digital portfolios, and longitudinal tracking can provide a deeper understanding of the long-term impact of 3D modeling on student development.

In addition, the development of new assessment tools and methodologies to better assess the creative and cognitive outcomes of 3D modeling activities, as well as the introduction of formative and generalizing assessments that reflect the multifaceted nature of creativity and problem-solving skills, would provide valuable information.

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