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Developing pupils' creativity through 3D modeling: an experimental study

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The research investigates the impact of 3D modeling on the development of creativity in elementary school pupils. The investigation was conducted on a sample of 160 pupils from 5 elementary schools in the South Bohemia region, who were divided into control and experimental groups. The experimental group received technical education lessons using 3D modeling, while the control group worked with traditional methods such as construction kits and physical models. Creativity was assessed using the Torrance Tests of Creative Thinking, which measures four key components of divergent thinking: fluency, flexibility, originality, and elaboration. Statistical analysis showed that 3D modeling had a positive effect on all of these components in the experimental group. On the other hand, there were no statistically significant differences between the experimental and control groups in the output creativity tests results, suggesting that traditional methods can also promote creative thinking. Additionally, there were no significant differences between younger and older students. Based on these findings, we recommend the integration of 3D modeling into the teaching of technical and creative subjects as an effective tool for the development of creativity. Furthermore, it is recommended to combine 3D modeling with other innovative methods and to provide sufficient time for the acquisition of these tools. Future research should focus on the long-term impact of 3D modeling and its integration with augmented and virtual reality to support students' creative thinking.

KEYWORDS

torrance figural tests of creative thinking, fluency, flexibility, originality and elaboration, divergent thinking, technical education, onshape, innovative educational methods

1 Introduction

The development of creativity should be closely linked to the development of digital technologies in primary school education. This topic was mostly addressed by experts at the turn of the 20th and 21st centuries (Ebersole and Hess, 1998; Robinson, 1999; Slavík and Wawrosz, 2004; Coughlan and Johnson, 2006). In their study, Ebersole and Hess (1998) point to the crucial role of creativity-enhancing activities in maintaining and enhancing cognitive abilities and overall psychological well-being. The authors suggest that current approaches could incorporate digital tools—such as interactive platforms or digital applications—as a means of stimulating creativity. According to Robinson (1999), the development of creativity is a key element of the educational process. The authors argue that it is essential to incorporate elements of creativity and cultural education throughout the school curriculum in order to maximize the potential of pupils. They also stress that modern approaches should use digital technologies such as interactive platforms and digital applications that not only facilitate access to information but also support individual and collective creative processes and enable the emergence of new learning formats that meet the demands of the 21st century. Overall, their work highlights that effective educational strategies must combine traditional teaching methods with modern digital tools to effectively develop students' creative and cultural skills and prepare them for future challenges. Slavík and Wawrosz (2004) present the art experience as a crucial means of cognition, emphasizing the key role of expressive art in art education. The authors extend traditional teaching methods to include the use of digital technologies, which open up new possibilities for interaction in visual communication. Thanks to tools such as programmable graphic editors and multimedia platforms, it is possible to experiment with visual content and transform images, which greatly enhances students' creativity. In their study, Coughlan and Johnson (2006) analyze how digital technologies and interactive interfaces affect creative processes. They highlight that carefully designed digital systems can facilitate iterative idea generation and promote collaboration, which stimulates creative activity. Digital tools allow users to easily experiment with visual and conceptual content, leading to better feedback and faster development of new ideas. This makes the digital environment not only a platform for sharing information, but also a catalyst for creative thinking.

Digital technologies, which are gradually emerging as innovations across all fields, are also appearing in technology. In the Czech Republic, the issue of digital technologies began to be addressed by the professional community after 2010, and it was only in 2014 that they began to be implemented in education.

The topic of digital technology is also a bridge between the classical concept of technology education and new technologies, which can include 3D modeling such as (Chen et al., 2024). Chen et al. in their study, they investigated how 3D modeling in virtual reality affects creativity and problem-solving ability in elementary school students. The results showed that this method significantly improved students' creative thinking, including aspects such as challenge, imagination, and curiosity, compared to traditional approaches to 3D modeling in virtual reality. Similarly, a positive effect on problem-solving skills was observed. In addition, 3D modeling reduced students' cognitive load during the learning process, especially in the area of mental effort. These findings suggest that the use of immersive virtual reality in education can effectively promote the development of creativity and problem-solving skills in elementary school students.

The issue of teaching 3D modeling at primary school has not been extensively researched in this country or in the world. In Czech education, 3D modeling is slowly but surely making its way into schools, but so far only as a support for 3D printing, for example (Honzíková et al., 2024; Fadrhonc et al., 2025). The study by Honzíková et al. (2024) focuses on measuring creativity and spatial imagination in the virtual environment of SketchUp. The authors innovated Urban's creativity test to improve the evaluation and effectiveness of the learning process. The results confirmed that this test can be successfully adapted to commonly available 3D modeling environments. In addition, the level of spatial imagination in the test group was shown to increase with age. These findings suggest that the integration of digital technologies such as SketchUp can effectively support the development of key competences of students and graduates, which is essential for the transition to Industry 5.0. The study by Fadrhonc et al. (2025) focuses on the integration of 3D modeling into primary school teaching and its use to assess pupils' creativity. The authors present a methodology for teaching 3D modeling using SketchUp. The results suggest that integrating 3D modeling into the curriculum increases students' motivation and engagement, which is key to developing their creative thinking in a rapidly changing world full of complex problems and new challenges.

In the world, this issue is mainly addressed in Asia, where most of the papers in our search are from, for example Chang et al. (2016); Wu et al. (2018) or Wen et al. (2023). Even by the date of publication, it is clear that this topic is new and still rather unexplored. In the context of 3D modeling, the authors mainly focus on spatial imagination, visualization and computational thinking. Chang et al. (2016) in their study investigated the effect of 3D CAD applications on the design creativity of students with different representational abilities. A moderately strong positive correlation was observed between students' representational abilities and their creative performance; furthermore, the use of 3D CAD tools significantly improved students' creative performance, especially in the areas of functionality and expressiveness of design. A study by Wu et al. (2018) focused on assessing students' 3D modeling abilities in a K-12 setting, evaluating the completeness of models and patterns of model use. The analysis included various indicators such as the number of connected components, the ratio of the largest component to the overall model, and the complexity of shape, subdivisions, and blocks. The results suggest that the way in which 3D modeling tools are used significantly influences the creative abilities of pupils and students, highlighting the importance of digital technologies in the development of spatial imagination and creativity. Wen et al. (2023) analyzed how different behavioral patterns in 3D modeling affect creativity in sustainable building design. They identified behavioral patterns that have a significant positive correlation with creative performance in this context. These findings highlight the importance of digital technologies such as 3D modeling in promoting innovative and effective sustainable building design.

Overall, these studies suggest that integrating digital technologies such as 3D modeling and virtual reality into the educational process can effectively support the development of creativity in primary school students, which is essential for their success in today's dynamic world.

1.1 Creativity

Creativity as such cannot be defined in a general and complete way. The main reason given is that it permeates all areas of human life. Nevertheless, many authors have attempted to define the concept of creativity. In Sternberg's definition, creativity as one of the cognitive functions can be broadly defined as the process of producing ideas and possibly ideas based on them or solutions to problems that are both original and of high quality (Sternberg, 2002). Another broad definition speaks of creativity as the tendency to produce new and unusual solutions to a particular situation or problem (Ghosh, 2003). Other authors who attempt to define the concept of creativity make similar points. Torrance (1969) sees creativity as the process of generating new hypotheses that one has not known or that did not exist before and confirming them. Hlavsa (1985) conceives of creativity as a form of human activity that is characterized by novelty, originality, and utility at the same time. According to Dacey and Lennon (2000), creativity is characterized by the generation of new, unusual, yet acceptable and useful thoughts, solutions or ideas.

Perhaps the most current definition is that creativity stems from the ability to generate diverse responses, think innovatively, move between different categories, and process ideas (Weiss and Wilhelm, 2021).

Elementary school pupils demonstrate the ability to think and create originally. Their talent for innovative ideas develops over time—younger children often show intense periods of imagination and imaginative play that foster their creativity. As they grow older and gain school experience, these skills change, influenced by factors such as the school environment, the teaching methods used and the cultural context. Research shows that incorporating arts and creative activities into schooling contributes significantly to children's development by enhancing their critical thinking, collaborative skills, and emotional stability (Plucker et al., 2004; Runco and Acar, 2012; Smare and Elfatihi, 2023; Zhang and Kaufman, 2023).

Pupils and students are gradually given the opportunity to develop their creativity through a variety of activities, projects and programs, helping them to prepare for a successful and fulfilling life and career in the modern society and at the same time, in conjunction with other appropriate competencies, develop a portfolio of skills that are linked to the current societal setting (Eckhoff, 2011; van Laar et al., 2017). In the 21st century, the development of creativity in education is seen as an essential element that prepares students for rapid changes in society and the labor market. The following scientific studies emphasize the importance of creativity within the educational process (Runco and Jaeger, 2012; Sawyer, 2012; Kučerová and Švecová, 2020; Jackson and Shaw, 2020; Novotná and Kuříková, 2020; Kim, 2022).

1.2 Divergent thinking

In the 1950s, Guilford defined convergent and divergent thinking using a structural model of intelligence. These concepts can be described as components that together form the operative dimensions of human thinking. The components differ in their view of working with ideas (Guilford, 1956). The term divergent thinking most often refers to a thinking process where the output is a higher number of novel thoughts, ideas or solutions. This process can also be referred to as "divergent" thinking, where ideas "run wild" based on a problem or situation and seek as many alternative solutions as possible (Wigert et al., 2022). Divergent thinking is generally considered to be an important and dominant aspect in the assessment of creativity (Beaty et al., 2023). In contrast, convergent thinking focuses on finding one optimal solution or one answer to a given problem or question. This approach emphasizes logic, speed, and the ability to apply known procedures or techniques to achieve the goal of selecting the best solution from a variety of solutions (Yoruk and Runco, 2014).

The two types of thinking, both convergent and divergent, can complement each other and play a key role in the creative process and in dealing with diverse situations (Lundsteen, 1986). Both forms are important for creative processes and decision making (Cropley, 2006).

1.2.1 Divergent and convergent thinking

Convergent and divergent thinking represent two distinct cognitive approaches. Already Guilford (1956) formulated the basic concept that convergent thinking aims at finding a single correct answer through a logical and systematic process, while divergent thinking promotes the generation of a wide range of original ideas. Torrance (1974) further developed methods of measuring creativity, with his tests helping to identify the level of divergent thinking in individuals. In later studies, Cropley (2006) highlighted that convergent thinking plays a key role in processing familiar information and solving standard tasks, which is essential for academic and professional practice. On the other hand, Chamorro-Premuzic and Reichenbacher (2008) research has shown that personality traits, especially openness and extroversion, have a significant impact on the ability to produce new ideas, which is an essential feature of divergent thinking. McCrae (1992) further confirms that openness is closely related to creativity and the ability to generate unconventional solutions. Studies focusing on specific cognitive abilities, such as the work of Clark et al. (1965), indicate that convergent thinking is associated with better academic performance and fewer homework problems in talented adolescents. Another interesting contribution is the finding by Hommel et al. (2011) that bilingualism may enhance convergent thinking but slightly reduce divergent abilities, suggesting some trade-off between the two types of thinking.

Overall, the development of creativity and effective problem solving requires a synergy of both approaches—the ability to generate many ideas while being able to select the most appropriate solution. These studies provide a comprehensive view of how convergent and divergent thinking complement each other and influence different aspects of human cognition.

1.2.2 Creative and critical thinking

Divergent (creative) and convergent (critical) thinking are key components of cognitive processes (Arafah et al., 2021). Together, they support the development of Higher-Order Thinking Skills (HOTS; Yuliati and Lestari, 2018). Higher-order skills involve the analysis, synthesis, evaluation and application of knowledge in new contexts (Singh and Marappan, 2020). This is essential for effective problem solving and decision making (Singh and Marappan, 2020). According to Bloom's Taxonomy of Educational Objectives, HOTS constitute higher-level cognitive processes (Sagala and Andriani, 2019). They are those that require not only the memorization of information, but also a deeper understanding of it and the ability to apply it in different situations (Sagala and Andriani, 2019). The development of these skills is essential to foster critical thinking (Widana et al., 2018). Critical thinking enables an individual to evaluate information, reason, and make informed decisions (Widana et al., 2018). Creative thinking supports the generation of new and original ideas (Setiawan et al., 2018). Critical thinking allows these ideas to be analyzed, evaluated, and implemented effectively (Setiawan et al., 2018). In this way, students learn not only to generate innovative solutions but also to critically assess and apply them in practice (Alkhatib, 2019).

1.2.3 Divergent and convergent thinking of elementary school pupils

In his seminal work, Guilford (1956) introduced the concept that human intelligence involves both convergent thinking, which aims at finding a single correct answer, and divergent thinking, which is characterized by the generation of a range of alternative ideas. Subsequent studies, such as Kim (2006), show that divergent thinking can be developed in elementary school pupils through targeted instructional interventions, which fosters their creative potential. Research by Plucker et al. (2004) then demonstrates that although the manifestation of both types of thinking in younger students may vary depending on specific tasks or domains, both systems are present at an early age. In addition, Cropley (2006) highlights that convergent thinking plays a key role in problem solving where there is one correct solution, highlighting the need for balanced development of both cognitive processes. Finally, Runco (2007) summarizes that well targeted and innovative pedagogical approaches can not only help to develop divergent thinking, but also promote the analytical skills associated with convergent thinking, thereby enhancing children's overall cognitive capacity.

1.3 Creative thinking

Guilford (1967), followed by other authors such as (Torrance, 1969; Sternberg and Lubart, 1999; Amabile, 1996; Lokšová and Lokša, 1999; Dacey and Lennon, 2000), divided the components of divergent thinking into six intellectual components in his theories using factor analysis. These are fluency, flexibility, originality, sensitivity, restructuring and elaboration. Sternberg and Lubart (1996) state that a creative outcome is produced through a synergy of intellectual ability, knowledge, mindset, personality traits, motivation and environmental influences. According to Amabile (1996), creativity is a process in which original ideas and solutions to problems are generated through a combination of expertise, creative thinking and intrinsic motivation. Her theory emphasizes three essential components: domain-specific expertise, the ability to think creatively, and motivation, which comes primarily from within. Lokšová and Lokša (1999) define creativity as the ability to react quickly and recall words and concepts, which enables the generation of a large number of ideas, and at the same time as the skill of finding innovative solutions that overcome common stereotypes, whereby the individual creates original and unusual solutions by perceiving reality from a new angle. They further stress that creativity involves sensitivity and empathy, which allow solutions to be found that are hidden from others, along with the ability to rearrange old information in a new way and to elaborate on a problem in a thorough way that results in a coherent solution. In their book Creativity, Dacey and Lennon (2000) describe 10 key traits of a creative personality. These traits include tolerance of ambiguity, which allows an individual to remain open-minded and unbiased in ambiguous or novel situations. Stimulus freedom is the ability to break out of traditional ways of thinking and accept new stimuli, while functional freedom refers to using objects in nontraditional ways, i.e., going beyond their normal functions. Flexibility allows one to view problems from different perspectives and to adapt to new circumstances. Willingness to take risks reflects a readiness to face uncertainty and the possibility of failure in the search for new solutions. A preference for disorder reflects the ability to find order and meaning even in chaotic or disorderly situations. Satisfaction preference refers to the ability to work toward long-term goals without the need for immediate rewards. Freedom from sex role stereotypes means that the individual is not constrained by traditional expectations associated with sex. Perseverance refers to the ability to continue to strive despite obstacles and setbacks, while courage refers to the boldness to push for new ideas and practices, even though they may be controversial or unpopular. Together, these qualities support the creative potential of the individual.

Guilford later reduced his components to four in the framework of divergent thinking. These are described, for example, by Torrance (1969); Lewis (2008) or Godart et al. (2020) as follows:

- Fluency—the ability to come up with a large number of alternative thoughts, ideas and solutions.
- Flexibility—the ability to flexibly change options, approaches, solutions to a given problem and the ability to view a problem from multiple angles.
- Originality—the ability to generate new, strange, alternative or unusual solutions, thoughts or ideas. However, all must be based on previously demonstrated but distant associations, often accompanied by humor or ingenuity.
- Elaboration—the ability to gracefully elaborate, to think through details about particular ideas or solutions that are sustainable and can be built upon in the future.

Of these, fluency, flexibility and originality are the most frequently used, which also applies in terms of testing divergent thinking.

In this study, divergent thinking processes are worked with to characterize how 3D modeling can influence the development of creativity of pupils in the 2nd stage of elementary school.

1.4 3D modeling

3D modeling can be described simply as the process of shaping and creating spatial models using computer software. Most often, these are so-called CAD systems (Computer Aided Design) (Horová, 2008). Goner et al. (2017) characterize 3D modeling as the process of creating three-dimensional parts using CAD systems. This software is usually used throughout the construction of the model (sketching, creating the model in space, drawing documentation etc.). Probably the biggest benefit of virtual 3D modeling is the possibility of its subsequent transfer to the real environment, using other technologies (3D printing, Computer Aided Manufacturing—CAM, etc.). An example of this is the design, construction and realistic creation of complex shapes of bodywork and other car parts (Fořt and Kletečka, 2000). Every industry uses powerful fifth generation CAD systems that can already create parametric models, allowing easy modification and dimensional changes of the model in progress. These CAD systems contain a number of tools and functions that are to some extent tailored to a specific industry, such as the aerospace industry. There are also CAD systems with a more limited range of tools and functions, e.g., versions designed for schools, demo versions, etc. These simpler systems can be more easily controlled by users (Chow et al., 2015). CAD systems have problems with artistic designs, such as sculpture, where creativity and esthetic sensibility are some of the main factors. They are not prepared and set up sufficiently for these factors, as they were originally mainly focused on engineering and architecture (Pham, 2000). Pham (2000) wonders whether machine or computer software can also help people in the field of creativity and inspire them while working on 3D models or shapes in general in the context of fashion design.

Available research suggests that, when properly deployed, 3D modeling, for example through dynamic 3D models and animations, can significantly contribute to a better understanding of complex concepts, which in turn reduces the cognitive demands associated with information processing (especially mental effort) without directly negatively affecting vision (Teplá et al., 2022; Chen et al., 2024). On the other hand, prolonged work with digital devices, whether in 2D or 3D mode, is associated with symptoms of computer vision syndrome, such as eyestrain, blurred vision, or headaches (Seresirikachorn et al., 2022). Furthermore, studies comparing 3D and 2D visualization in virtual environments show that 3D presentations facilitate better comprehension and are more subjectively pleasing, which can lead to reduced visual load (de Boer et al., 2016). Additionally, research on the use of 3D printed interactive models in visual science education confirms that these technologies improve understanding of complex structures and may even alleviate subjective eye fatigue (Cameron, 2021).

These studies show that properly implemented 3D modeling, with respect to ergonomics and regular breaks, does not directly damage vision but can help to better understand complex topics and reduce cognitive demands in learning. On the other hand, prolonged work with digital devices, whether in 2D or 3D mode, is associated with the risk of developing symptoms of computer vision syndrome, which highlights the need to monitor optimal exposure times.

1.4.1 3D modeling and creativity

In their publication 3D Modeling in Elementary Schools and its Use in Testing Creativity, the authors describe how creative thinking and creativity play a vital role in adapting modern technologies such as 3D modeling to human needs, including its development in education. Creative thinking is a key element of education because it helps students navigate an ever-changing world full of complex challenges. It strengthens their ability to analyze problems, come up with innovative solutions and adapt flexibly to new situations. At the same time, in school settings, creative thinking increases students' motivation and engagement by enabling them to actively participate in the learning process (Fadrhonc et al., 2025). Modern technology in general is gaining importance in the assessment of creativity. One of the most progressive approaches is the integration of 3D modeling with virtual reality (IVR). A study looking at the effects of this method found that the combination of virtual reality and 3D modeling significantly promotes creative thinking and develops problem-solving skills in primary school students (Chen et al., 2024). It has been previously shown (Kuna et al., 2017) that creativity or technical creativity can be developed through the teaching of technical subjects with the help of modern technologies. Krotký (2014) states that 3D modeling develops a number of qualities, such as imagination, fantasy, logical thinking, technical thinking, etc. According to Lieban and Lavicza (2019), the combination of concrete and abstract ideas, with the help of physical and computer modeling, should improve the creativity of pupils and students. Kozov et al. (2018), in their investigation of 3D virtual models as a precursor to 3D printing in teaching secondary school students, believe that 3D modeling has many effects on students, manifested in increased levels of creativity, increased motivation, acquisition of relevant skills, and increased self-confidence due to the results achieved. Pytlík and Kostolányová (2018) point out the benefits of creating 3D models on mobile devices in the context of engineering students' education, which also serves as a tool for developing spatial imagination and creativity. Honzíková et al. (2024) point out that 3D modeling programs can be used to test and compare the level of creative skills, using standardized creativity tests, of individual users, while promoting the development of creativity and spatial imagination. In the teaching environment at the University of La Laguna in the Canary Islands, a Stella 3D workshop focused on alternative modeling methods ran throughout the 2013/2014 academic year (Cantero et al., 2015). This type of workshop proved to be a somewhat creative tool that not only helps to improve the knowledge of engineering students, but also develops their competences, such as spatial skills.

A research at Taipei Art High School consisting of 215 students investigated how 3D modeling develops creativity in design. Most students made only moderate progress in this research. Based on these results, the authors of the research (Chang et al., 2016) recommend that developers should create a hand-drawing option in 3D modelers to encourage creativity more. Research at Tsinghua University and Beijing University of Technology in China, conducted by authors Wen et al. (2023) on 115 architecture students, showed that if students follow appropriate behavioral patterns when designing buildings during 3D modeling, 3D modeling can be closely linked to creativity. According to the authors, appropriate behavioral patterns are:

- frequently used commands,
- frequently used objects,
- sufficient time for familiarization with tools and commands,
- experience with tools that can be applied appropriately.

The adoption of 3D modeling technologies in developing countries poses specific challenges that often differ from those in developed countries. For example, Anđić et al. (2023) in their study comparing the use of 3D modeling and 3D printing (3DMP) in education in Montenegro, a developing country aspiring to join the EU, and Austria revealed significant differences in technological readiness. In particular, Montenegrin teachers expressed concerns about the funding and maintenance of 3D printers, the high cost of materials and teacher training, the lack of flexibility in curricula to integrate 3DMP, and language barriers as most of the available teaching materials are in English. On the other hand, Austrian teachers, although also pointing to financial issues, perceived wider opportunities to integrate 3D modeling with the teaching of different STEAM subjects and showed a greater willingness to adopt technological innovations. Furthermore, a study by Bayaga and du Plessis (2023) focusing on the Unified Theory of Acceptance and Use of Technology (UTAUT) in South Africa identified key factors influencing the adoption of new technologies, including the implementation of 3D modeling, in higher education in developing countries, which include expected benefits, perceived difficulty, attitudes toward technology, social influence, confidence in using technology, anxiety and availability of supportive conditions.

2 Present study

The aim of this study was to investigate whether experimental teaching of 3D modeling has an effect on the creativity of pupils in the 2nd stage of elementary school in terms of the four components of divergent thinking. It was investigated whether the experimental teaching affects the students' scores achieved in the creativity test and also whether there are differences in the results of the output creativity tests between the control and experimental groups. It was also investigated whether the results differed between younger and older pupils. The following hypotheses were examined:

> *H*1: There is a difference between the results of the input and the output creativity test of the pupils, in the context of experimental teaching of 3D modeling.
>
> *H*2: There is a difference between the results of the output tests of the control and experimental groups.
>
> *H*3: There is a difference between the results of the output creativity tests for the younger and older school-age pupils.

3 Materials and methods

This chapter describes the research methodology, including the characteristics of the sample, the creativity assessment tool used, and the experimental teaching process. First, the selection of participants and their division into two groups with different teaching approaches is presented. Then, the Torrance Test of Creative Thinking (TTCT) as the main instrument for measuring pupils' creativity is described.

The chapter then details the method of data collection and analysis and presents the course of the experimental teaching divided into two phases.

3.1 Participants

A total of 160 pupils participated in the study, of which 78 were from Year 6 (age 11–12) and 82 from Year 9 (age 15–16). The sample was selected from 5 elementary schools in the South Bohemia region in the Czech Republic. Table 1 lists the schools selected for the research. A combination of purposive and stratified sampling was used to select respondents (pupils), followed by stratification into comparable groups. This process was carried out in several successive steps:

3.2 Selection of schools

First, five elementary schools were deliberately selected, trying to reflect their diversity:

- In their selection, an attempt was made to take into account possible differences between small and large schools, urban and rural schools, not only in terms of the number of pupils, but also in terms of equipment
- The only technical requirement was a computer room with internet access

The selected schools thus represented different types of educational institutions, see Table 1.

TABLE 1 List of cooperating schools.

Name of school	School type and population	Total capacity of pupils
ZŠ and ZUŠ Bezdrevská ČB	regional city – 93,426	1,150
ZŠ Dubné	village – 1700	450
ZŠ Matice školské ČB	regional city – 93,426	550
ZŠ Strýčice	village – 61	200
ZŠ Volary	town – 3,755	500

3.3 Selection of respondents (pupils)

Pupils from these schools were included in the research in grades 6 and 9, which allowed comparisons between younger and older pupils. The total number of respondents before the exclusion criteria were applied was 172 pupils. In the research, selection was made by dividing the total pool of respondents into groups of approximately equal numbers, with members from each group having comparable conditions and opportunities.

3.4 Elimination criteria

Some pupils had to be excluded from the original sample based on the following criteria:

- Previous experience with 3D modeling (to avoid data distortion)
- Prolonged absence during research
- Incomplete or incorrectly completed tests
- Psychological disadvantage in the context of inclusion

After the application of these criteria, the final sample was 160 pupils, of which 78 pupils from Year 6 (age 11–12) and 82 pupils from Year 9 (age 15–16).

3.5 Division into research groups

For the experimental design, the pupils were divided into two groups.

3.5.1 First group

This group was taught technical education without 3D modeling, but with its substitution by other means (construction kits, construction of bodies using materials etc.). It served as a control group to the second group.

3.5.2 Second group

The second group took 3D modeling in Onshape classes and served as an experimental group compared to the first group. Onshape is CAD software available online via a SaaS (software as a service) model (Junk and Kuen, 2016).

The distribution was made so that each group contained approximately the same number of pupils with comparable conditions. This technique of selecting respondents meets the needs of quantitative research, where it is important that the characteristics of the sample under investigation statistically match those of the whole group it represents.

3.6 Instrument

This chapter explores the use of the Torrance Test of Creative Thinking as a tool for the objective assessment of creativity. Subsequently, the chapter focuses on the analysis of the data collected and the research methodology, including the allocation of participants and the organization of the experimental teaching. The final section details the process of the actual teaching, which took place in three phases: initial familiarization with the tools, work in a 2D environment and final realization of the 3D objects.

3.6.1 Torrance tests of creative thinking

The instrument chosen for data collection was the Torrance Tests of Creative Thinking. "*Torrance himself evaluates the test as test activities that model the creative process, with each activity involving different kinds of thinking and each contributing something unique to the whole*" (Honzíková, 2008).

Ellis Paul Torrance developed a test in the United States in the 1960s that was originally called the "Minnesota Tests of Creative Thinking" and only later became known as the "Torrance Figural Test." Torrance included four components in his test that are assessed in the context of divergent thinking, which were named by another prominent author, Guilford (1950). These components are generally considered to be indicators of various aspects of creativity (Jurčová, 1984). Honzíková (2008) states that Torrance's standardized figural test measures a person's ability to think divergently and is useful for determining the creative potential of the individual being studied. She points to the fact that it is a figural (i.e., picture) test that can be used with pupils of any age category because the pupils' answer is in the form of a cartoon picture, albeit named with a word.

This test is evaluated by scores in the areas of fluency, flexibility, originality and elaboration. An extensive scoring methodology has been developed for the test. The Torrance Test of Creative Thinking (TTCT) is one of the most recognized methods for assessing creativity. The test assesses creativity based on key dimensions including fluency, variability, originality and elaboration. The assessment criteria and rubrics focus on different aspects of creative thinking (Goff and Torrance, 2002; Kim, 2006; Dostál and Plháková, 2014). Table 2 describes each dimension and its indicators.

The Torrance Test of Creative Thinking was used in accordance with and with the approval of the Psychology Department in the Faculty of Education of our university where this test is used in research.

3.6.2 Data analysis

Data analysis was conducted in the statistical program R. Since the pupils' final scores on the TTCT were based on the four basic factors of creativity, it was necessary to extend the basic hypotheses to include these four factors. A significance level of $\alpha = 0.05$ was chosen to test the hypotheses.

3.7 Procedure

The teaching was implemented from September 2022 to December 2023 on a continuous basis in all schools described (Table 1). Pupils were divided into two groups so that each group had approximately the same number of pupils with the same conditions (Figure 1).

These two groups include pupils in the 6th and 9th year of the selected elementary schools. All groups participated in the lessons, which took place over a period of 3 months with a time allocation of 1 h per week (Figure 2).

The groups were subjected to a pre-test and a post-test as a part of the TTCT (Honzíková, 2008). The data obtained were then statistically evaluated against the hypotheses.

Teaching was always conducted by the same teacher in order to eliminate possible differences resulting from the teaching of several teachers, for example to ensure the same approaches, methods and forms of teaching in all schools.

An important factor is that none of the students had experience with 3D modeling at the time of the research whether in the teaching of technology or other subjects such as computer science.

3.7.1 Teaching the experimental group

The lessons at each school began with an explanation of what would happen, that the creativity tests would not be used to assess learning. At the same time, a pre-TTCT was administered (Figure 3).

TABLE 2 Detailed table of indicators for TTCT evaluation (Torrance, 1974).

Dimensions of creative thinking	Indicator	Description
Fluency (continuity)	Number of ideas	It measures the number of ideas the test subject generates. A higher number of ideas may indicate better fluency.
Flexibility (variability)	Diversity of ideas	It measures how diverse the ideas are, i.e., whether the examinee thinks in different directions and not just in stereotypical or familiar categories.
Originality (novelty)	Novelty of ideas	It assesses the level of originality of ideas, meaning how unusual or original the proposed answers are compared to the average answers from other participants.
Elaboration	Detail and elaboration	An assessment of how thoroughly and in detail the examinee develops ideas, whether they focus on specific details or use deeper considerations.

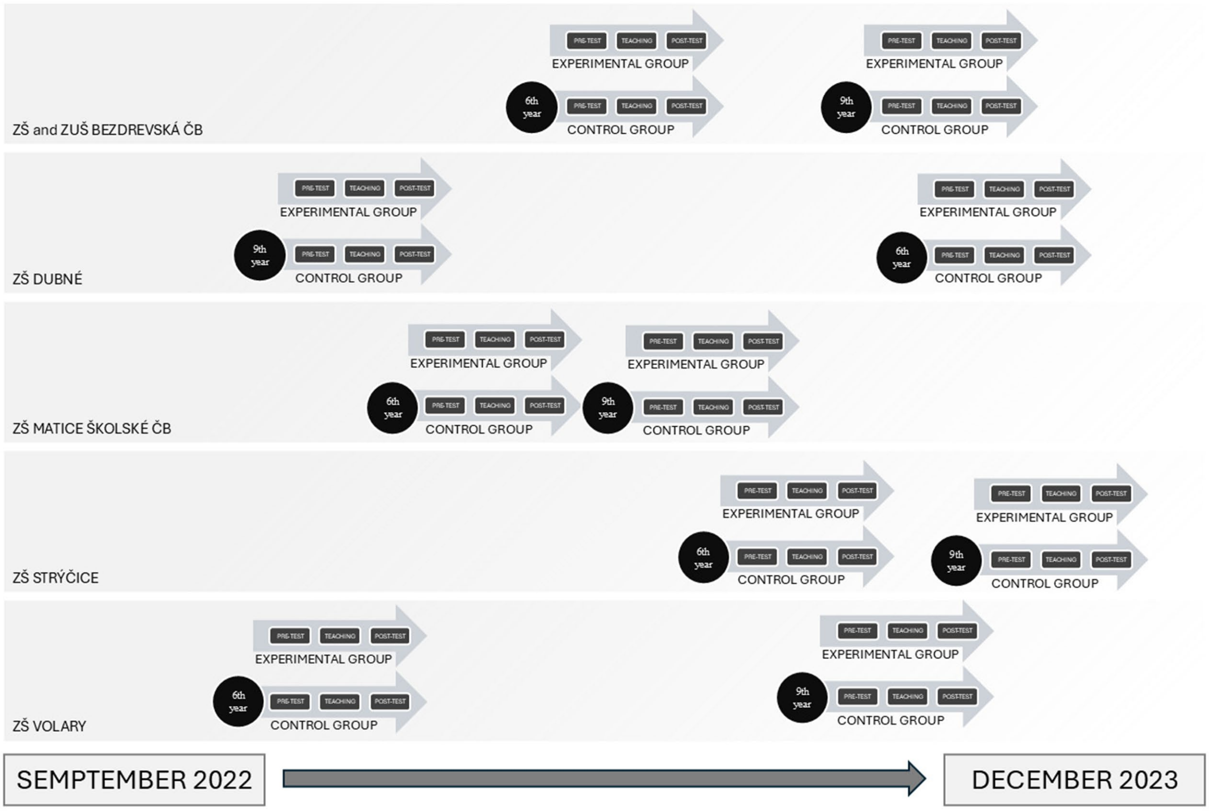

FIGURE 1
A diagram of the teaching processes taking place in all schools simultaneously in two different groups: experimental and control and also in two different years: in the 6th and 9th year of the selected elementary schools.

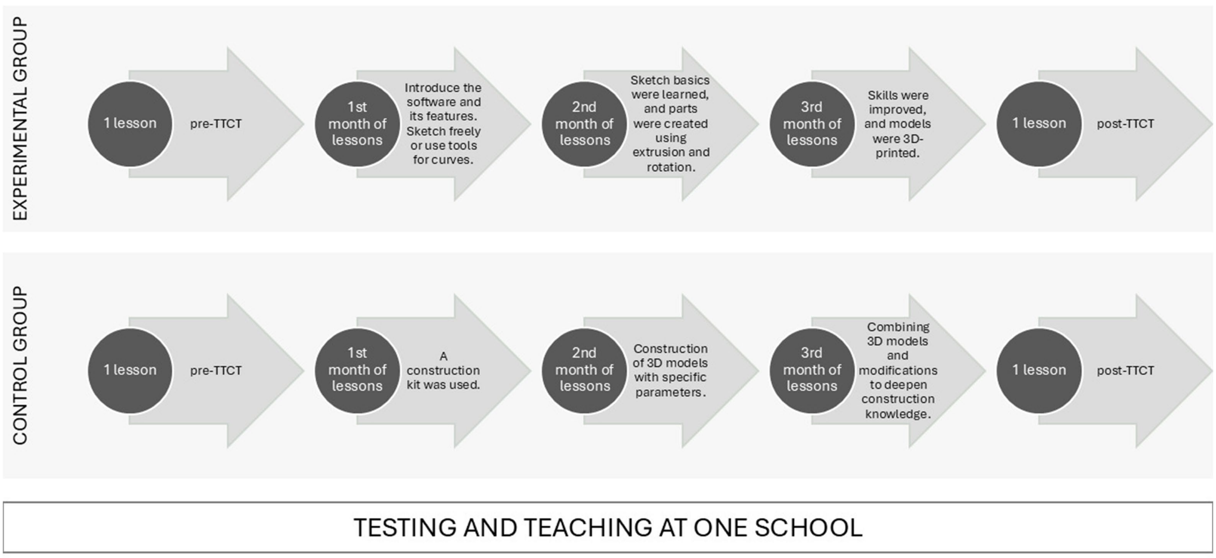

FIGURE 2
The teaching process scheme takes place at one school simultaneously in two different groups: experimental and control.

Each experimental class followed a similar procedure and performed similar activities during the 3D modeling lessons.

The control classes, which were taught using construction kits and physical models, also had identical instruction to each other and the same teacher.

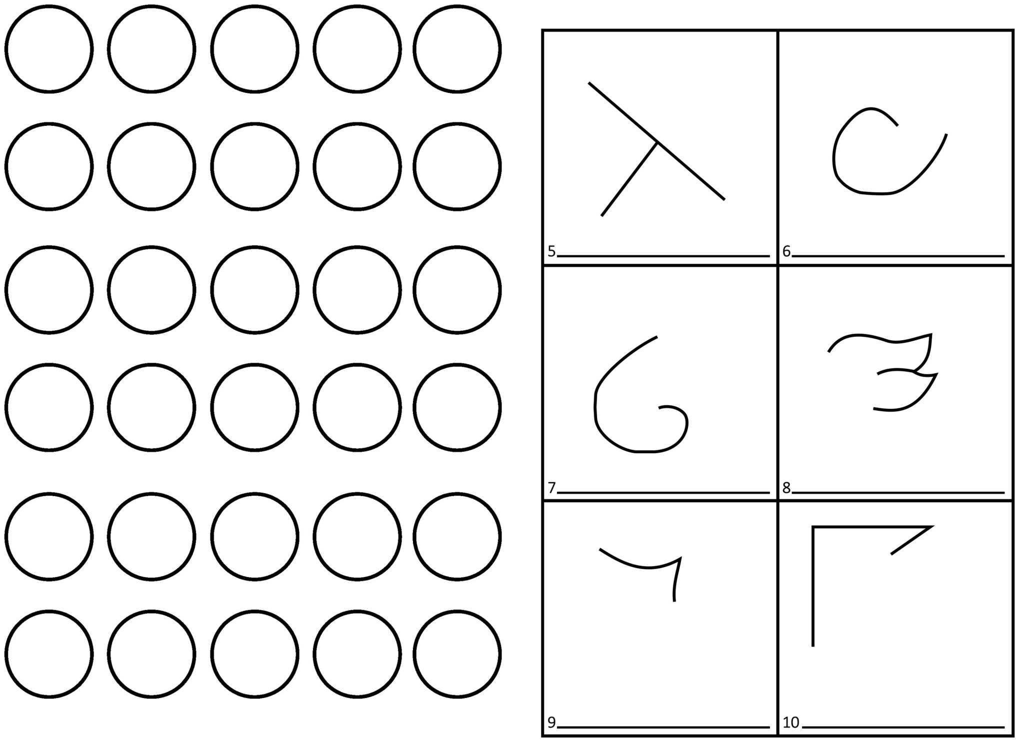

FIGURE 3
A preview of the torrance tests of creative thinking (Honzíková, 2008).

3.7.2 First month of teaching

In the first month, the pupils were introduced to the software and its possibilities (basic interface, tools, functions etc.). This part of the lesson was about sketching, i.e., drawing arbitrary shapes or using the tools to create special curves (circles, lines etc.). The pupils had the opportunity to try out the software with complete independence, but sometimes needed guidance from the teacher. Although the Onshape software is in English, the pupils did not have much difficulty using it, unlike some teachers who were also familiar with the software.

In the control group, students used a construction kit. First there was a short introduction to the kit in the form of simple constructions, which the pupils designed and tried to make themselves. By the end of the month, pupils were designing more complex constructions.

3.7.3 Second month of teaching

In the second month of teaching, all pupils had mastered the basics of working with sketches and could start creating parts using different functions (ejection and rotation), from simple to more complex. The sketches from the first month were mainly used to create the parts. It was during this part of the training that the pupils showed the greatest improvement in their mastery of the program.

The second month was marked by the construction of individual three-dimensional models, which should already meet certain parameters (height, width or shape).

3.7.4 Third month of teaching

In the third and final month of teaching, the pupils deepened their knowledge and improved their work with the program. At the end, the pupils were given space to create their own models, which they then printed on a 3D printer.

The last month has seen a combination of three-dimensional models and their modifications, deepening the knowledge of construction.

On the last day of the class, pupils were given a post-TTCT.

4 Results

Since the TTCT used measures the 4 components of divergent thinking, the hypotheses had to be extended to include these components. For each component, an index from A to D was chosen.

> *H*1: There is a difference between the results of the input and the output creativity test for pupils, in the context of experimental teaching of 3D modeling, in all the factors listed below:
>
> $H1_A$: In the fluency factor.
>
> $H1_B$: In the flexibility factor.
>
> $H1_C$: In the originality factor.
>
> $H1_D$: In the elaboration factor.

4.1 Hypothesis H1

Hypothesis H1 stated that there is a difference between the input and the output test of creativity as a result of experimental teaching of 3D modeling in four factors: fluency, flexibility, originality, and elaboration. The nonparametric Wilcoxon

TABLE 3 Descriptive statistical scores for the evaluation of hypothesis H1.

TTCT component and phase/group	Mean	Median	SD	SE	Skewness	Kurtosis
SumF_In	6.623	6	2.462	0.2964	0.4658	−0.5103
SumF_Out	8.217	8	2.344	0.2822	0.3493	−0.2707
SumFx_In	5.203	5	1.914	0.2304	0.7558	−0.1874
SumFx_Out	6.232	6	1.964	0.2364	0.7015	0.5974
SumO_In	15.8	15	5.028	0.6053	0.325	−0.5702
SumO_Out	19.71	19	5.099	0.6139	0.1149	−0.817
SumE_In	8.522	8	2.908	0.3501	0.4535	−0.2854
SumE_Out	10.91	11	2.984	0.3592	−0.1364	−0.6135

matched-pairs test method was used for testing. In Table 3 we can see the descriptive statistical scores for the evaluation of hypothesis H1. In the table we find the values of the total scores of fluency (SumF), flexibility (SumFx), originality (SumO) and elaboration (SumE), always in the pre-test (In) and post-test (Out) of creativity.

- Fluency: Statistically significant difference was found ($W = 10$, $p < 0.001$). Hypothesis $H1_A$ was confirmed.

In Figure 4 we can see a graphical representation of the overall difference between the input and the output valuesfrom the TTCT results for the fluency factor. In this graph and in the graphs that follow, the x-axis schematically shows the comparison groups, control (In) and experimental (Out), pretest and posttest results. The y-axis shows the range of ratings (scores) achieved by the comparison groups on the factor. The bottom of each box shows the 25% quantile, the top of the box shows the 75% quantile, and the divider shows the median, i.e., the 50% quantile.

As can be seen from the position of the boxes, there was a significant increase in the fluency factor score in the experimental group compared to the control group.

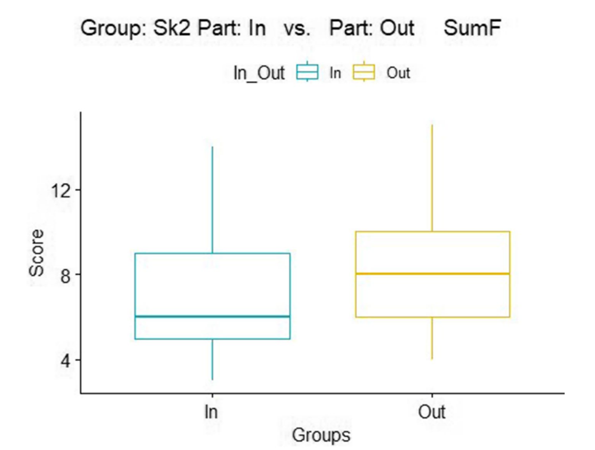

FIGURE 4
Comparison of input (In) and output (Out) values for the fluence factor.

- Flexibility: Statistically significant difference was found ($W = 155$, $p < 0.001$). Hypothesis $H1_B$ was confirmed.

In Figure 5 we can see a graphical representation of the overall difference between the input and the output values from the TTCT results for the flexibility factor.

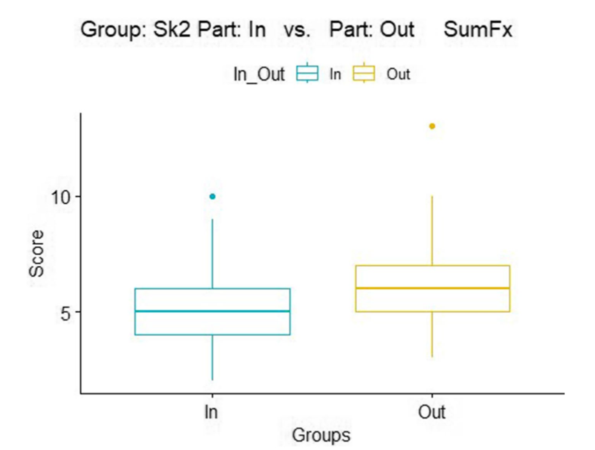

FIGURE 5
Comparison of input (In) and output (Out) values for the flexibility factor.

- Originality: Statistically significant difference was found ($W = 0$, $p < 0.001$). Hypothesis $H1_C$ was confirmed.

In Figure 6 we can see a graphical representation of the overall difference between the input and the output values from the TTCT results for the originality factor.

- Elaboration: Statistically significant difference was found ($W = 215.5$, $p < 0.001$). Hypothesis $H1_D$ was confirmed.

In Figure 7 we can see a graphical representation of the overall difference between the input and the output values from the TTCT results for the elaboration factor.

The results of the statistical analysis led to the acceptance of the hypothesis H1. For the pupils involved in the experimental 3D modeling lessons, a statistically significant difference was found

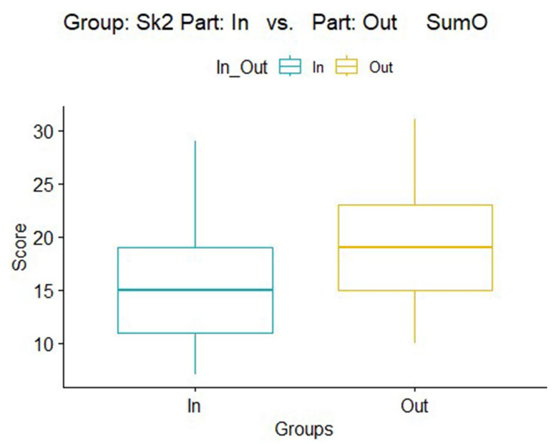

FIGURE 6
Comparison of input (In) and output (Out) values for the originality factor.

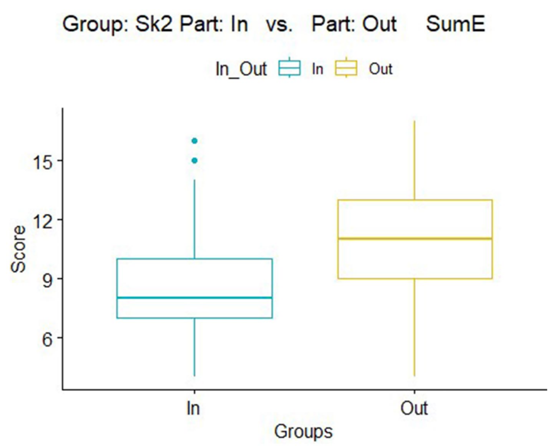

FIGURE 7
Comparison of input (In) and output (Out) values for the elaboration factor.

between the pre- and post-TTCT results in all factors (fluency, flexibility, originality and elaboration).

4.2 Hypothesis H2

Hypothesis H2 predicted differences between the control and experimental groups' performance on the output TTCT. The Mann–Whitney test was used for the analysis. In Table 4 we can see the descriptive statistical score for the evaluation of hypothesis H2. In the table we find the values of the total scores of fluency (SumF), flexibility (SumFx), originality (SumO) and elaboration (SumE) in the creativity output test, always for the control group (G1) and the experimental group (G2).

- Fluency: No statistically significant difference was found ($W = 2438.5$, $p = 0.805$). Hypothesis $H3_A$ rejected.
- Flexibility: No statistically significant difference was found ($W = 2536.5$, $p = 0.502$). Hypothesis $H3_B$ rejected.
- Originality: No statistically significant difference was found ($W = 2170.5$, $p = 0.371$). $H3_C$ hypothesis rejected.
- Elaboration: No statistically significant difference was found ($W = 2003.5$, $p = 0.107$). Hypothesis $H3_D$ rejected.

The results showed no statistically significant differences between the control and experimental groups in any of the four factors (fluency, flexibility, originality and elaboration).

4.3 Hypothesis H3

Hypothesis H3 said that there would be differences between the results of the output TTCT for younger and older school-age pupils. Testing was again conducted using the Mann–Whitney test. In Table 5 we can see the descriptive statistical scores for the evaluation of hypothesis H3. In the table, we find the values of the total scores of fluency (SumF), flexibility (SumFx), originality (SumO) and elaboration (SumE) in the creativity output test, always for younger (Y) and older school-age pupils (O).

- Fluency: No statistically significant difference was found ($W = 4977.5$, $p = 0.377$). Hypothesis $H3_A$ rejected.
- Flexibility: No statistically significant difference was found ($W = 4912.5$, $p = 0.298$). Hypothesis $H3_B$ rejected.
- Originality: No statistically significant difference was found ($W = 4{,}783$, $p = 0.184$). Hypothesis $H3_C$ rejected.
- Elaboration: No statistically significant difference was found ($W = 5366.5$, $p = 0.980$). $H3_D$ hypothesis rejected.

The results showed no statistically significant differences between the results of the output TTCT of younger and older pupils in any of the four factors (fluency, flexibility, originality and elaboration).

The results obtained from Tables 3–5 confirm that the experimental intervention based on 3D modeling led to significant improvements in the students' individual components of divergent thinking. Specifically, it was found that the mean fluency score increased from 6.62 to 8.22, while a similar positive trend was observed for the factors of flexibility, originality and elaboration. Statistical analysis using Wilcoxon paired test confirmed the high statistical significance of these changes ($p < 0.001$).

Comparison of posttest results between the experimental group that received instruction using 3D modeling and the control group using traditional methods (e.g., construction kits and physical models) showed no statistically significant differences in all of the divergent thinking factors examined. This finding suggests that both teaching methods may contribute to the development of creative abilities, but significant improvement in the experimental group was only detected when pre-post changes were observed.

Another analysis comparing scores between younger and older school-age pupils also showed no significant differences in scores on the individual factors of divergent thinking. The mean values for both age groups were very similar, confirming that the effect of 3D modeling on the development of creativity is consistent across school years. These findings underline that although experimental teaching

TABLE 4 Descriptive statistical scores for the evaluation of hypothesis H2.

TTCT component and phase/group	Mean	Median	SD	SE	Skewness	Kurtosis
SumF_G1	7.717	7	2.211	0.1882	0.3405	−0.2738
SumF_G2	7.42	7	2.525	0.215	0.3142	−0.4136
SumFx_G1	5.993	6	1.858	0.1582	0.0376	−0.1878
SumFx_G2	5.717	5	2	0.1702	0.6818	0.226
SumO_G1	18.01	17.5	4.72	0.4018	0.4086	−0.06588
SumO_G2	17.75	18	5.414	0.4609	0.1913	−0.6633
SumE_G1	9.681	10	3.118	0.2654	0.03837	−0.5011
SumE_G2	9.717	10	3.171	0.27	0.1427	−0.7086

TABLE 5 Descriptive statistical scores for the evaluation of hypothesis H3.

TTCT component and younger/older	Mean	Median	SD	SE	Skewness	Kurtosis
SumF_Y	8.51	8	2.62	0.2595	0.7214	1.29
SumF_O	8.667	9	1.92	0.1874	−0.002393	−0.3223
SumFx_Y	6.461	6	2.16	0.2139	0.4176	−0.2845
SumFx_O	6.638	7	1.468	0.1433	0.3082	−0.3611
SumO_Y	20.04	19.5	5.728	0.5672	0.8782	2.157
SumO_O	20.74	21	4.954	0.4834	0.04227	−0.3325
SumE_Y	10.75	11	3.199	0.3167	−0.0006245	−0.7648
SumE_O	10.71	11	3.1	0.3025	−0.1186	−0.5004

using 3D modeling leads to significant improvements in performance within one group (pre-post tests), the differences between teaching methods are not sufficiently significant in the post-tests. Moreover, the absence of age differences indicates the universal benefit of this methodology for promoting divergent thinking regardless of school year. Thus, the results provide a solid basis for further discussion on the optimization of teaching strategies and the integration of digital technologies into the educational process in order to enhance students' creativity.

5 Discussion

The results of this study show that experimental 3D modeling instruction has a significant effect on the development of pupils' creativity, specifically in the four components of divergent thinking—fluency, flexibility, originality and elaboration. These components were measured using the Torrance Figure Creativity Test and statistical analysis revealed significant differences between pretest and posttest scores in the experimental group. The main finding of the study was the confirmation of hypothesis H1, which predicted a positive effect of 3D modeling on creativity test scores. Statistically significant differences in all four factors suggest that 3D modeling does indeed promote students' creative thinking. This finding is consistent with previous research (Krotký, 2014; Lieban and Lavicza, 2019; Runco and Acar, 2012) and confirms that digital technologies can increase not only spatial imagination but also motivation and creative skills of pupils (Karademir and Deniz, 2022; Chen et al., 2024).

Furthermore, we can say that the results of hypotheses H2 and H3 did not show statistically significant differences between the control and experimental groups in the creativity output test or between younger and older students. This suggests that although 3D modeling contributes to the development of creativity within each group, its effect may not manifest itself as a significant difference to traditional methods of teaching engineering education on a wider scale. Another possible explanation is that traditional methods such as construction kits or physical models may also develop pupils' creative abilities in a similar way to 3D modeling (Wen et al., 2023; Resnick et al., 2009). Moreover, it was found that the age of the pupils did not have a significant effect on the level of creativity development, which is supported by studies by Junk and Kuen (2016) and Kaufman and Beghetto (2009). This finding underlines that the benefits of digital technologies depend on prior experience and individual ability rather than age differences (Junco et al., 2010).

Additionally, the integration of 3D modeling into the educational process is part of a broader trend of using digital technologies to support creative thinking and problem solving. For example, a study conducted by Karademir and Deniz (2022) showed that 3D modeling significantly supports key 21st century competencies, including critical thinking and collaboration. Similarly, Chen et al. (2024) demonstrated that the use of immersive technologies in education improves pupils' ability to solve complex problems by reducing cognitive load and providing an intuitive environment for experimentation. Other research indicates that 3D printing and modeling can lead to increased creativity and pupils engagement, which is reflected in positive educator evaluations (Zimmerman, 2018; Shim and Lee, 2019).

From a practical perspective, it can be recommended that 3D modeling be integrated into the curriculum of both engineering and art subjects to maximize its potential in promoting divergent thinking and creative skills. Furthermore, it is advisable to combine 3D modeling with other digital tools, such as virtual and augmented reality applications, to provide an even richer and more interactive learning environment (Chen et al., 2024; Fu, 2022). It is also necessary to ensure adequate training of educators so that they are able to effectively integrate new technologies into the classroom and adapt the methodology to the needs of individual pupils, and to implement sufficient time for the acquisition and practice of 3D modeling skills, which is crucial for optimal results (Zimmerman, 2018).

The main limitations of this study include the relatively short duration of the experimental phase, which may have affected the detection of differences between teaching methods, and the specifics of the selection of respondents whose previous experience with technology may not have been completely eliminated. Furthermore, the influence of external factors such as individual pupils' motivation or the variability of pedagogical approaches should be taken into account (Friedel et al., 2021). Moreover, some studies point to the need for long-term follow-up, as the "novelty effect" may diminish over time (Tsay, 2018).

Future research would benefit from extending the intervention period and monitoring the long-term effects of 3D modeling on pupils' creativity, incorporating a wider range of teaching methods and digital technologies to more comprehensively evaluate their contribution to the development of creative skills (Shim and Lee, 2019). Furthermore, it would be beneficial to develop multimodal evaluation methodologies to capture the more subtle aspects of the creative process and to better understand the interaction between traditional and innovative approaches in education (Junco et al., 2010). We also recommend conducting comparative studies involving different age groups and geographical regions to test the universality of the benefits of 3D modeling across different contexts (Resnick et al., 2009).

It should also be emphasized that the results of this study are consistent with the theory of embodied cognition, which argues that cognitive processes are closely linked to bodily interactions with the environment, and that immersive environments can reduce cognitive load and promote deeper learning (Chandler and Sweller, 1991; Özgen, 2020). This theoretical background underscores the importance of linking 3D modeling with pedagogical principles that promote collaboration and an interdisciplinary approach that can further enhance pupils' engagement, creativity, and ability to solve complex problems (Zimmerman, 2018; Trilling and Fadel, 2009).

6 Conclusion

The results of this study showed that 3D modeling positively influences the development of creativity of pupils in the 2nd stage of elementary school, especially in the components of divergent thinking such as fluency, flexibility, originality and elaboration. Statistical analysis showed significant differences between pretest and posttest in the experimental group, confirming the effectiveness of 3D modeling as a pedagogical tool to promote pupils' creative thinking and cognitive abilities.

There were no significant differences between the control and experimental groups in the results of the ouput creativity test, suggesting that traditional methods of technical education can contribute to the development of creative thinking in a similar way. Also, no differences were found between younger and older pupils, indicating the universal benefit of 3D modeling independent of age.

From a practical point of view, we recommend including 3D modeling as a key element of the educational process, especially in the areas of technical and artistic education. Virtual environments allow the use of a virtually infinite number of combinations of tools and features, which fundamentally distinguishes this method from traditional approaches such as construction kits or physical models that are limited by the number of physical components (Chang et al., 2016; Wen et al., 2023). In addition to the reusability and variability of combining digital tools (Bower et al., 2020; Cantero et al., 2015), 3D modeling is proving to be a more effective means of stimulating creative thinking—allowing students to not only experiment with different elements, but also to focus strictly on specific tools to produce innovative solutions. Such an approach encourages a higher level of originality and diversity of outcomes than can be achieved with limited physical materials, making 3D modeling a more effective tool for developing creativity (Amabile, 1996; Eckhoff, 2011).

Nevertheless, several limitations of this study should be taken into account. The relatively short duration of the experimental period—3 months with an hourly subsidy per week—may have limited the manifestation of the long-term effects of 3D modeling (Chang et al., 2016). Another limitation is that the sample was drawn from selected primary schools in one region, reducing the possibility of generalizing the results to a wider population (Honzíková et al., 2024). Methodologically, the Torrance Figurative Test of Creativity was used exclusively (Honzíková, 2008). Future research should emphasize long-term monitoring of the effects of 3D modeling on creativity development, and therefore longitudinal studies should be conducted to monitor the effects of this teaching method over a longer time frame. Such a study would make it possible to evaluate the stability of the effects achieved and shed light on whether the effectiveness of the method increases with time (Runco and Acar, 2012; Chang et al., 2016). It would also be beneficial to integrate 3D modeling with modern technologies such as virtual and augmented reality (VR/AR) to explore the synergistic effects of combining different digital tools and their impact on divergent thinking (Bower et al., 2020; Cantero et al., 2015).

A further direction would be a more comprehensive evaluation of creativity, involving a combination of quantitative and qualitative methods, which would allow a more detailed analysis of individual differences and specific manifestations of creativity. It is also necessary to take into account socio-cultural and individual factors, such as previous experience with digital technologies or the level of motivation of students, which can significantly influence the effectiveness of teaching methods (Honzíková et al., 2024). Such a multidisciplinary approach would not only deepen the understanding of the mechanisms by which 3D modeling promotes creativity, but also contribute to the optimisation of teaching methods and their wider implementation in the educational process.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the study involving human samples in accordance with the local legislation and institutional requirements because the study exclusively used samples for which written informed consent for participation was obtained from the participants' legal guardians/next of kin, and this consent covered the scope of the research as well as the publication of any potentially identifiable images or data.

Author contributions

TS: Conceptualization, Data curation, Formal analysis, Investigation, Supervision, Visualization, Writing – original draft, Writing – review & editing. VV: Conceptualization, Formal analysis, Investigation, Supervision, Writing – review & editing. MŠ: Data curation, Investigation, Writing – review & editing. JB: Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted without any business or financial relationships that could be construed as a potential conflict of interest.

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