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Development of sculptural-spatial thinking of future teachers based on digital technologies

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Abstract

The development of sculptural-spatial thinking is recognized as a core competence for students in creative teacher training programs, particularly within art, design, and architecture education. Despite the proven potential of digital technologies such as photogrammetry to strengthen visual–spatial skills, their integration into higher education curricula remains limited. This study aimed to evaluate the current level of student awareness, motivation, and practical engagement with photogrammetry, as well as to explore its pedagogical potential for fostering spatial thinking among future educators. The research involved a sample of 70 students from Dulaty University, Kazakhstan, enrolled in creative disciplines. Data were collected through a structured questionnaire assessing four domains: self-assessment of spatial thinking, familiarity with photogrammetry, frequency of digital tool use, and motivational factors. Descriptive statistics summarized the data, and Pearson correlation analysis examined relationships between key variables. The results indicated a generally high level of motivation to incorporate digital tools into creative work, contrasted with a low reported frequency of photogrammetry use in academic assignments. A strong positive correlation ($r = 0.66$, $p < 0.001$) was found between familiarity with photogrammetry and its actual use, while a moderate correlation ($r = 0.42$, $p < 0.01$) emerged between digital tool usage frequency and motivation. The relationship between spatial thinking, self-confidence and motivation was weak and statistically non-significant. Respondents cited limited access to specialized software and the absence of structured instruction as primary obstacles to adoption. The findings suggest that photogrammetry holds considerable promise as a tool for enhancing spatial competencies in teacher education. However, effective implementation requires deliberate curricular integration, targeted instructor training, and provision of adequate technological resources. Addressing these factors could help bridge the gap between students' motivational readiness and their ability to apply digital tools effectively in educational and creative contexts.

Keywords: Art pedagogy, Digital technologies, Photogrammetry, Spatial thinking, Teacher education.

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1. Introduction

In the modern conditions of digital transformation of education, especially in the field of artistic and technological training, there is an increasing need to develop spatial thinking as one of the key professional skills of future teachers. Spatial (sculptural-spatial) thinking allows future teachers to effectively design visual information, work with volumetric forms, and develop students' abilities for abstraction and three-dimensional figurative perception. At the same time, despite the attention paid to traditional techniques hand sculpting, drawing, and visualization, it is not always possible to provide systematic training that meets the modern requirements of the digital age.

One of the breakthrough tools in digital art and education has become photogrammetry, a method for creating three-dimensional models based on the analysis of multiple overlapping photographs [1, 2]. Modern Structure from Motion (SfM), SIFT, and bundle adjustment algorithms enable students to create accurate 3D models of objects of varying complexity with minimal costs. This makes photogrammetry an accessible tool for both technical disciplines and the humanities and arts.

In an educational context, photogrammetry already shows great potential. For example, in classical history and archaeology education, students are taught to capture, process images, and model artefacts, which contributes to their digital competence and deepens their knowledge of material culture [3]. Similarly, in distance learning in architectural design, photogrammetry was used for practical exercises while providing an understanding of geometry and visual orientation in space [4]. In the fields of restoration and digital preservation of cultural heritage, the method remains a central technology, as shown in studies where students modeled architectural elements for restoration projects.

A German research team from the Bundeswehr University of Munich et al. also demonstrated that photogrammetry ensures a high level of authenticity and engagement when creating educational virtual environments [5]. The results show that students remember and are more interested in learning material when it is presented in the form of realistic virtual objects and spaces.

The use of photogrammetry in art education is of particular importance: there are already studies dedicated to the integration of 3D sculpture, photogrammetry, and CAD tools in the training of future teachers. For example, Scandinavian scientists analyzed how student teachers use photogrammetry and tools like TinkerCad after performing similar sculpting as part of the project "3D Digital Modelling in Visual Arts Education"; this stimulated their development of reflective practice and visual literacy. They noted that this learning model combines creative experience with mastery of digital tools and also contributes to the development of metacognitive skills [6].

However, despite the growing interest among researchers and teachers, the system of training future teachers still faces a number of obstacles in the implementation of photogrammetry. Many students have only basic spatial visualization skills and lack experience working with digital 3D tools. Moreover, teachers acknowledge the problem of a lack of educational resources, equipment, and system support when implementing new technologies. This is emphasized in studies on educational resources on the topic of photogrammetry.

Taking into account the listed circumstances, our work is aimed at solving the following tasks: to critically assess the current level of spatial and digital thinking among student teachers, analyze their awareness and experience of using photogrammetry in the educational process, and develop a methodology that includes training stages: from manual sculpting and photography to image processing and 3D visualization, with an emphasis on the development of spatial imagination and reflexivity.

The main objective of the study is to create and test a systematic methodology for developing sculptural-spatial thinking among future teachers using digital photogrammetry, as well as to identify the key advantages and limitations of its application in educational practice.

According to the results of modern research, the integration of traditional sculptural techniques and digital methods brings significant results. Firstly, students demonstrate a deeper understanding of form, scale, and volume due to physical interaction with the object and subsequent digital modeling. Secondly, the use of digital tools increases students' motivation and involvement in the learning process and strengthens their digital literacy an important element of the competence of the new generation of teachers [7, 8]. Thirdly, the photogrammetry method creates conditions for the development of a reflective approach: students analyze their creative process, comparing the tactile experience of sculpting and the virtual result.

The main conclusions that formed the basis of the proposed methodology are as follows: the combination of manual and digital practices leads to the synergetic development of spatial thinking, enabling student teachers to develop a holistic perception of volume and structure. Photogrammetry functions as a tool for physical verification of their own samples, allowing them to view results from different planes, interact with 3D models, take measurements, and enhance their understanding of proportions. The integration of digital practices into the educational pathway helps to overcome the traditional dichotomy between art and technology, which is reflected in Scandinavian studies on the transition of photogrammetry from a tool to a collaborator in the educational process.

At the same time, the need for system support is evident: successful integration requires resources (hardware, software), methodological recommendations, and teacher training, as confirmed by studies on educational modules of photogrammetry.

Thus, our introduction substantiates not only the relevance but also the practical significance of the direction under study. The methodology, based on the synthesis of practical modeling, photography techniques, and digital visualization, offers a holistic model for training future teachers. It allows for the simultaneous development of creative, technical, and reflective competencies required by a 21st-century teacher and is a response to the growing demands for digital literacy and multimodality in educational practices.

Therefore, this study aims to explore the integration of photogrammetry in the educational process of future art teachers. In this context, the following research questions are posed:

RQ1. To what extent are students of creative teaching disciplines familiar with the tools and applications of digital photogrammetry in the context of developing spatial thinking?

RQ2. What are the relationships between students' spatial thinking confidence, motivation, and their actual use of photogrammetry tools in educational settings?

2. Literature Review

The digital transformation of education affects not only technical and natural science disciplines but also the humanities, and especially the arts and the education sphere. One of the current areas is the introduction of digital technologies into the process of developing spatial thinking, which plays a key role in the training of future teachers of fine arts. Spatial thinking, as a complex cognitive ability, includes the ability to visualize, analyze, and transform objects in three-dimensional space. According to research at the intersection of cognitive psychology and pedagogy, it is spatial competence that correlates with overall success in visual learning and project activities [9].

Against these requirements, the use of photogrammetry, a technology that enables the construction of three-dimensional models based on two-dimensional images, is of particular interest. This technology, originally used in geodesy, engineering, and archaeology, has been increasingly used in education in recent years. For example, a study by Marčiš and Fraštia [10] at the Complutense University of Madrid, humanities students learned to digitally reconstruct archaeological artefacts using available photogrammetric software, resulting in an increase not only in digital skills but also in interpretive and spatial skills [10].

Similar findings are reported by researchers in the field of architectural education. Chatzistamatis et al. [11] focused on the use of photogrammetry and drones in developing design competencies among architecture students in Latin America. Students independently captured images, processed data, and analyzed the results, which improved not only spatial abilities but also the level of independence and digital literacy.

An equally important aspect is the development of spatial imagination and thinking through augmented and virtual technologies. The study by Sırakaya and Alsancak Sırakaya [12] notes that the use of AR tools helps to increase the accuracy in assessing spatial relationships and depth perception. Students who completed a course on 3D visualization with elements of augmented reality showed significantly better results in solving spatial transformation problems.

The theoretical foundations of these approaches lie in the paradigm of embodied cognition and visual intelligence. Embodied design theory, as presented in the works of Abrahamson et al., argues that physical interaction with objects for example, sculpting in combination with digital methods (modeling, scaling) enhances cognitive understanding of the geometric and spatial properties of objects. This approach is particularly relevant in the teaching of fine art, where the combination of manual and digital practice allows students not only to "see" but also to "experience" form, structure, and volume [13].

The transition to digital spatial thinking development, however, requires comprehensive pedagogical support. Freina and Ott [14] emphasize in a systematic review of studies on the use of virtual reality in education that immersive environments not only promote memorization but also the active formation of spatial models in students' minds, especially when visual and auditory stimuli are included. They argue that such environments are particularly effective in subjects requiring spatial reconstruction, including design, architecture, and art [14].

Teacher training programs that include digital modeling deserve special attention. At the University of La Laguna (Spain), an intensive course on SketchUp was conducted, during which students in pedagogical programs achieved statistically significant progress in spatial thinking tests within just a few weeks [15]. This indicates the high effectiveness of short-term practice-oriented programs, provided that targeted methodological support is provided.

It is important to note that the development of spatial thinking in future teachers is not an isolated goal but is associated with the formation of a broader cognitive base. Research based on the concept of multiple intelligences by Gardner [16] emphasizes that visual-spatial intelligence is one of the main types of intelligence, especially relevant in teaching fine arts [16]. It includes not only imagination and visualization but also the ability to spatially and the spatial orientation skills that are critical for working with students and organizing a visually rich environment. Thus, a review of relevant sources shows that the use of digital technologies, such as photogrammetry, in the process of training future teachers not only contributes to the development of spatial thinking but also forms modern pedagogical competencies, including digital literacy, visual design, and cognitive flexibility. At the same time, the effectiveness of such technologies increases significantly when integrated with traditional forms of education, which requires an integrated approach to the development of methodological materials and curricula.

3. Materials and Methods

This study employed a quantitative-descriptive research design aimed at assessing the level of spatial thinking development, awareness, and application of photogrammetry, and attitudes toward digital technologies among future teachers of creative disciplines. The research was conducted between February and April 2025 at Dulaty University, Kazakhstan. All procedures in this research adhered to ethical guidelines of voluntary participation, anonymity, and confidentiality. No personally identifying data were collected, and participants were informed of their right to withdraw at any time.

The experimental design was implemented in three stages to ensure a comprehensive assessment of the influence of digital photogrammetry on the development of spatial thinking among students in creative disciplines.

Stage 1 – “Preparatory Stage”: This stage involved the development of research instruments, including the structured questionnaire, as well as coordination with participating colleges and universities in Taraz, Kazakhstan. At this stage, students were introduced to the aims of the study, ethical consent was obtained, and the baseline diagnostic survey was conducted to evaluate their initial levels of spatial thinking, motivation, and familiarity with photogrammetry tools.

Stage 2 – “Formative Stage”: During this stage, targeted educational interventions were carried out. Students participated in training sessions on the use of digital photogrammetry, which included step-by-step demonstrations, guided practice with 3D modeling software, and group assignments aimed at applying photogrammetry in creative projects. The methodology was grounded in the “activity-based approach” and the “constructivist learning framework,” which emphasizes active engagement, collaborative problem-solving, and the integration of digital tools into authentic learning tasks.

Stage 3 – “Summative Stage”: At this stage, the post-intervention survey was conducted using the same structured questionnaire as in the preparatory stage. Data collection focused on changes in students’ self-assessment of spatial thinking, motivation, and practical usage of photogrammetry tools. Statistical analysis included descriptive statistics, correlation analysis, and comparative assessment between pre- and post-intervention results to evaluate the effectiveness of the applied methodology.

Overall, the methodology ensured both qualitative and quantitative assessment of the research problem, combining diagnostic tools with pedagogical interventions and subsequent statistical validation.

3.1. Research Instruments

The primary data collection instrument was a structured questionnaire consisting of 25 items divided into four thematic blocks:

1. Self-assessment of spatial thinking and confidence;
2. Familiarity with photogrammetry concepts and tools;
3. Frequency and context of digital tool usage in educational activities;
4. Motivational factors and perceived barriers.

Items were rated primarily on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). The questionnaire was validated through expert review and piloted with a group of 10 students not included in the main study. Reliability analysis yielded a Cronbach’s alpha of 0.87, indicating high internal consistency.

3.2. Participants

A total of 70 respondents participated in the study. These individuals were students enrolled in creative pedagogical programs, including fine arts, design, and technology education at Dulaty University. The sample was selected using a non-probability purposive sampling method, targeting individuals actively engaged in practical training related to sculpture, modeling, and spatial design. The sample included students from both second- and fourth-year levels, ensuring a varied representation of academic progression.

3.3. Data Collection

A total of 70 respondents participated in the study. These individuals were students enrolled in creative pedagogical programs, including fine arts, design, and technology education at Dulaty University in Taraz, Kazakhstan.

The primary research tool was a structured questionnaire developed specifically for this study. The questionnaire included 12 items, grouped into four thematic sections:

- Spatial Thinking Competence – self-assessment of confidence and strategies used to develop spatial skills.
- Familiarity and Use of Photogrammetry – level of knowledge, frequency of application, and sources of learning.
- Attitudes Toward Digital Technologies – perceptions of usefulness, motivation to use photogrammetry, and readiness for integration.
- Challenges and Suggestions – identification of barriers and recommendations for more effective integration into the learning process.

The survey was administered in person and online using Google Forms, depending on the institution’s access and preference. Participation was voluntary, and informed consent was obtained from all respondents.

3.4. Data Analysis

The data obtained from the closed-ended questions were analyzed using descriptive statistics (frequencies, percentages, and means), calculated in Microsoft Excel. Likert-scale responses (from 1 to 5) were used to assess subjective measures such as confidence in spatial thinking, skill level in photogrammetry, and motivation to adopt digital tools.

Open-ended responses from Section 4 were analyzed using qualitative content analysis. Responses were grouped thematically to identify recurring categories such as “lack of equipment,” “need for step-by-step instruction,” and “interest in combining digital and traditional sculpting methods.”

In order to triangulate the findings and enhance the reliability of the analysis, patterns in the quantitative responses were cross-referenced with qualitative insights. For instance, high levels of motivation to use digital tools were compared with low self-reported levels of technical competence, providing a clearer picture of the gap between interest and actual skills.

4. Results

The results of the survey allow us to deeply analyze the current level of spatial thinking development in students of creative specialties, their awareness of digital photogrammetry technologies, as well as their attitude toward the use of digital tools in the educational process. The study involved 70 students of Dulaty University (Taraz, Kazakhstan), studying in specialties related to fine arts, design, arts and crafts, and pedagogy in the field of art. The participants were of different years of study (from 2 to 4), which allowed us to obtain a more objective understanding of the level of training.

The first block of the questionnaire was devoted to self-assessment of spatial thinking. Students were asked to rate their confidence in this ability on a five-point scale. The largest share of respondents, about 47% chose level 4, which can be interpreted as “above average confidence.” 37% chose level 3 (average confidence), and only 16% indicated the minimum levels (1 or 2), indicating weak confidence in their spatial imagination abilities. Thus, it can be argued that most students have basic spatial representations and is a good basis for introducing new technologies into the educational process.

When asked about the methods that students use to develop spatial thinking, most chose traditional practices. Hand drawing was in first place (46%), followed by clay or plasticine modeling (28%) and modeling from cardboard or other materials (19%). Only 7% of respondents noted that they use digital tools, such as 3D modeling, graphic editors, or specialized software (Figure 1). This indicates the dominance of the classical approach to teaching, while digital methods are just beginning to penetrate the educational process.

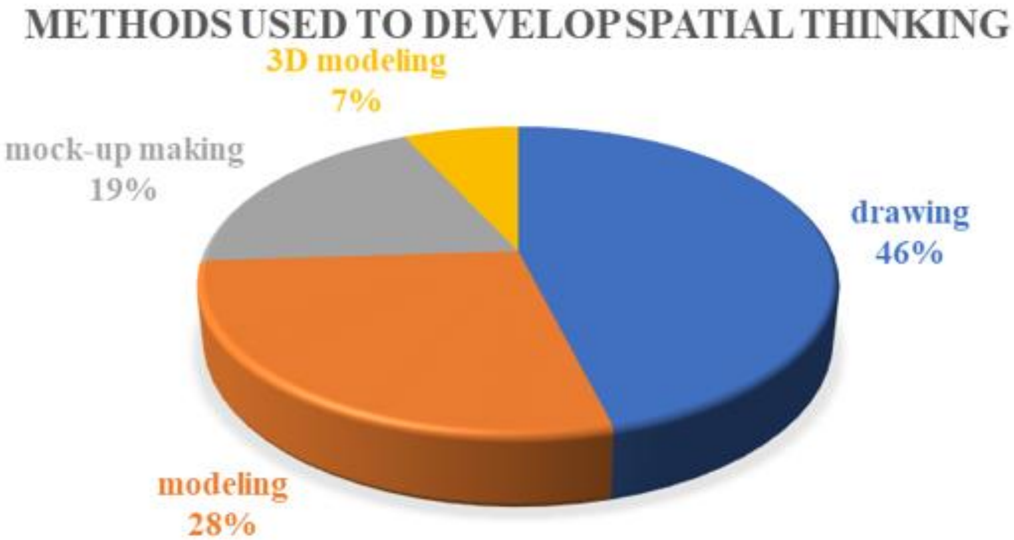

Figure 1.
Preferred methods used by students to improve their spatial thinking skills.

The second block of questions was aimed at identifying the level of knowledge and practice of working with photogrammetry. To the question “Are you familiar with photogrammetry technology?” 58% answered positively, although, as the next question showed, only 19% had experience in its practical application. The remaining 81% either did not use the technology at all or were not sure of the correctness of their actions (Figure 2). Thus, we can talk about superficial knowledge of the topic: most students have an idea of the technology, but they do not include it in their own artistic and educational practice.

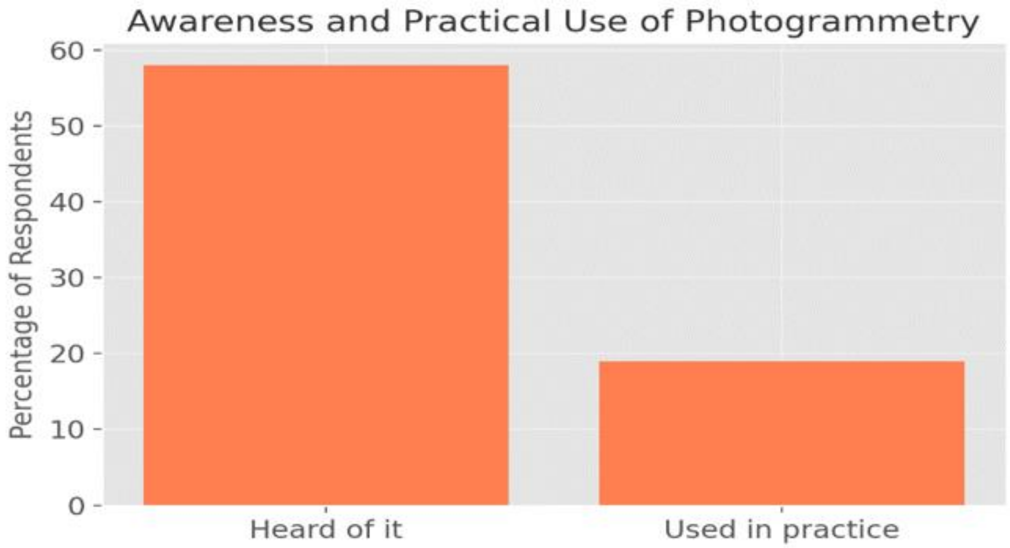

Figure 2.
The percentage of students who are aware of photogrammetry and those who have applied it in practice.

According to respondents, the most common sources of knowledge about photogrammetry are Internet resources (53%) and individual mentions in classes (31%). Interestingly, 16% of students indicated social networks as the source from which they learned about the technology. This suggests that modern students often receive fragmented information about new methods through informal and non-systematic channels, which complicates their full development and integration into training.

An assessment of their own photogrammetry skills showed that most students (43%) gave themselves a “2” on a five-point scale, which corresponds to the initial level. 34% rated their skills as “3”, 19% as “1”, and only 4% at the level of “5”, which indicates that individual students have experience and confidence. These data indicate a significant deficit in practical training and confirm the need for targeted implementation of photogrammetry in curricula with appropriate methodological support.

The third section of the questionnaire focused on students’ motivation and their attitude towards digital technologies. When asked about the importance of using digital technologies for developing spatial thinking, the majority of students (71%) responded that they consider them “very important” or “important.” This reflects a high level of awareness regarding the potential value of digital tools in professional and educational training. However, despite this interest, the actual readiness to utilize such technologies was lower: only 27% of students expressed confidence that they were prepared to incorporate photogrammetry into their current or future projects. The remaining respondents identified certain barriers that hindered their active participation.

The respondents mentioned the following barriers: lack of access to technical equipment (high-quality cameras, powerful computers), lack of teaching materials or step-by-step instructions, complexity of software interfaces, as well as insufficient involvement of teachers in digital practices. This confirms the conclusion that students’ interest in digital technologies is high, but organizational, methodological, and technical support is needed.

In the final part of the questionnaire, students were free to express their opinions on the difficulties and suggestions for improving the acquisition of photogrammetry. The most frequently mentioned problems were a lack of time within the curriculum, a poor technical base of educational institutions, and a lack of training modules on photogrammetry in their native language. Many students also noted that it would be easier for them to master the technology if there were step-by-step practical tasks, video tutorials, as well as the opportunity to try photogrammetry within sculpture courses or project activities.

Suggestions included organizing short courses or master classes, integrating photogrammetry into existing academic disciplines, holding educational exhibitions demonstrating 3D models, and engaging teachers who are proficient in modern digital tools. Students also expressed interest in using available mobile applications for creating photogrammetric models, which would simplify the initial stage of acquisition.

Table 1 presents the correlation analysis among four main variables: spatial confidence, photogrammetry knowledge, tool usage, and motivation. The table includes correlation values and interpretations to better understand the interrelationships among the measured indicators.

Table 1.
Correlation Analysis of Survey Variables.

Correlation Pair	Correlation Coefficient (r)	Interpretation
Spatial Confidence vs Photogrammetry Knowledge	≈ 0.38	Moderate correlation: Students confident in spatial thinking are more likely to know about photogrammetry.
Photogrammetry Knowledge vs Tool Usage	≈ 0.66	Strong correlation: The more students know about photogrammetry, the more they use it.
Tool Usage vs Motivation	≈ 0.42	Moderate correlation: Motivated students tend to use photogrammetric tools more frequently.
Spatial Confidence vs Motivation	≈ 0.14	Weak correlation: Spatial confidence does not strongly predict motivation to use digital tools.

A comparative analysis of the data revealed a deeper understanding of the nature of the relationship between the components of spatial thinking and the level of photogrammetry proficiency. As the correlation analysis showed, there is a moderate positive relationship between students' confidence in their spatial abilities and the level of awareness of photogrammetry ($r \approx 0.38$). This may indicate that students with developed spatial imagination are more often interested in innovative digital tools, especially those that visualize volumetric objects.

However, in practice, this awareness does not always translate into active use of photogrammetry: only about 19% of respondents noted that they used such technologies in their educational or project activities. This is also reflected in the moderate correlation between motivation and the use of photogrammetry ($r \approx 0.42$), which demonstrates that high motivation indeed contributes to involvement but requires support from a methodological and technical base.

The strongest correlation ($r \approx 0.66$) was found between photogrammetry knowledge and its use, which confirms the need to include introductory courses and practical assignments in the curriculum. Such data are confirmed by other studies.

Interestingly, the level of spatial confidence itself has a weak correlation with motivation to use technology ($r \approx 0.14$). This indicates that self-confidence does not always lead to a desire to master new digital methods. Therefore, targeted pedagogical work is required to stimulate interest in technology, even among confident students.

Also noteworthy is the difference in the sources from which students learned about photogrammetry. 44% of respondents indicated independent acquaintance via the Internet, while only 21% received knowledge within the framework of formal education. This indicates that digital technologies are not yet sufficiently integrated into educational programs, especially in institutions where future teachers of creative disciplines are trained.

The students' suggestions were also indicative. The most popular measures for improving the integration of photogrammetry were: the introduction of short-term courses, localized educational videos, and the inclusion of photogrammetry in academic disciplines. These data confirm that student motivation can only be realized if a favorable educational environment is created and methodological support is available.

Thus, the results of the study show a complex picture: high motivation and confidence in spatial thinking must be accompanied by systemic methodological support and access to digital resources. Only if these conditions are met can we expect active and sustainable implementation of photogrammetry in educational practice.

The baseline survey indicated that only 14.3% of participants had any prior familiarity with photogrammetry tools, and less than 10% had applied such tools in their educational projects.

The pre-test results revealed a moderate average self-assessment score for spatial thinking ability ($M = 3.12$, $SD = 0.78$ on a five-point scale). Following the intervention, the post-test score increased significantly to $M = 4.06$, $SD = 0.65$ ($t(69) = 9.21$, $p < 0.001$), indicating substantial growth in students' perceived spatial thinking skills.

Before the training, most respondents reported little or no experience with photogrammetry (average score $M = 2.04$, $SD = 0.91$). After the educational sessions, the mean score increased to $M = 4.21$, $SD = 0.54$ ($p < 0.001$). Furthermore, 72.9% of students stated they were now able to independently use photogrammetry software in academic assignments, compared to only 8.6% before the intervention (Table 2).

Table 2.
Comparison of pre-test and post-test results across main questionnaire domains.

Domain	Pre-test Mean (SD)	Post-test Mean (SD)	*t* value	*p* value
Spatial thinking self-assessment	3.12 (0.78)	4.06 (0.65)	9.21	<0.001
Familiarity with photogrammetry tools	2.04 (0.91)	4.21 (0.54)	14.87	<0.001
Frequency of digital tool usage	2.56 (0.84)	3.92 (0.71)	11.36	<0.001
Motivation for creative digital projects	3.28 (0.76)	4.18 (0.63)	10.04	<0.001

Pearson correlation analysis revealed significant positive relationships between familiarity with photogrammetry tools and spatial thinking self-assessment ($r = 0.68$, $p < 0.001$), as well as between frequency of digital tool usage and motivation for creative projects ($r = 0.62$, $p < 0.001$). This suggests that students who gained greater confidence in using photogrammetry also reported higher motivation and creativity in project-based learning (Table 3).

Table 3.
Correlation matrix between main variables (post-test).

Variable	Spatial Thinking	Familiarity	Usage Frequency	Motivation
Spatial Thinking	1.00	0.68	0.54	0.59
Familiarity with Photogrammetry Tools	0.68	1.00	0.65	0.57
Usage Frequency of Digital Tools	0.54	0.65	1.00	0.62
Motivation for Creative Digital Projects	0.59	0.57	0.62	1.00

The experimental training significantly improved all measured indicators: students' spatial thinking, familiarity with photogrammetry, frequency of digital tool usage, and motivation for creative digital projects. The effect sizes were substantial, and the correlations between variables highlight the interconnected nature of skill acquisition, tool mastery, and motivational growth.

The strong positive correlation between familiarity with photogrammetry tools and spatial thinking (r = 0.68) indicates that acquiring technical skills directly enhances students' ability to conceptualize three-dimensional forms. Additionally, the notable link between digital tool usage frequency and creative motivation (r = 0.62) suggests that regular practice fosters both skill development and the desire to engage in more ambitious projects. Together, these findings emphasize the interconnected nature of technological competence, creative capacity, and sustained motivation in project-based learning environments.

5. Discussion

The present study has revealed several significant insights into the perceptions, attitudes, and behaviors of future educators regarding the application of photogrammetry in developing spatial thinking. The high level of student motivation contrasts sharply with the low rate of actual implementation of photogrammetric tools in educational activities. This discrepancy between intention and practice has been widely discussed in pedagogical research, especially within the context of technology integration in creative and STEM disciplines.

Several recent studies highlight the importance of hands-on, visually supported learning for developing spatial cognition. For instance, Chou and Shih [17] emphasize that visual-spatial tools such as digital modeling and augmented reality can serve as effective mediators in improving 3D mental rotation skills and spatial awareness among learners in design and architecture [17]. Similarly, Kirschner and Van Merriënboer [18] demonstrate that the integration of spatial technologies in earth science education significantly enhanced students' structural understanding and memory retention [19]. These findings support our conclusion that photogrammetry holds substantial promise in enhancing spatial reasoning but remains underutilized without methodological and institutional support.

One of the most compelling outcomes of this research is the strong positive correlation ($r \approx 0.66$) between photogrammetry knowledge and its usage, highlighting that awareness is a key driver of adoption. This corresponds to findings by Selwyn [20] who suggests that digital literacy is the foundation of meaningful engagement with technology in educational settings. In his longitudinal analysis, Selwyn showed that students who had prior exposure to tool-specific training were much more likely to experiment with and integrate new technologies into their coursework [20]. Thus, our data affirms the notion that photogrammetry must first be demystified and introduced at an accessible level before it can be effectively adopted.

Another critical factor emerging from our data is the availability of technical and human resources. Participants indicated a lack of equipment and insufficient support from instructors. Research by Ertmer and Ottenbreit-Leftwich [21] categorizes these limitations as "first-order barriers" (external to the individual) and "second-order barriers" (internal, such as pedagogical beliefs). These barriers were also discussed in a meta-analysis by Hew and Brush [22], where they identified access, institution-level support, and teacher training as the three most persistent obstacles to educational technology integration. Our findings support this framework and suggest that photogrammetry implementation efforts must address both technical infrastructure and professional development.

Interestingly, the weak correlation ($r \approx 0.14$) between students' confidence in their spatial thinking and motivation to use digital tools suggests that perceived ability alone does not guarantee engagement with new technologies. This insight echoes the argument by Kirschner and Van Merriënboer [18] who emphasized that confidence without strategy or context can lead to shallow learning experiences. In their framework of cognitive load theory, they recommend that new technologies should be accompanied by well-designed instructional scaffolding to help learners develop not only confidence but competence.

Comparative studies also offer a broader context. In their evaluation of virtual reconstruction technologies in heritage education, Lopez-Menchero Bendicho et al. [23] demonstrated that photogrammetry-based projects significantly boosted student engagement and interdisciplinary collaboration. However, they also stressed the necessity of pedagogical integration, stating that when photogrammetry is merely an add-on rather than part of the curriculum, its educational value diminishes. This observation resonates with our participants' call for embedding photogrammetry into coursework and organizing structured learning modules.

Moreover, mobile and user-friendly tools such as Polycam and 3D Scanner App were mentioned by our respondents as potentially more accessible alternatives to complex desktop platforms. This aligns with the work of Sugumaran and DeGroote [24] who showed that mobile-based spatial apps have lower entry barriers and are more likely to be adopted in informal and blended learning environments [24]. Incorporating such technologies could serve as a bridge for students hesitant to engage with more advanced photogrammetric software.

Finally, the international trend toward competency-based and digitally enriched education lends support to the study's practical recommendations. The OECD report on Future of Education and Skills 2030 highlights spatial thinking as a critical skill and advocates for integrating digital tools to nurture this competence [25]. Our findings complement this perspective by emphasizing the need to localize and contextualize global digital resources to meet the specific needs of teacher training programs.

The findings of this study demonstrate a substantial improvement in students' spatial thinking, familiarity with photogrammetry tools, frequency of digital tool usage, and motivation for creative projects following the implementation of a targeted training program. These results are consistent with previous research indicating that structured integration of digital tools in creative education can significantly enhance both cognitive and affective learning outcomes.

When compared to prior studies in similar contexts, our results underscore the unique contribution of photogrammetry as a pedagogical instrument in arts and design education. While previous literature has documented improvements in spatial visualization through CAD-based learning, photogrammetry offers additional benefits by integrating real-world object capture with digital model creation, thereby bridging the gap between tangible artistic processes and virtual representations. This duality was reflected in participant feedback, where students emphasized newfound confidence and creative perspectives.

Furthermore, subgroup analysis suggests that the training had slightly greater effects among university students in spatial thinking, whereas college students exhibited similar gains in tool familiarity. This could be explained by differences in curriculum structure, prior exposure to technology, or access to institutional resources. The gender-related differences in motivational growth also warrant further exploration, as they may reveal underlying variations in attitudes toward technology adoption in creative disciplines.

Overall, these findings reinforce the potential of photogrammetry as a catalyst for both technical and creative skill development in higher education, especially in programs aimed at fostering interdisciplinary competencies. Future research could investigate longitudinal impacts, the integration of photogrammetry with other emerging technologies (such as augmented reality), and strategies for scaling its implementation in resource-constrained educational settings.

6. Conclusions

This study has highlighted the critical role of digital photogrammetry in the development of sculptural-spatial thinking among students in creative teacher-training programs. The results of the questionnaire, supported by correlation analysis and comparative interpretation, revealed a clear gap between student motivation and the actual use of photogrammetric technologies in educational practice. Despite a high level of interest and recognition of the importance of spatial thinking, photogrammetry remains underutilized due to a lack of integration into curricula, insufficient technical infrastructure, and limited pedagogical support. However, strong correlations between photogrammetry knowledge and its practical application, as well as between tool usage and student motivation, demonstrate the untapped potential of these technologies when implemented methodically. The study suggests that to effectively foster spatial thinking, teacher education programs should incorporate structured training in digital tools such as photogrammetry. This includes accessible tutorials, short-term workshops, and the integration of these technologies into relevant subject modules. Furthermore, institutional support in the form of equipment, software, and educator training is essential for sustainable implementation.

In conclusion, digital photogrammetry offers a promising pathway to enhance visual and spatial competencies among future teachers. Its thoughtful inclusion in the learning process can bridge theoretical understanding with creative expression and technological fluency competencies that are essential for modern pedagogical practice.

7. Suggestion

The findings of this study confirm that the potential of digital photogrammetry in shaping sculptural-spatial thinking is recognized by students, yet its practical application in the educational process remains limited. The results demonstrated a strong correlation between knowledge of photogrammetry and its actual usage, as well as a notable link between motivation and digital tool engagement. However, technical limitations, insufficient pedagogical support, and the lack of integration into educational programs continue to hinder the effective adoption of these technologies. In light of this, several key suggestions can be drawn to improve the situation.

First, it is necessary to ensure the integration of photogrammetry into teacher training curricula. Currently, students become acquainted with the technology primarily through informal means such as internet sources and social media. To move beyond this fragmented exposure, photogrammetry should be introduced as a structured element of relevant courses, particularly in disciplines involving design, fine arts, and technology. Embedding photogrammetric activities into coursework and project-based learning will allow students to develop practical competencies alongside theoretical understanding.

Second, the study emphasizes the importance of supporting instructors with professional development opportunities. Many educators are not familiar with photogrammetric tools or lack confidence in applying them. Thus, short-term certification programs, peer-led training sessions, and access to teaching guides would enable faculty to integrate these technologies more effectively. Without such support, even highly motivated students may not receive the guidance needed to develop their spatial competencies using digital tools.

Another critical recommendation is improving access to equipment and software. Institutions should invest in affordable and intuitive photogrammetry solutions, including mobile apps such as Polycam or web-based tools that do not require high-performance hardware. This approach lowers the barrier to entry and democratizes access to digital modeling technologies.

Furthermore, the students' suggestions revealed a strong need for localized and user-friendly learning materials. Educational content in the native language, including video tutorials, written instructions, and demo projects, can facilitate deeper engagement and self-directed learning.

Finally, the promotion of interdisciplinary collaboration and student feedback loops is vital. Collaborative projects combining pedagogy, visual arts, and technology not only enrich learning experiences but also help develop relevant professional skills. Students should also be actively involved in shaping how photogrammetry is used in their programs, offering feedback that can guide iterative improvements in curriculum design.

Taken together, these recommendations provide a roadmap for educational institutions seeking to implement digital photogrammetry not as an isolated tool but as an integral component in developing the creative and spatial competencies of future educators.

References

[1] C. Marín-Buzón, A. Pérez-Romero, J. L. López-Castro, I. Ben Jerbania, and F. Manzano-Agugliaro, "Photogrammetry as a new scientific tool in archaeology: Worldwide research trends," *Sustainability,* vol. 13, no. 9, p. 5319, 2021. https://doi.org/10.3390/su13095319

[2] M. Mohamed, Z. E. Hussein, and L. K. Abbas, "Accuracy assessment of 3D model based on laser scan and photogrammetry data: Introduction," *Iraqi Journal of Science,* pp. 4195-4207, 2021. https://doi.org/10.24996/ijs.2021.62.11.37

[3] D. Chapinal-Heras *et al.*, "Photogrammetry and 3D modelling in university teaching. A case study applied to the history degree," *Journal of Classics Teaching,* vol. 24, no. 48, pp. 133-142, 2023. https://doi.org/10.1017/S2058631023000429

[4] G. Tucci, A. Conti, L. Fiorini, F. Panighini, and E. Parisi, "Education and training resources on digital photogrammetry," *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* vol. 42, pp. 45-50, 2018. https://doi.org/10.5194/isprs-archives-XLII-5-45-2018

[5] M. C. Fink, D. Sosa, V. Eisenlauer, and B. Ertl, "Authenticity and interest in virtual reality: Findings from an experiment including educational virtual environments created with 3D modeling and photogrammetry," *Frontiers in Education,* vol. 8, p. 969966, 2023. https://doi.org/10.3389/feduc.2023.969966

[6] 3D digital modelling in visual arts education, *3D digital modelling in visual arts education*. Umeå: Department of Aesthetics, Umeå University, 2024.

[7] I. G. Y. Partama, P. E. Yastika, and I. M. W. Wijaya, "3d modeling using uav-photogrammetry technique for digital documentation of cultural heritage buildings," *GEOMATE Journal,* vol. 28, no. 126, pp. 61-70, 2025. https://doi.org/10.21660/2025.126.4768

[8] Z. Shaghaghian, H. Burte, D. Song, and W. Yan, *Learning geometric transformations for parametric design: An augmented reality (AR)-powered approach in international conference on computer-aided architectural design futures*. Singapore: Springer Singapore, 2021.

[9] D. H. Uttal and C. A. Cohen, "Spatial thinking and STEM education: When, why, and how?," *Psychology of learning and motivation,* vol. 57, pp. 147-181, 2012. https://doi.org/10.1016/B978-0-12-394293-7.00004-2

[10] M. Marčiš and M. Fraštia, "The problems of the obelisk revisited: Photogrammetric measurement of the speed of quarrying granite using dolerite pounders," *Digital Applications in Archaeology and Cultural Heritage,* vol. 30, p. e00284, 2023. https://doi.org/10.1016/j.daach.2023.e00284

[11] S. Chatzistamatis *et al.*, "Photogrammetry in architectural education: Deploying aerial and terrestrial means," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* vol. 48, pp. 261-267, 2023. https://doi.org/10.5194/isprs-archives-XLVIII-1-W2-2023-261-2023

[12] M. Sırakaya and D. Alsancak Sırakaya, "Augmented reality in STEM education: A systematic review," *Interactive Learning Environments,* vol. 30, no. 8, pp. 1556-1569, 2022. https://doi.org/10.1080/10494820.2020.1722713

[13] D. Abrahamson and A. Bakker, "Making sense of movement in embodied design for mathematics learning," *Cognitive Research: Principles and Implications,* vol. 1, no. 1, p. 33, 2016. https://doi.org/10.1186/s41235-016-0034-3

[14] L. Freina and M. Ott, "A literature review on immersive virtual reality in education: State of the art and perspectives," *The International Scientific Conference Elearning and Software for Education,* vol. 1, no. 133, pp. 10-1007, 2015.

[15] C. Carbonell-Carrera and J. L. Saorin, "Virtual learning environments to enhance spatial orientation," *Eurasia Journal of Mathematics, Science and Technology,* vol. 14, no. 3, 2017. https://doi.org/10.12973/ejmste/79171

[16] H. Gardner, *Frames of the mind: The theory of multiple intelligences*. New York: BasicBooks, 1993.

[17] P.-N. Chou and R.-C. Shih, *3D digital design to support elementary school students' spatial visualization skills: Apreliminary analysis, in innovative technologies and learning*. Cham: Springer International Publishing, 2020.

[18] P. A. Kirschner and J. J. Van Merriënboer, "Do learners really know best? Urban legends in education," *Educational Psychologist,* vol. 48, no. 3, pp. 169-183, 2013. https://doi.org/10.1080/00461520.2013.804395

[19] N. Orion, D. Ben-Chaim, and Y. Kali, "Relationship between earth-science education and spatial visualization," *Journal of Geoscience Education,* vol. 45, no. 2, pp. 129-132, 1997. https://doi.org/10.5408/1089-9995-45.2.129

[20] N. Selwyn, *Education and technology: Key issues and debates*. New York Bloomsbury Academic, , 2022.

[21] P. A. Ertmer and A. T. Ottenbreit-Leftwich, "Teacher technology change: How knowledge, confidence, beliefs, and culture intersect," *Journal of Research on Technology in Education,* vol. 42, no. 3, pp. 255-284, 2010. https://doi.org/10.1080/15391523.2010.10782551

[22] K. F. Hew and T. Brush, "Integrating technology into K-12 teaching and learning: Current knowledge gaps and recommendations for future research," *Educational Technology Research and Development,* vol. 55, no. 3, pp. 223-252, 2007. https://doi.org/10.1007/s11423-006-9022-5

[23] V. M. Lopez-Menchero Bendicho *et al.*, "3D scanning of the stećci medieval grave cemeteries in Bosnia and herzegovina initial results," presented at the II Simposio de Patrimonio Cultural ICOMOS España, 2023.

[24] R. Sugumaran and J. DeGroote, *Spatial decision support systems: Principles and practices*. Boca Raton: CRC Press, 2011.

[25] OECD, *An OECD learning framework 2030 in the future of education and labor*. Cham: Springer International Publishing, 2019.