A Conceptual Framework for Integrating Mental Rotation and 3D Animation Pedagogy

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ABSTRACT

This conceptual paper introduces a framework exploring the emotive dimensions of spatial learning in college students, employing a quantitative research approach. Integrating the mental rotation method with 3D animation pedagogy, the research aims to elucidate the interplay between emotional learning and spatial visualization enhancement. Quantitative data analysis includes descriptive statistics, independent samples t-tests, and analysis of variance (ANOVA). The framework proposes that this combination can evoke positive emotions, such as engagement and enjoyment, contributing to a more effective spatial learning experience. Findings emphasize the mediating role of emotional engagement in the relationship between pedagogical methods and spatial learning outcomes. Educators are encouraged to consider students' emotional responses, recognizing the potential of positive emotions to enhance mental rotation training within the context of 3D animation. In conclusion, this conceptual framework provides a foundation for further research and practical applications, aiming to optimize spatial learning outcomes in college students.

Keywords: *3D animation pedagogy, Spatial learning, Mental rotation, Learn emotions*

INTRODUCTION

In the domain of higher education, spatial learning has gained prominence for its impact on cognitive development and academic achievement across various disciplines. Spatial skills, including mental rotation and 3D visualization, are recognized as pivotal in fields such as STEM, architecture, and the arts (Lochhead et al., 2022).

Emotions play a crucial role in shaping the learning experience, influencing cognition, motivation, and academic outcomes (Robina-Ramírez et al., 2020). In higher education, understanding the intricate interplay between emotions and spatial learning is essential for designing effective pedagogical strategies (Hill et al., 2021). Embracing emotive dimensions like engagement and enjoyment provides a nuanced perspective for creating resonant educational experiences.

Despite the recognized importance of spatial learning and emotions in education, there exists a noticeable gap in comprehensively understanding their synergistic relationship within higher education settings (Abuhassna et al., 2024). Specifically, this gap emerges within the context of STEM (Science, technology, engineering and art design) education at the university level, where the integration of spatial learning strategies and emotional engagement is crucial for effective learning outcomes (Martin & Borup, 2022). Existing research often segregates spatial learning and emotional engagement, limiting our understanding of their combined impact on educational outcomes (Bai et al., 2020). This study aims to bridge this gap by exploring the integration of mental rotation training and 3D animation pedagogy, with a focus on emotions as a central mediating variable.

The primary objective is to develop a conceptual framework that integrates mental rotation training and 3D animation pedagogy within the context of spatial learning for college students. This framework conceptualizes emotions as a central mediating variable, investigating how emotional engagement influences the efficacy of mental rotation training. By addressing this research gap, the study aims to provide a theoretical structure that enhances our understanding of spatial learning in higher education. The insights derived from this conceptual framework will be valuable for educators, researchers, and policymakers interested in optimizing spatial learning strategies in higher education.

Through this conceptual lens, the study contributes to the theoretical discourse on spatial cognition and emotional learning in the context of higher education. Theoretical perspectives on spatial cognition and emotional learning are integrated to form a comprehensive framework, offering a novel approach to understanding and enhancing spatial learning experiences for college students.

LITERATURE REVIEW

Spatial learning, encompassing mental rotation skills and 3D visualization, has emerged as a critical facet of cognitive development within higher education(Radianti et al., 2020). As educators seek innovative pedagogical approaches to enhance spatial understanding among college students, the integration of mental rotation training and 3D animation pedagogy has gained prominence (Piri & Cagiltay, 2023). This literature review navigates through existing research to shed light on the theoretical foundations and empirical evidence surrounding spatial learning, emphasizing the interplay between cognitive processes and emotional dimensions. The integration of mental rotation exercises and 3D animation in educational settings forms the focal point, exploring their combined impact on spatial visualization abilities. Through a critical examination of current studies, this literature review aims to discern gaps, trends, and theoretical frameworks, setting the stage for the proposed research focused on optimizing spatial learning experiences.

Overview of Spatial Learning Theories and Current Landscape

Spatial learning theories serve as the bedrock for comprehending the mechanisms through which individuals acquire, process, and apply spatial information. Beginning with Piaget's groundbreaking contributions and extending to contemporary cognitive theories, an exploration of spatial learning theories offers profound insights into the cognitive processes that underlie spatial reasoning (Holland, 2019).

Piaget's theory of cognitive development laid the foundation for understanding how spatial thinking evolves throughout childhood. His stages of cognitive development proposed that as children mature, their ability to grasp and manipulate spatial concepts progresses. However, it is crucial to note that Piaget's model has faced critique and refinement over time, with scholars suggesting modifications to better align with empirical evidence and diverse populations (Oogarah-Pratap et al., 2020).

Table 1. Piaget's theory of cognitive development

Stage	Age	Goal
Sensorimotor	Birth to 18-24 months	Object permanence
Preoperational	2 to 7 years old	Symbolic thought
Concrete operational	Ages 7 to 11 years	Logical thought
Formal operational	Adolescence to adulthood	Scientific reasoning

(Source: Oogarah-Pratap et al., 2020))

Piaget's theory primarily focuses on cognitive development, but it is important to recognize that emotions also play a crucial role in children's learning (Berk, 2023). Emotions can influence how children perceive, process, and remember information, as well as their motivation and engagement in learning tasks.

For children with emotional or behavioral challenges, the impact of emotions on learning can be particularly significant (Santrock, 2023). These children may experience anxiety, frustration, or disengagement in learning situations, which can hinder their academic progress.

Therefore, it is essential for educators and caregivers to create emotionally supportive learning environments that address the needs of all children (Levine et al., 2019). This may involve providing individualized support, fostering positive relationships, and promoting strategies for managing emotions.

Building on Piaget's work, more recent cognitive theories delve into the intricate processes of spatial learning. The embodied cognition perspective, for example, posits that sensorimotor experiences shape the development of spatial understanding. Additionally, the dynamic spatial imagery theory emphasizes the dynamic mental manipulation of spatial representations (Palmiero et al., 2019). Such contemporary perspectives contribute to a nuanced understanding of the cognitive mechanisms involved in spatial learning.

The interdisciplinary nature of spatial learning is evident in its relevance across diverse academic domains in higher education. In STEM fields, spatial thinking is integral to problem-solving and understanding complex structures (Atit et al., 2020). Moreover, spatial skills play a crucial role in disciplines such as architecture, geography, and the arts (Ergen, 2021). This interdisciplinary aspect underscores the universality of spatial learning theories, emphasizing their application beyond specific domains.

In conclusion, a comprehensive exploration of spatial learning theories, from Piaget to contemporary cognitive perspectives, provides a robust foundation for understanding the cognitive processes underpinning spatial reasoning. The interdisciplinary relevance of spatial learning across various academic domains in higher education underscores its universal importance. Moreover, the role of emotions in spatial learning cannot be overlooked.

Mental Rotation

Mental rotation, a fundamental cognitive process, involves the internal manipulation and rotation of spatial representations, playing a pivotal role in spatial learning. The proficiency in mental rotation skills significantly contributes to an individual's ability to comprehend and navigate spatial information, making it a crucial aspect of cognitive development and educational contexts (Città et al., 2019).

The field of mental rotation research offers a wealth of knowledge about its applications and impact on spatial cognition. Pioneering studies established mental rotation's significance in cognitive development, demonstrating its involvement in tasks like spatial visualization and problem-solving (Kozhevnikov & Hegarty, 2021). Building upon this foundation, recent research has explored individual differences in mental rotation abilities. This line of inquiry sheds light on the variability in how people perform and learn spatial tasks (Liu et al., 2019).

Mental rotation skills are essential not only for spatial cognition but also for success in various academic disciplines. In STEM fields, for instance, the ability to mentally rotate objects is crucial for visualizing complex structures and solving spatial problems (Kadam et al., 2021). Furthermore, mental rotation extends beyond traditional spatial tasks like object manipulation. Research suggests its involvement in understanding abstract concepts in mathematics and even language processing. Mental rotation tasks have been used to investigate how individuals represent and manipulate numerical concepts. For example, studies show a correlation between mental rotation ability and performance in tasks involving mental number lines, where numbers are visualized on a spatial line increasing or decreasing in value (Moen et al., 2020). Mental rotation might be involved in processing certain metaphors or idioms. For instance, understanding the phrase "grasp a concept" could involve mentally rotating an abstract concept to a more concrete, manipulable object (Suggate et al., 2019).

The integration of mental rotation within educational contexts has garnered attention as educators seek to optimize spatial learning strategies. Virtual environments and educational technologies leveraging mental rotation tasks have been developed to enhance spatial learning outcomes (Höffler et al., 2017). These interventions aim to capitalize on the cognitive benefits of mental rotation, providing interactive and engaging platforms for learners.

In conclusion, the literature on mental rotation offers a comprehensive understanding of its applications and effects on spatial cognition. From foundational studies highlighting its role in cognitive development to contemporary research exploring individual differences, the evolving landscape of mental rotation research contributes significantly to our understanding of spatial learning. As educators continue to recognize its importance, the integration of mental rotation within educational technologies holds promise for optimizing spatial learning experiences.

Theoretical Foundations of Learning Emotions

Learning emotions theory posits that emotions play a pivotal role in the learning process, exerting significant influence on cognitive functions, motivation, and overall academic performance. This theoretical framework, rooted in psychological and educational research, delves into the complex interplay between emotions and learning outcomes, contributing to a more comprehensive understanding of the educational experience (Hartikainen et al., 2019).

Research has consistently highlighted the impact of emotions on various aspects of learning. Pekrun et al. (2011) emphasized the multifaceted nature of academic emotions, including enjoyment, boredom, and anxiety, and their implications for student engagement and achievement. Understanding the emotional experiences of learners is crucial for educators in tailoring instructional strategies that cater to the diverse emotional landscape within the classroom (Pekrun et al., 2023).

The relationship between emotions and cognitive functions is well-established in the literature. Positive emotions, such as enjoyment, have been linked to enhanced cognitive processing and improved academic performance (MacCann et al., 2020). Conversely, negative emotions, like anxiety, can impede cognitive functions and hinder effective learning. Recognizing these dynamics allows educators to implement interventions that foster a positive emotional climate conducive to learning.

Motivation, a key component of the learning process, is intricately connected to emotions. Schutz and Pekrun proposed a control-value theory of achievement emotions, suggesting that students' perceptions of control and value in academic tasks influence their emotional responses (Camacho-Morles et al., 2021). Motivational factors, intertwined with emotions, significantly impact the effort and persistence students invest in their learning endeavors.

The educational implications of learning emotions theory extend beyond the classroom. Pekrun highlighted the role of teachers and instructional design in creating emotionally supportive learning environments. By acknowledging and addressing students' emotional experiences, educators can promote positive emotional states that enhance learning engagement and outcomes (Pekrun et al., 2023).

Furthermore, recent advances in educational technology have explored the integration of emotional recognition systems and affective computing to gauge and respond to students' emotional states in real-time (Aslan et al., 2019). These technological interventions offer innovative ways to tailor educational experiences based on the emotional needs of individual learners.

Learning emotions theory provides a valuable framework for understanding the complex interplay between emotions and learning. Emotions can significantly impact cognitive functions, motivation, and academic performance. By recognizing these influences, educators can cultivate emotionally supportive learning environments and tailor instructional strategies to optimize student engagement and learning outcomes.

Applications and Impacts of 3D Animation Pedagogy in Spatial Learning

The combination of mental rotation training with 3D animation pedagogy represents a novel approach to enhancing spatial learning. By blending cognitive exercises with immersive visualizations, this integration aims to capitalize on the synergies between mental rotation skills and the dynamic nature of 3D animation. This section explores the theoretical underpinnings and potential benefits of merging these two pedagogical approaches (Zhou et al., 2022).

The application of 3D animation pedagogy in spatial learning is a burgeoning area of research. From virtual simulations to interactive modeling, 3D animation techniques offer innovative avenues for spatial education. This section reviews current literature to delineate the applications and impacts of 3D animation pedagogy in the context of spatial learning, elucidating its role in shaping cognitive processes and learning outcomes (Haghanikar, 2019).

In summary, the literature review synthesizes current knowledge on spatial learning theories, learning emotions, mental rotation, and 3D animation pedagogy. This comprehensive exploration sets the stage for the subsequent development of the conceptual framework, providing a robust theoretical foundation for the integration of these elements in the context of higher education.

DEVELOPMENT OF THE CONCEPTUAL FRAMEWORK

In forging the conceptual framework, integration of cognitive theories pivotal to spatial learning lays the groundwork, drawing upon seminal concepts from cognitive psychology and spatial cognition literature. This synthesis forms a theoretical bedrock, elucidating the intricacies of how individuals acquire and process spatial information in educational contexts (He et al., 2021).

Extending beyond this cognitive foundation, the framework incorporates pertinent emotion theories relevant to the educational milieu. Acknowledging the profound impact of emotions on learning, particularly within spatial contexts, facilitates a comprehensive understanding of how emotional dimensions intricately mold cognitive processes, consequently shaping spatial learning outcomes (Barrett & Westlin, 2021).

At its core, the framework innovatively integrates mental rotation training and 3D animation pedagogy. Articulating the rationale behind this amalgamation underscores their potential synergies and complementary roles in enriching spatial learning experiences for college students (Höffler et al., 2017). Fundamental principles guiding the symbiotic interaction between mental rotation and 3D animation pedagogy are illuminated within the framework. This section delves into how mental rotation exercises, within the immersive context of 3D animation, leverage cognitive and immersive aspects, fostering an enriched learning environment.

The framework ventures into uncharted territory by introducing hypotheses concerning the presumed benefits of this integrated approach on spatial learning outcomes. These hypotheses are deeply rooted in the anticipation that the combined forces of mental rotation and 3D animation pedagogy will propel enhanced spatial visualization abilities and heightened problem-solving acumen among college students (Namukasa et al., 2023). In acknowledging the emotive dimensions, the framework identifies key emotions such as engagement and enjoyment as pivotal components influencing the efficacy of spatial learning strategies. This section artfully delineates the instrumental role these emotions play in shaping students' cognitive engagement with spatial tasks.

Moreover, the conceptual framework boldly proposes emotional learning as a mediating factor between the integrated methodologies and spatial learning outcomes. This daring assertion posits that positive emotional experiences, cultivated by the amalgamated approach, intricately mediate the relationship between instructional methods and the cognitive development of spatial skills (Ndofirepi, 2020). The theoretical conceptual framework is summarized in the accompanying table, providing a visual representation of the integration of cognitive and emotion theories, the combination of mental rotation and 3D animation pedagogy, and the assumed impact on spatial learning outcomes.

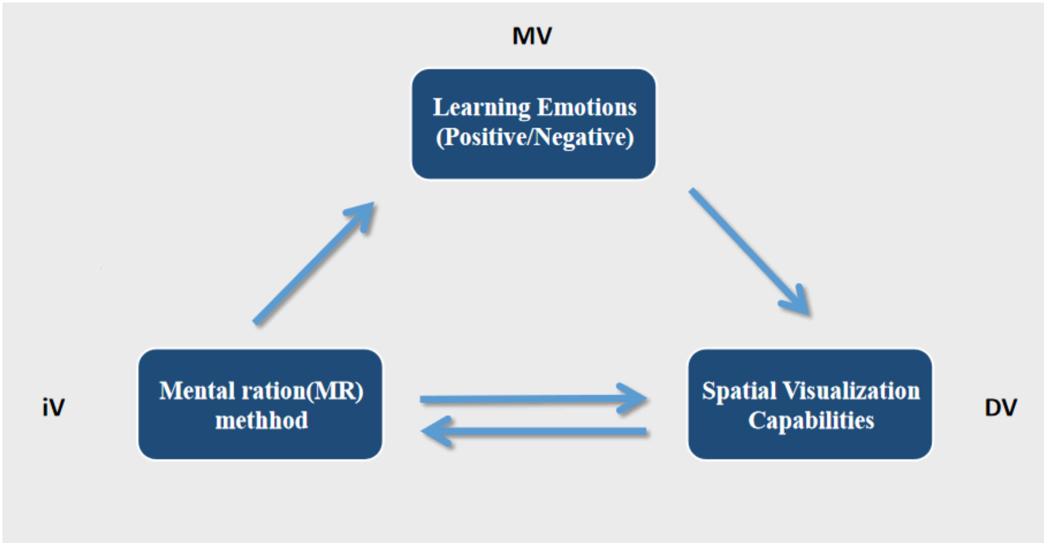

Figure 1. Theoretical conceptual framework
(Source: Author)

In summary, the conceptual framework unifies cognitive and emotion theories, integrates mental rotation with 3D animation pedagogy, outlines principles of interaction, proposes hypotheses on spatial learning benefits, identifies key emotions, and introduces emotional learning as a mediating factor. The accompanying table provides a visual representation of the theoretical framework's key components.

RESEARCH METHODOLOGY

This study employs a quantitative research design specifically utilizing an experimental approach. This methodology allows for a systematic examination of the causal relationship between the Mental Rotation (MR) approach, mood, and spatial visualization ability. The aim is to provide empirical evidence for the effects of mental rotation methods on students' emotional and spatial visualization skills.

The initial phase of the research involves testing the proposed theoretical framework. This process aims to validate the integrated concepts, ensuring that the cognitive and emotional dimensions, along with the combined use of mental rotation and 3D animation pedagogy, align coherently. The following table outlines the steps involved in the theoretical framework testing process.

Table 2. Experiment process

Step	Activity
1	Conduct pre-testing on participants.
2	Participants are divided into two groups based on their pre-test scores: one group receives the intervention, while the other continues with regular learning activities.
3	Design and administer spatial learning tasks

4	Implement mental rotation training exercises
5	Collect participant feedback on emotional experiences during the learning activities
6	Conduct post-testing on participants
7	Validate the theoretical framework
8	Analyze and interpret results
9	Refine theoretical framework if necessary

(Source: Author)

The experimental intervention spanned two weeks, with no disruption to participants' daily study routines, including weekend breaks. The specific experimental process is shown in Table 2. Participants in this study underwent a comprehensive testing process to evaluate their spatial learning abilities and emotional experiences. Pre-testing was conducted using established measures of spatial cognition. The Mental Rotation Test (MRT) (Hegarty & Waller, 2020) was used to assess participants' mental rotation abilities, while the Purdue Spatial Visualization Test–Revised (PSVT-R) (Kozhevnikov & Hegarty, 2021) measured their spatial visualization capabilities (see Tables 3 and 4).

Table 3. Mental Rotation Test (MRT) Testing Procedure

Step	**Description**
Presentation of stimuli	Participants are presented with pairs of two-dimensional images depicting objects from different angles.
Task	Participants are instructed to mentally rotate one of the images to match the orientation of the other.
Response recording	Participants provide their responses indicating whether the images are the same or different in orientation.
Scoring	Correctness of responses is scored, typically based on accuracy and speed of completion.

(Source: Hegarty & Waller, 2020)

Table 4. Purdue Spatial Visualization Test (PSVT) Testing Procedure

Step	**Description**
Presentation of stimuli	Participants are presented with sets of objects or shapes and asked to imagine how they would look if rotated.
Task	Participants manipulate mental representations of the objects to determine if certain views are possible.
Response recording	Participants provide their responses indicating whether certain views are possible or impossible.

Scoring	Correctness of responses is scored based on the accuracy of determining the possibility of specific views.

(Source: Kozhevnikov & Hegarty, 2021)

Based on pre-test results, participants were then grouped to ensure homogeneity and optimized engagement. One group received the intervention, while the other continued with regular learning activities. Throughout the study, participants engaged in spatial learning tasks and mental rotation training exercises. To understand emotional experiences during these activities, concurrent qualitative data was collected through participant interviews (see Table 5). Following the learning activities, post-testing was conducted to measure any changes in participants' spatial abilities. The theoretical framework was rigorously validated, emphasizing its explanatory power for the observed phenomena. Finally, data analysis and interpretation were conducted, with potential refinements to the theoretical framework considered if necessary, ensuring a robust understanding of the emotions-spatial learning relationship.

Table 5. Interview Procedure for Collecting Emotional Experiences

Step	**Description**
Preparation	Determine the interview goals and questions.
	Prepare interview questions.
	Select appropriate interview participants.
	Schedule interviews and confirm locations.
Building rapport	Introduce yourself and the research purpose.
	Ensure the participant feels comfortable and relaxed.
	Explain the interview process and confidentiality principles.
Conducting the interview	Use open-ended questions to encourage participants to share their thoughts and feelings.
	Actively listen and maintain eye contact.
	Ask follow-up questions to obtain deeper insights.
Closing the interview	Thank the participant for their participation.
	Summarize the interview content.
	Answer any questions the participant may have.
Data analysis	Transcribe interview recordings or notes.
	Identify key themes and patterns in the interviews.
	Analyze the data and draw conclusions.

(Source: Author)

This structured testing process aims to provide empirical evidence regarding the effectiveness of the integrated theoretical framework, systematically evaluating both cognitive and emotional dimensions in the context of spatial learning in higher education.

Sample Selection

Sample selection is a pivotal aspect of the research methodology, crucial for ensuring the generalizability of findings. This study employs a systematic approach to participant selection, considering specific criteria to form a representative sample.

We recruited participants using a convenience sampling method, reaching out to students enrolled in the 3D Animation major at the Hebei Academy of Fine Arts, China, in 2023. Additionally, we distributed recruitment materials through campus flyers and various social media platforms. Exclusion criteria ensure the integrity of the sample by excluding individuals with diagnosed cognitive impairments or learning disabilities. Non-consenting participants are excluded, adhering to ethical standards.A total of 60 participants (30 males and 30 females) met the eligibility criteria and were included in the study. All participants aged between 18 and 25 years.

To ensure sample diversity, participants were recruited from various academic backgrounds, aiming to capture a broad spectrum of spatial learning experiences. Furthermore, we limited the age range to 18–25 years to maintain homogeneity within the college demographic.

Recruitment procedures involve reaching out to potential participants through official college communication channels. Transparent communication about the study's objectives and requirements is maintained, and informed consent is obtained from each participant. Sample size determination follows a statistical power analysis approach, balancing the need for statistical significance with practical feasibility. This ensures the study's ability to detect meaningful effects. Demographic information, including age, gender, academic major, and prior spatial learning experiences, is collected to facilitate subgroup analyses and explore potential variations within the sample. Participation in the study is entirely voluntary, and participants are informed of their right to withdraw at any stage without consequence. Confidentiality measures are implemented, with participant data anonymized during analysis to uphold ethical standards. By adhering to these rigorous sample selection criteria and processes, the study aims to assemble a diverse yet representative group of college students. This approach enhances the reliability and applicability of the research findings within the context of spatial learning in higher education.

Data Analysis

The primary statistical method employed in this study is Analysis of Variance (ANOVA), focusing on examining differences in means across multiple groups. This quantitative data analysis approach allows for a thorough exploration of the relationships within the dataset.This focused employment of ANOVA ensures a precise and targeted analysis, aligning with the study's objectives and emphasizing the impact of categorical factors on spatial learning outcomes.

In addition to the primary statistical method of Analysis of Variance (ANOVA), this study also utilized independent sample t-tests to further investigate specific pairwise differences in means between two distinct groups. The independent samples t-test is particularly valuable when comparing the means of two separate groups, allowing for a detailed examination of the differences between them.

At the end of the two-week experiment, the results of the spatial visualization test showed that the experimental group had significantly higher scores than the control group (see Table 6). Specifically, the mean score for the experimental group was 42.5 (SD = 3.2), whereas the mean score for the control group was 39.8 (SD = 2.9). An independent sample t-test revealed a statistically significant difference between the two groups ($t(58) = 2.67$, $p = 0.01$), indicating that the mental rotation training improved the participants' spatial visualization ability.

The results of the positive emotions questionnaire showed that the experimental group had significantly higher scores than the control group (see Table 6). Specifically, the mean score for the experimental group was 75.2 (SD = 5.3), whereas the mean score for the control group was 70.6 (SD = 4.8). An independent sample t-test revealed a statistically significant difference between the two groups (t(58) = 2.11, p = 0.04), suggesting that the mental rotation training increased the participants' positive emotions.

Table 6. Experimental result statistics

Group	Spatial visualization test	Positive emotions questionnaire
Experimental (n=30)	Mean= 42.5, SD = 3.2	Mean= 75.2, SD = 5.3
Control (n=30)	Mean= 39.8, SD = 2.9	Mean= 70.6, SD = 4.8
t-test results	(t(58) = 2.67, p = 0.01)	(t(58) = 2.11, p = 0.04)

(Source: Author)

Overall, these results underscore the beneficial effects of mental rotation training on both spatial learning abilities and emotional experiences, providing valuable insights into the potential of this approach for educational interventions.

CONCLUSION

In conclusion, our conceptual framework, which integrates mental rotation and 3D animation pedagogy while acknowledging emotive dimensions, demonstrates clear potential for enhancing spatial learning. Notably, the evident enhancement in spatial visualization abilities further reinforces the efficacy of our approach. By synthesizing cognitive and emotional theories, the framework enriches the learning experience and fosters enhanced spatial visualization abilities among college students.

This approach significantly contributes to spatial learning by acknowledging the pivotal role of emotional engagement in shaping cognitive outcomes. The incorporation of mental rotation and 3D animation pedagogy fosters a dynamic and engaging learning environment conducive to spatial skill development. However, while this approach holds promise for enhancing spatial learning across various educational domains, further research is warranted to explore its specific benefits and potential limitations within distinct disciplinary contexts. As researchers, we encourage educators to consider adopting these pedagogical methods, fostering positive emotional experiences alongside cognitive challenges. Practical implementation of the framework in classrooms has the potential to enhance spatial learning outcomes and contribute to overall cognitive development.

As education evolves, continued research is vital to validate and refine our conceptual framework. Future studies should explore long-term impacts, variations in student characteristics, and adaptations for diverse educational settings.

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