Original Article

# Exploring the Influence of Anatomical Clay Modeling on Metacognitive Learning Among Emergency Medical Sciences Students: A Qualitative Study

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## Abstract

**Background:** Anatomy education requires students to develop accurate three-dimensional mental representations of complex anatomical structures. However, many learners experience difficulties in visualizing spatial relationships and evaluating the depth of their own understanding. Metacognitive skills, including awareness and regulation of learning processes, are essential for effective and lifelong learning. This study aimed to explore students' experiences of anatomical clay modeling and its perceived contribution to active and metacognitive learning among Emergency Medical Sciences students.

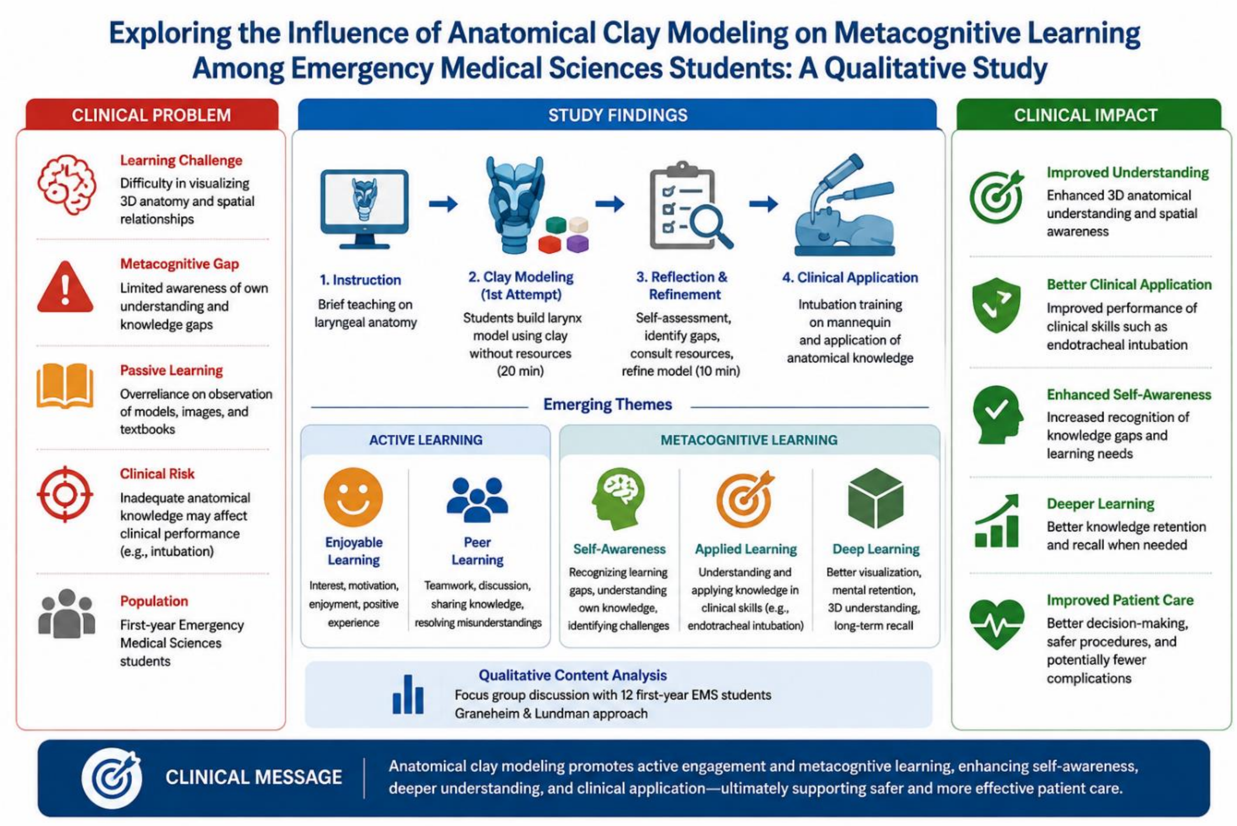
**Methods:** This qualitative study was conducted among 12 first-year Emergency Medical Sciences students at Bushehr University of Medical Sciences. Participants engaged in an anatomy-based educational intervention using colored modeling clay to construct a three-dimensional model of the larynx. Data were collected through a semi-structured focus group discussion and analyzed using qualitative content analysis based on the Graneheim and Lundman approach.

**Results:** Qualitative analysis of the interview data revealed two overarching themes: Active Learning and Metacognitive Learning. These themes included five categories: enjoyable learning, peer learning, self-awareness, applied learning, and deep learning. Participants reported that the modeling activity promoted engagement, facilitated peer interaction, increased awareness of knowledge gaps, supported clinical application of anatomical knowledge, and enhanced three-dimensional understanding and knowledge retention.

**Conclusion:** Anatomical clay modeling represents a learner-centered educational approach that supports active engagement and metacognitive learning in anatomy education. By encouraging students to construct, evaluate, and refine their anatomical representations, this approach may enhance self-awareness, deeper understanding, and long-term retention of knowledge.

**Implications for Patient Care:** Integrating anatomy-based modeling and metacognitive learning strategies into healthcare education may strengthen learners' clinical competency by improving three-dimensional anatomical understanding, self-awareness, and the ability to apply knowledge during clinical procedures. Such educational approaches may contribute to preparing future healthcare professionals for safer and more effective clinical practice.

**Keywords:** Anatomy; Metacognition; Qualitative Research; Content Analysis; Active Learning




**Graphical Abstract. The graphical abstract summarizes the impact of anatomical clay modeling on active and metacognitive learning among Emergency Medical Sciences students.** The educational intervention transformed anatomy learning from passive observation into an active, reflective, and clinically oriented process. Three-dimensional clay modeling enabled students to reconstruct anatomical structures, recognize knowledge gaps, refine mental models, and enhance peer learning, self-awareness, and knowledge retention. Integration with endotracheal intubation training supported the translation of anatomical understanding into clinical skill application. Overall, anatomical modeling may strengthen clinical competency, decision-making, and patient safety by improving three-dimensional anatomical understanding and metacognitive regulation.

## Introduction

Students preparing for health-related professions are required, during their first year of university study, to study and complete a course in human anatomy as part of their educational curriculum. This course serves as a prerequisite for a substantial portion of their subsequent specialized training (1). Human anatomy appears to be one of the most challenging subjects during students' first year of study. Despite dedicating a considerable amount of study time to this course, many students fail to achieve satisfactory learning outcomes. Despite course completion, a significant proportion of students fail to grasp the three-dimensional complexity of human anatomy, often leading to suboptimal academic outcomes or course failure (2).

It is a fact that students in the early years of their university studies possess different levels of metacognitive abilities and awareness. Metacognition is known to play an important role in academic success. However, students often struggle to identify effective study strategies or to determine whether they have truly mastered the material (3). Therefore, an approach that encourages learners to develop these skills during class, without requiring additional study time, would be highly valuable. During practical anatomy sessions, students often engage in passive learning by observing anatomical models, cadaveric specimens, and numerous images. Many students develop a false sense of confidence, believing that they have genuinely learned the material (4). In other words, many students are unaware of the depth of their own learning and do not realize that they have only inadequately understood the material they have observed and have not comprehended it in depth. Students' inaccurate perceptions of their own academic performance, particularly the tendency to overestimate achievement despite poor examination outcomes, further support this argument. Such patterns may reflect inadequate metacognitive awareness and limited ability to accurately monitor and evaluate one's own knowledge and learning progress (5). Although active learning strategies, including anatomical drawing, three-dimensional modeling, and hands-on activities, have been increasingly incorporated into anatomy education, previous studies have primarily focused on their effects on knowledge acquisition, spatial understanding, and student satisfaction. Less attention has been given to how these approaches influence students' awareness of their own learning processes, recognition of knowledge gaps, and development of metacognitive skills. In particular, limited qualitative evidence exists regarding students' lived experiences of anatomical modeling as a tool for promoting metacognitive learning among Emergency Medical Sciences students. If students can be supported in their learning through metacognitive activities, it is hoped that the occurrence of failure, frustration, and the tendency to withdraw from university during the first year can be reduced. In the present study, an anatomical clay modeling activity was implemented to explore whether this approach could enhance students' awareness of their learning processes, deepen their anatomical understanding, and promote active engagement during practical anatomy education. Through this approach, which combined metacognition with active learning, students worked in groups within an interactive learning environment to construct a model of the larynx using modeling clay.

**Materials and Methods**

This qualitative study was conducted among first-year Emergency Medical Sciences students at Bushehr University of Medical Sciences. Participants were recruited using purposive sampling. The inclusion criteria were willingness to participate and provision of informed consent. Recruitment continued until data saturation was achieved, defined as the point at which no new concepts or categories emerged from subsequent interviews. Ethical approval for this study was obtained from the Ethics Committee of Bushehr University of Medical Sciences (Ethics approval code: IR.BPUMS.REC.1401.132).

All participants were informed about the study objectives and procedures, and written informed consent was obtained before participation. The sample size was determined based on data saturation, which was achieved when no new concepts or categories emerged from subsequent interviews. Upon arrival at the university Skills Lab, students were informed about the study objectives, procedures, and confidentiality of the collected data. They were provided with sufficient time to consider participation, and written informed consent was obtained from those who agreed to participate. Following enrollment, participants were randomly assigned to one of three working groups (A, B, or C) to facilitate collaborative anatomical clay modeling activities.

To provide all participants with a comparable baseline understanding before the modeling activity, a brief instructional session on the anatomy of the respiratory system, with particular emphasis on the laryngeal structures, was provided using selected images from standard anatomy atlases presented in PowerPoint format. Following the instructional session, each group received a sufficient amount of colored modeling clay (Aria 12-color modeling clay, Model 1058, Iran). The students were asked to work together, through discussion and cooperation with their group members, for 20 minutes to construct a model of the larynx using the modeling clay, based on the relative positions of the laryngeal cartilages, the connective tissues between them, and the locations of the true and false vocal folds. During this phase, students were intentionally asked to construct the model without access to external learning resources, including textbooks, images, handouts, mobile phones, or other references. This approach was designed to encourage retrieval of their existing mental representations, reveal potential gaps in their anatomical understanding, and promote reflection on their own learning process. Throughout the activity, anatomy instructors observed each group and documented students' collaboration, problem-solving processes, and challenges encountered during model construction, without providing corrective feedback or direct instructional guidance.

After the initial modeling period, students were asked to pause the activity and reflect on the completeness and accuracy of their constructed models. Each group was encouraged to evaluate their own understanding, identify areas of uncertainty, and determine whether additional resources were required to improve the model. At this stage, anatomy faculty members visited each group, evaluated the anatomical components of the constructed models, and documented their observations without providing corrective feedback. If students identified deficiencies in their visual or conceptual understanding of the laryngeal structures, they were allowed to consult reference materials of their choice for 10 minutes. Subsequently, students returned to their groups and refined their models based on the information they had obtained. During this refinement phase, anatomy faculty members continued to observe the students' activities without providing direct instruction or guidance. At the end of the second modeling attempt, the supervising faculty member evaluated the anatomical accuracy of the completed models and discussed the model components and students' reasoning with the group members.

Following a short break, students participated in a practical skills session designed to explore the application of their anatomical understanding in a clinical context. The session focused on endotracheal intubation, a procedure that requires accurate knowledge of laryngeal anatomy. During this session, an Emergency Medical Sciences instructor provided a brief introduction to endotracheal intubation and the required equipment using PowerPoint-based instructional materials. The instructor subsequently demonstrated the procedure on a mannequin, emphasizing the anatomical considerations relevant to successful intubation. Subsequently, each student performed endotracheal intubation once on a mannequin under instructor supervision, allowing them to apply their anatomical knowledge during a simulated clinical procedure. At the end of the session, the participants' views regarding their experience of the modeling activity were obtained. Data were collected using the focus group discussion (FGD) method (6). All participants provided consent for audio recording of the focus group sessions. Data were collected through semi-structured group discussions guided by an interview framework consisting of broad, exploratory questions (7), such as: "What was your experience of the implemented program and the modeling activity?" and "Do you think that modeling can contribute to a deeper understanding of anatomical concepts? Please explain your opinion." Probing questions were used to clarify participants' responses, summarize the discussion, and obtain feedback to ensure that the researchers had accurately understood the participants' perspectives. The interview continued until no new information was added by the participants. The focus group discussion lasted approximately 60 minutes.

**Data analysis**

In this study, qualitative content analysis was performed using the Graneheim and Lundman approach (8,9). In the first stage, immediately after each interview, the interview was transcribed verbatim, and the written transcript was compared with the audio recording to ensure its accuracy. In the second stage, the text was divided into meaning units, which were then condensed. In the third stage, the condensed meaning units were abstracted, and initial codes were generated. The coding process was conducted iteratively, and the research team discussed the extracted codes, categories, and themes until consensus was reached. In the fourth stage, similar initial codes were merged into broader categories. Every effort was made to achieve maximum homogeneity within the categories and maximum heterogeneity between the categories, ensuring that no data were assigned to more than one category. In the subsequent stage, the main theme of the categories was identified (8,9).

To ensure the trustworthiness of the findings, the criteria of credibility, dependability, confirmability, and transferability were considered throughout the research process. To enhance credibility, the extracted codes, categories, and themes were reviewed and discussed by the research team, including supervisors and faculty members experienced in qualitative research, until consensus was reached regarding the interpretation of participants' experiences. To ensure dependability, all stages of the research process, including data collection procedures, coding decisions, and theme development, were documented. Confirmability was addressed by maintaining an audit trail of analytical decisions and by ensuring that the findings were grounded in the participants' statements rather than the researchers' assumptions. Transferability was supported by providing detailed descriptions of the study context, participants, and educational intervention to allow readers to assess the applicability of the findings to other educational

**Results**

The participants included 12 first-year Emergency Medical Sciences students aged 19–25 years (mean age: 21 ± 1 years) who participated in the focus group discussion. During the initial phase of analysis, meaning units related to the research question were identified, condensed, and transformed into initial codes. Approximately 100 initial codes were generated during this process. During the subsequent stages, similar and overlapping codes were compared, merged, and organized into subcategories and categories. Throughout the process of theme development, the researchers discussed the emerging interpretations with other members of the research team, including supervisors and the academic advisor, and consensus was reached regarding the final themes. Following content analysis of the interview data and the coding process, a total of five categories and six subcategories were identified. The categories derived from the content analysis were enjoyable learning, peer learning, self-awareness, applied learning, and deep learning. These categories were further grouped into two overarching themes: active learning and self-aware learning. Table 1 presents the themes, categories, subcategories, and the extracted codes.

One of the themes that emerged from the students' experiences was the effect of the modeling process on their active learning. This theme encompasses the categories of "enjoyable learning" and "peer learning." According to the students, the modeling experience was accompanied by a willingness to learn.

| Theme | Category | Subcategory | Initial Codes |
|---|---|---|---|
| **Active Learning** | Enjoyable learning | Interest in learning | Satisfaction with learning; positive experience; enjoyment; excitement about learning; enthusiasm; willingness to learn; motivation |
| | Peer learning | Understanding the importance of teamwork | The impact of teamwork on learning; the role of teamwork in resolving ambiguities and individual misconceptions; overcoming weaknesses and challenges |
| **Metacognitive Learning** | Self-awareness | Understanding one's own level of learning | Demonstration of learning gaps; awareness of one's own knowledge; identification of weaknesses in one's knowledge; recognition of learning challenges |
| | Applied learning | Understanding the application of knowledge | Conscious performance of a professional skill; understanding each step of performing a professional skill (intubation); application of knowledge; the effect of knowledge on performing a professional skill; confidence in performing the skill; facilitating the acquisition of a professional skill; flawless performance of a professional skill |
| | Deep learning | Understanding the content through mental visualization | Better visualization of anatomical structures; better identification of anatomical landmarks; improved understanding of the subject; engagement of multiple senses; three-dimensional learning |
| | | Mental retention | Retention of the material in the mind; recall and retrieval of knowledge when needed |

**Table 1. Themes, categories, and subcategories of Emergency Medical Services students' experiences with the modeling activity.**

They described this experience using concepts such as satisfaction with learning, a positive experience, enjoyment, excitement about learning, enthusiasm, willingness to learn, feeling energetic, and the absence of fatigue. The findings of this study indicate that, during the group modeling process, students considered interaction with their peers within the group to be effective in facilitating learning. According to the participants, teamwork and benefiting from the knowledge and skills of their peers within each group contributed to resolving ambiguities and individual misconceptions, as well as overcoming deficiencies and challenges encountered while constructing the requested model.

**Self-aware Learning**

Analysis of the students' experiences indicated that the modeling process facilitated metacognitive learning by encouraging students to reflect on their understanding, recognize knowledge gaps, and evaluate their learning process. The modeling process prompted them to reflect on their own level of understanding and awareness. This theme encompasses the categories of "self-awareness," "applied learning," and "deep learning." Analysis of the participants' experiences showed that the modeling activity enabled students to gain an accurate understanding of their own level of knowledge and awareness. According to the participants, the modeling activity provided an opportunity to reveal learning gaps, become aware of their own knowledge, identify weaknesses in their knowledge, and recognize their learning challenges. The analysis of the participants' experiences also indicated that they believed the modeling activity enabled them to learn the content in an applied manner. The modeling activity provided them with the opportunity to perform professional skills consciously and to understand the rationale behind each step of performing the professional skill (endotracheal intubation). This approach helped them acquire their professional skills more effectively and more rapidly. Furthermore, analysis of the participants' experiences indicated that they believed the modeling activity facilitated learning through mental visualization. The modeling activity promoted better visualization of anatomical structures, better identification of anatomical landmarks, and a better understanding of the subject matter. In this approach, because multiple senses are engaged, multidimensional learning is achieved. According to the students, the modeling activity facilitates the retention of knowledge, as well as the recall and retrieval of information when needed; in other words, it promotes deep learning.

**Discussion**

The findings of this study suggest that anatomical modeling using clay provided a learner-centered educational experience that supported both active engagement and metacognitive development among Emergency Medical Sciences students. The modeling activity appeared to transform anatomy learning from a predominantly observational process into an interactive experience in which students actively constructed, evaluated, and refined their understanding. The emergence of active learning as one of the overarching themes highlights the importance of learner involvement, emotional engagement, and collaborative participation in facilitating meaningful learning experiences. In addition to individual engagement, peer interaction represented an important dimension of the modeling process. Collaborative construction of anatomical models required students to explain their reasoning, compare their internal representations of anatomical structures, discuss differences in understanding, and collectively resolve uncertainties. These social interactions may enhance cognitive processing by encouraging students to externalize their thoughts and critically evaluate their own understanding. Therefore, the group-based nature of the modeling activity may have contributed not only to active learning but also to metacognitive processes by promoting reflection, recognition of knowledge gaps, and monitoring of learning progress.

In this regard, researchers, including Chabrier (10), have suggested that the active, hands-on nature of modeling and drawing provides an effective means of supporting metacognitive learning. Specifically, it promotes planning, monitoring of understanding, error detection and correction, and reflection on errors, ultimately leading to deeper awareness of the learning process. Furthermore, this approach is enjoyable and accommodates different learning styles.

The findings of the present study are also consistent with those reported by Correa et al. (11). According to these authors, clay modeling is an active learning strategy that enhances peer interaction and improves students' understanding of anatomical positions and spatial relationships in human anatomy. They further suggest that this approach engages multiple senses during the learning process while allowing students to benefit from collaborative learning and peer interaction. They conducted a study to investigate the effect of constructing anatomical clay models on students' awareness and understanding of their own thinking processes, as well as to determine whether clay modeling promotes collaborative learning. This cross-sectional study was conducted among ten third-year undergraduate students as a reflective exercise to enhance metacognition. After being assigned to groups, students were asked to construct anatomical clay models and complete a reflective assignment and an evaluation form as part of their applied anatomy assessment. The reflective assignment was based on Gibbs' Reflective Cycle. According to the authors, such assignments encourage students to reflect on their learning experiences and consequently enhance metacognitive skills. The findings indicated that clay modeling is an effective learning tool and a valuable educational strategy in undergraduate clinical anatomy. Participants reported that this approach improved their anatomical knowledge and facilitated collaborative learning (11).

The findings of DeHoff et al. (12) are consistent with those of the present study. These researchers compared two instructional methods—clay modeling and cat dissection—for teaching muscles, peripheral nerves, and blood vessels. They assessed undergraduate students' performance using both lower-order and higher-order cognitive questions for each anatomical system and also evaluated students' perceptions using a Likert-scale questionnaire. The results showed that both methods were effective in achieving learning outcomes in human anatomy. However, a considerable proportion of students in the clay modeling group reported that the technique was enjoyable, facilitated learning and knowledge transfer, and was their preferred method for studying anatomy.

In two related studies, Krontiris-Litowitz et al. examined the use of hands-on instructional tools, including clay modeling, for teaching neuroanatomy and physiology concepts. Their findings indicated that most students found the activity enjoyable and beneficial for learning, and reported improved understanding through group interaction. The authors concluded that these interactions contributed to positive perceptions of clay modeling (13,14). An important finding of the present study was the contribution of anatomical modeling to students' metacognitive learning. By requiring students to construct anatomical representations based on their existing knowledge, the activity encouraged them to evaluate their own understanding, recognize knowledge gaps, and refine their mental models. This process reflects key components of metacognitive regulation, including monitoring comprehension and adjusting learning strategies. Furthermore, linking the modeling activity with endotracheal intubation training provided an opportunity to apply anatomical knowledge in a clinical context. The three-dimensional and hands-on nature of modeling may have facilitated the formation of more structured anatomical representations, supporting the transfer of knowledge from conceptual understanding to clinical application. In the present study, students completed the modeling activity in two successive attempts. During the first attempt, they relied on their usual learning strategies. At this stage, their learning difficulties became apparent, allowing them to recognize the level of understanding and insight required to develop a complete mental representation of the educational content and to identify the aspects that required greater attention. During the second attempt, students were given another opportunity to use the educational resources, enabling them to address the gaps in their knowledge. Subsequently, feedback from the faculty members on the models they had constructed helped them evaluate both the extent and the quality of their understanding. They were able to distinguish between the areas in which they felt confident and those in which they remained uncertain. This process enabled them to recognize their actual level of understanding and compare it with the level of understanding expected of them. These findings are consistent with those reported by Velaz-Martínez et al. (15), who introduced a simple and inexpensive method to improve radiology residents' understanding of musculoskeletal anatomy and pathology and to facilitate the application of anatomical knowledge in clinical practice. The residents were provided with soft modeling compounds, such as Play-Doh®, in different colors, along with pottery tools, to construct three-dimensional models of complex musculoskeletal anatomy and pathology. Qualitative feedback indicated that this educational experience enhanced their understanding of musculoskeletal pathology. The residents described the approach as positive, enjoyable, and low-stress, and reported that its unique hands-on nature made the learning experience memorable (15).

Similarly, Oh et al. incorporated clay modeling into neuroanatomy courses to facilitate students' understanding of cross-sectional anatomy. In their study, students constructed clay models of anatomical cross-sections and compared them with CT and MRI images. Most participants responded positively to this approach and achieved higher mean scores than those who did not use clay modeling. The authors concluded that clay modeling is a valuable adjunct to radiological anatomy education (16). Stanton et al. also emphasized that a metacognitive approach enables learners to evaluate their own learning processes realistically, think independently when confronted with different problems, enhance their cognitive abilities, and adopt new learning strategies when existing ones prove ineffective (17).The findings of the present study suggest that clay or dough modeling, through the engagement of multiple senses, including the sense of touch, enhances students' understanding and promotes metacognitive processes, ultimately contributing to deeper learning. These findings are supported by Jones et al. (18), who argued that learners acquire knowledge more effectively when they actively engage in movement, experience, and experimentation, all of which are inherent features of modeling activities. They further reported that, regardless of learners' preferred learning styles, tactile learning promotes active participation, improves three-dimensional spatial understanding, increases enjoyment, and fosters metacognitive development (18).

Overall, the findings of the present study indicate that dough modeling, by promoting active and metacognitive learning, effectively fostered metacognitive development among Emergency Medical Services students learning the anatomy of the larynx. As observed in the present study, students constructed the models in an environment free from retrieval cues and relied solely on their internal mental representations. Retrieving these mental representations strengthened knowledge retention and promoted deep learning.These findings are consistent with those reported by Naug et al. (19), who found that modeling techniques enhance metacognitive awareness by engaging memory, kinesthetic learning, and experiential learning. They argued that, unlike traditional anatomy laboratories, this learning environment is free from educational resources, thereby encouraging self-reflection and increasing awareness of one's own learning processes.

Lara Nokovitch and colleagues demonstrated that spatial visualization ability plays a fundamental role in students' understanding of anatomy. They highlighted that visual–spatial thinking extends beyond simple visual perception and involves the construction, organization, and integration of visual information into coherent mental representations, together with the ability to mentally manipulate three-dimensional spatial relationships among anatomical structures (20). Aso, Yvonne M. Baptiste and colleagues identified that although textbooks, cadaveric specimens, and digital anatomy models provide essential external representations for anatomical learning, three-dimensional digital models can enhance students' visualization of complex anatomical relationships and support the development of spatial understanding and mental images (21).

**Conclusion**

The findings of this study suggest that anatomical modeling using clay is a valuable learner-centered approach that promotes active engagement and supports metacognitive development among Emergency Medical Sciences students. By encouraging learners to construct, evaluate, and refine their own anatomical representations, this approach may enhance self-awareness, deeper understanding, and long-term retention of knowledge. Integrating modeling activities into anatomy education may therefore provide an effective strategy for bridging conceptual learning with clinical application.

**Study Limitations**

This study has several limitations. First, it was conducted at a single institution and included a small purposive sample of first-year Emergency Medical Sciences students; therefore, the transferability of the findings to other educational settings and student populations should be considered with caution. Second, because data were collected through a focus group discussion, participants may have been influenced by social desirability or group dynamics when expressing their experiences. Third, this study explored students' perceptions and experiences of the modeling activity and did not include objective measures of knowledge acquisition or clinical skill performance. Future studies using longitudinal designs and quantitative assessments, such as knowledge tests or objective structured clinical examinations (OSCEs), may further evaluate the educational effectiveness of modeling-based approaches.

**Implications for Patient Care**

Although this study focused on an educational intervention rather than direct patient outcomes, its findings have potential implications for future clinical practice. Developing accurate three-dimensional anatomical understanding and metacognitive skills during early healthcare training may improve learners' ability to recognize anatomical relationships, apply knowledge during clinical procedures, and adapt their decisions in complex situations. By promoting self-awareness, reflection, and deeper understanding, modeling-based education may contribute to the development of healthcare professionals who are better prepared to perform clinical skills safely and effectively. Incorporating active and metacognitive learning strategies into health professions education may therefore represent a valuable approach for strengthening clinical competency and potentially improving the quality and safety of patient care.

**Conflict of Interest**

The authors declare that they have no conflicts of interest related to this study.

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**Ethics Approval and Consent to Participate**

This study was approved by the Ethics Committee of Bushehr University of Medical Sciences (Ethics approval code: IR.BPUMS.REC.1401.132). Written informed consent was obtained from all participants prior to participation.

**Ethics Statement**

The authors confirm that all ethical principles of research and scientific publication, including plagiarism prevention, data integrity, and avoidance of duplicate publication, were fully observed.

**Data Availability Statement**

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

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**Use of Artificial Intelligence in the Writing Process**

Generative artificial intelligence (AI) tools were used solely to improve the language quality, grammatical accuracy, and clarity of the manuscript. The authors carefully reviewed and edited all AI-assisted content and take full responsibility for the final version of the manuscript.

**Publisher's Note**

The graphical abstract was prepared by the journal's editorial team using artificial intelligence-assisted design tools and was reviewed and approved by the authors prior to publication.

**Reference**

1. Lodge JM, Kennedy G, Lockyer L, Arguel A, Pachman M. Understanding difficulties and resulting confusion in learning: An integrative review. InFrontiers in Education 2018 Jun 28 (Vol. 3, p. 314989). Frontiers.
https://doi.org/10.3389/feduc.2018.00049.

2. Cheung CC, Bridges SM, Tipoe GL. Why is anatomy difficult to learn? The implications for undergraduate medical curricula. Anatomical sciences education. 2021 Nov;14(6):752-63.
https://doi.org/10.1002/ase.2071.

3. El Saadawi GM, Azevedo R, Castine M, Payne V, Medvedeva O, Tseytlin E, Legowski E, Jukic D, Crowley RS. Factors affecting feeling-of-knowing in a medical intelligent tutoring system: the role of immediate feedback as a metacognitive scaffold. Advances in Health Sciences Education. 2010 Mar;15(1):9-30.
https://doi.org/10.1007/s10459-009-9162-6.

4. Bledsoe TS, Baskin JJ. Recognizing student fear: The elephant in the classroom. College Teaching. 2014 Jan 2;62(1):32-41.
https://doi.org/10.1080/87567555.2013.831022.

5. Alfaraj R, Ozdemir B, Aljuffali L, Alsabhan JF, Al Aloola N, Alkofide H, Aljadeed R, Aljadeed R, Alodaib F, Alkhudair N, Almalag HM. Metacognitive awareness and confidence as predictors of academic performance in pharmacy students: insights from grade predictions and structural equation modeling. Frontiers in psychology. 2026 Feb 27;17:1720303.
https://doi.org/10.3389/fpsyg.2026.1720303.

6. Bareither ML, Arbel V, Growe M, Muszczynski E, Rudd A, Marone JR. Clay modeling versus written modules as effective interventions in understanding human anatomy. Anatomical Sciences Education. 2013 May;6(3):170-6.
https://doi.org/10.1002/ase.1321.

7. Rajesh E, Subramaniam S, Pasupathy P, Suresh T, Gopichandran V. Lived experiences of medical students of online learning: lessons for adopting virtual learning in medical education. BMC Medical Education. 2024 Sep 10;24(1):982.
https://doi.org/10.1186/s12909-024-05953-7.

8. Graneheim UH, Lundman B. Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. Nurse education today. 2004 Feb 1;24(2):105-12.
https://doi.org/10.1016/j.nedt.2003.10.001.

9. Ghasemi SF, Valizadeh F, Heydari H. Exploring Nursing Students and Professors´ Perceptions about Academic Failure: A Qualitative Study. Research in Medical Education. 2025 Dec 10;17(4):15-28.
https://doi.org/10.22034/RMEGUMS.17.4.3.

10. Chabrier R, Janke C. The comeback of hand drawing in modern life sciences. Nature Reviews Molecular Cell Biology. 2018 Mar;19(3):137-8.
https://doi.org/10.1038/nrm.2017.126.

11. Correia JC, Baatjes KJ, Meyer I. Student-perceived value on the use of clay modelling in undergraduate clinical anatomy. InBiomedical Visualisation: Volume 12–The Importance of Context in Image-Making 2022 Sep 15 (pp. 153-170). Cham: Springer International Publishing.
https://doi.org/10.1007/978-3-031-10889-1_7.

12. DeHoff ME, Clark KL, Meganathan K. Learning outcomes and student-perceived value of clay modeling and cat dissection in undergraduate human anatomy and physiology.

Advances in physiology education. 2011 Mar;35(1):68-75.
https://doi.org/10.1152/advan.00094.2010.

13. Krontiris-Litowitz J. Using truncated lectures, conceptual exercises, and manipulatives to improve learning in the neuroanatomy classroom. Advances in Physiology Education. 2008 Jun;32(2):152-6.
https://doi.org/10.1152/advan.00103.2007.

14. Krontiris-Litowitz J. Using manipulatives to improve learning in the undergraduate neurophysiology curriculum. Advances in physiology education. 2003 Sep;27(3):109-19. https://doi.org/10.1152/advan.00042.2002.

15. Velez-Martinez O, Hom GL, Jayasinghe S, Kosaraju V, Faraji N, Nicholas J, Barger R. Play in the reading room: Utilizing soft modeling compound to teach musculoskeletal anatomy and pathology. Current Problems in Diagnostic Radiology. 2025 Jul 1;54(4):470-4.
https://doi.org/10.1067/j.cpradiol.2023.10.009.

16. Oh CS, Kim JY, Choe YH. Learning of cross-sectional anatomy using clay models. Anatomical sciences education. 2009 Jul;2(4):156-9.
https://doi.org/10.1002/ase.92.

17. Stanton JD, Sebesta AJ, Dunlosky J. Fostering metacognition to support student learning and performance. CBE—Life Sciences Education. 2021;20(2):fe3.
https://doi.org/10.1187/cbe.20-12-0289.

18. Jones MG, Minogue J, Tretter TR, Negishi A, Taylor R. Haptic augmentation of science instruction: Does touch matter?. Science Education. 2006 Jan;90(1):111-23.
https://doi.org/10.1002/sce.20086.

19. Naug HL, Colson NJ, Donner DG. Promoting metacognition in first year anatomy laboratories using plasticine modeling and drawing activities: A pilot study of the “blank page” technique. Anatomical Sciences Education. 2011 Jul;4(4):231-4.
https://doi.org/10.1002/ase.228.

20. Nokovitch L, El Hajj H, Deneuve S, De Andrade V, Gagnayre R, Margat A. Visual–spatial abilities enhancement and spatial anatomy learning: A systematic review. Medical Education. 2025 Dec;59(12):1322-32.
https://doi.org/10.1111/medu.70022.

21. Baptiste YM, Abramovich S. Community college student perceptions of digital anatomy models as a curricular resource. Anatomical Sciences Education. 2024 Dec;17(9):1731-48. https://doi.org/10.1002/ase.2523.