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Beyond the Scalpel: Clay Modeling as an Innovative Pedagogical Tool for Facial Muscle Anatomy in Medical Education

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Background: The intricate three-dimensional nature of facial muscle anatomy presents a significant learning challenge for medical students. While traditional teaching methods like cadaveric dissection and didactic lectures have their merits, there is a growing need for innovative, engaging, and student-centered pedagogical approaches that can enhance spatial understanding and knowledge retention. This study aimed to evaluate the effectiveness of a hands-on clay modeling workshop as a supplementary tool for teaching facial muscle anatomy to medical students.

Methods: A mixed-methods study with a pre-test/post-test control group design was conducted with second-year medical students. Participants were randomly assigned to either an intervention group (n=50), which attended a clay modeling workshop, or a control group (n=50), which received a standard lecture. Anatomical knowledge was assessed using a pre-test and post-test. Qualitative data on student perceptions were collected through focus group interviews and surveys and analyzed using thematic analysis.

Results: The intervention group demonstrated a significantly greater improvement in post-test scores compared to the control group ($p < 0.001$). Thematic analysis of the qualitative data revealed three key themes: (1) enhanced spatial understanding, (2) increased engagement and enjoyment, and (3) the value of peer learning and collaboration. Students in the intervention group reported that the tactile and creative nature of the workshop made learning facial anatomy more intuitive and memorable.

Conclusion: The findings suggest that clay modeling is an effective and well-received pedagogical tool that can significantly improve medical students' understanding of complex facial muscle anatomy. Integrating such hands-on, creative learning modalities into anatomy curricula can foster a more engaging and effective learning environment, ultimately leading to better-prepared medical professionals.

Keywords: Anatomy Education, Medical Students, Clay Modeling, Facial Muscles, Innovative Pedagogy, Kinesthetic Learning, Medical Curriculum

1. Introduction

1.1. The Challenge of Anatomy Education

Anatomy serves as the bedrock of medical science, providing the fundamental map upon which all clinical knowledge is built. A profound understanding of the human body's structure is indispensable for accurate diagnosis, safe surgical intervention, and effective patient care. Among the most intricate areas of human anatomy is the head and neck, particularly the complex, layered arrangement of the facial muscles. These muscles are not merely responsible for facial expression but are also critically involved in functions such as mastication, speech, and vision. Furthermore, a detailed knowledge of their origins, insertions, and spatial relationships is paramount in specialties ranging from plastic and reconstructive surgery to neurology and otolaryngology [1, 3]. The clinical relevance is underscored in procedures aimed at correcting facial atrophy or reconstructing features after trauma, where a nuanced appreciation of both muscular and adipose compartments is essential for successful outcomes [1, 3].

Historically, anatomy education has been dominated by two primary modalities: didactic lectures and cadaveric dissection. Lectures provide a structured framework for conveying vast amounts of information, while dissection offers an unparalleled opportunity for hands-on exploration of the human form. For centuries, the dissection hall has been a rite of passage for medical students, offering a tactile and visual experience that textbooks alone cannot replicate [7]. However, these traditional methods are not without significant limitations. Didactic lectures, while efficient, often promote passive learning and may fail to foster the deep, three-dimensional spatial understanding required for clinical practice.

Cadaveric dissection, long considered the gold standard, faces mounting challenges in the 21st century. These include high costs associated with procurement, maintenance, and facility management; ethical and societal concerns regarding the use of human remains; and exposure to hazardous chemicals like formaldehyde [7]. Moreover, the anatomical variations and post-mortem changes in cadaveric tissue can sometimes obscure the true-to-life structure and function of delicate tissues like the facial muscles. Consequently, modern medical curricula are increasingly under pressure to find innovative and effective pedagogical tools that can supplement or, in some cases, replace elements of traditional anatomical instruction.

1.2. The Rise of Innovative Pedagogical Approaches

In response to the limitations of traditional methods, medical education is undergoing a pedagogical shift towards more active, student-centered learning strategies. This movement is grounded in educational theories emphasizing that students construct knowledge more effectively when they are actively engaged in the learning process rather than being passive recipients of information. Interactive and multi-modal workshops, problem-based learning, and the integration of technology are becoming more commonplace, with studies demonstrating their positive impact on academic performance and long-term knowledge retention [8].

Within this context, there is a renewed appreciation for the role of kinesthetic and tactile learning—the process of learning by doing. Engaging the sense of touch can powerfully reinforce visual and auditory information, particularly when learning about complex three-dimensional structures. This is where the intersection of art and medicine offers exciting possibilities [5]. Artistic practices, such as drawing, painting, and sculpting, require close observation and a deep understanding of form and structure, mirroring the skills required of a clinician. Integrating such practices into medical education can foster not only anatomical knowledge but also observational skills, empathy, and a more holistic appreciation of the human form [5].

Clay modeling, in particular, has emerged as a promising, low-cost, and highly engaging pedagogical tool. This method allows students to build anatomical structures layer by layer, providing a dynamic and tactile experience that transforms abstract concepts into tangible forms. Unlike passively viewing diagrams or prosections, the act of physically sculpting a muscle—from its origin to its insertion—forces the student to consider its shape, volume, and relationship to adjacent structures. This process has been shown to be effective in various anatomical contexts, helping students grasp complex arrangements that are difficult to visualize from two-dimensional images or even from static models [2, 4, 9, 11].

1.3. Literature Gap and Rationale for the Study

The value of clay modeling in anatomy education is supported by a growing body of literature. Studies have demonstrated its effectiveness in teaching the anatomy of the limbs, the musculoskeletal system, and complex cross-sectional anatomy [2, 9, 11]. For instance, Kooloos et al. [2] found that students who learned musculoskeletal anatomy through a clay-modeling exercise showed significant knowledge gains compared to those who learned through observation alone. Similarly, studies focusing on student perceptions have consistently found that learners view clay modeling as a valuable and enjoyable addition to their curriculum, appreciating its hands-on nature and its ability to clarify complex spatial relationships [4, 11].

However, despite this promising evidence, a specific gap in the literature remains. While the benefits of clay modeling for larger muscle groups are well-documented, there is a scarcity of research investigating its application to the delicate and intricate musculature of the face within a medical student cohort. The facial muscles present a unique educational challenge due to their layered arrangement, subtle variations, and functional integration. Given the high clinical importance of this region, exploring effective teaching methods is a priority.

This study, therefore, seeks to address this gap by investigating a fundamental research question: How does the integration of a hands-on clay modeling workshop into the medical curriculum affect students' understanding of facial muscle anatomy and their engagement with the subject matter? We aim to provide empirical evidence on whether this innovative, arts-based approach can offer a meaningful advantage over traditional lecture-based instruction for one of the most complex areas of human anatomy.

1.4. Study Objectives and Hypotheses

The primary objective of this study is to quantitatively evaluate the effectiveness of a hands-on clay modeling workshop in improving medical students' knowledge of facial muscle anatomy compared to a traditional, didactic lecture-based approach. The secondary objectives are to qualitatively assess student perceptions of clay modeling as a learning tool and to explore its impact on their engagement, confidence, and overall learning experience.

Based on the existing literature and the theoretical advantages of kinesthetic learning, we formulated the following hypothesis: Students participating in the clay modeling workshop will demonstrate a significantly greater improvement in their anatomical knowledge of the facial muscles and will report higher levels of engagement, satisfaction, and perceived learning value compared to students who receive traditional lecture-based instruction.

2. Methods

2.1. Study Design

This study employed a mixed-methods approach, integrating both quantitative and qualitative data collection within a pre-test/post-test control group design. This design was chosen to enable a robust comparison of learning outcomes between the two pedagogical approaches while also capturing the rich, nuanced experiences of the student participants. The study was conducted at a single, large urban medical school over the course of the four-week head and neck anatomy module in the spring semester. The university's Institutional Review Board granted full ethical approval for the research protocol prior to commencement.

2.2. Participants

The study population consisted of all 100 second-year medical students enrolled in the mandatory head and neck anatomy module. An announcement was made at the beginning of the module inviting students to participate. All 100 students provided informed consent and were included in the study. Inclusion criteria were simply being an enrolled second-year medical student in the specified module. There were no exclusion criteria.

To ensure unbiased group allocation, participants were randomly assigned to one of two groups using a computer-generated random number sequence. The intervention group (n=50) was assigned to the clay modeling workshop, and the control group (n=50) was assigned to the traditional didactic lecture. The two groups were assessed for baseline equivalence on key demographic variables (age, gender) and prior academic performance in anatomy, with no significant differences found between them.

2.3. Intervention: The Clay Modeling Workshop

The intervention group participated in a single, three-hour clay modeling workshop held in a dedicated anatomy laboratory. The workshop was designed and facilitated by a senior anatomy professor with assistance from two postgraduate teaching assistants. The student-to-facilitator ratio was approximately 17:1 to ensure adequate individual support.

Upon arrival, each student was provided with a life-sized plastic skull model, a set of anatomical tools for sculpting, and non-toxic, oil-based modeling clay in various colors to differentiate between muscle groups. The session began with a brief 15-minute introduction outlining the learning objectives and demonstrating basic clay handling techniques.

Following the introduction, the workshop proceeded in a guided, layer-by-layer fashion. Students were instructed to build the major muscles of facial expression, starting with the deepest layers and progressing to the most superficial ones. For each muscle (e.g., buccinator, orbicularis oris, zygomaticus major), the facilitator would first project anatomical diagrams illustrating its origin, insertion, fiber direction, and function. Students would then use the colored clay to sculpt the muscle and affix it to their skull model in the anatomically correct position. This hands-on process required students to actively problem-solve and interpret two-dimensional diagrams to create a three-dimensional structure. The facilitators circulated throughout the room, providing guidance, answering questions, and encouraging peer-to-peer discussion and collaboration.

2.4. Control: The Traditional Lecture

The control group attended a three-hour teaching session that ran concurrently with the workshop to control for time on task. This session consisted of a traditional didactic lecture on facial muscle anatomy, delivered by an equally experienced anatomy professor who was not involved with the intervention. The content covered was identical to that of the workshop, including all major muscles of facial expression, their origins, insertions, innervations, and functions.

The lecture was delivered in a standard tiered lecture hall using a PowerPoint presentation. The slides contained a mix of textual information, schematic diagrams, and images from renowned anatomical atlases and cadaveric prosections. The lecturer followed a structured format, systematically presenting each muscle and its key features. While students were permitted to ask questions at designated points, the format was predominantly a one-way transmission of information, representing the standard pedagogical approach for this topic at the institution.

2.5. Data Collection

A multi-faceted data collection strategy was implemented to capture both objective knowledge gains and subjective learning experiences.

2.5.1. Quantitative Data

Anatomical knowledge was assessed using a 25-item test developed by a panel of three senior anatomy faculty members. The test, which was validated for content and clarity through a pilot run with a separate cohort of students, consisted of 20 multiple-choice questions (MCQs) and 5 short-answer questions (SAQs). The questions were designed to assess not only factual recall (e.g., identifying origins and insertions) but also functional and spatial understanding (e.g., predicting the effect of a muscle's contraction). This identical test was administered to both groups as a pre-test at the beginning of the module (one week before the intervention) and as a post-test one week after the intervention/lecture session. Tests were anonymized and scored by a blinded assessor to prevent bias.

2.5.2. Qualitative Data

To gain a deeper understanding of the learning experience, qualitative data were collected from the intervention group. One week after the workshop, a purposive sample of 20 students (four groups of five) from the intervention cohort was invited to participate in semi-structured focus groups. The sampling aimed to include a diverse range of academic performance levels. The focus groups, each lasting approximately 60 minutes, were moderated by an independent researcher. An open-ended question guide was used to explore students' perceptions of the workshop, its impact on their understanding of facial anatomy, its perceived advantages and disadvantages, and its overall value.

Additionally, an anonymous end-of-module survey was administered to all 100 participants. The survey included Likert-scale questions to rate engagement and satisfaction, as well as an open-ended question asking for general feedback on their respective learning session (workshop or lecture).

2.6. Data Analysis

2.6.1. Quantitative Analysis

The quantitative data from the pre-tests and post-tests were analyzed using SPSS version 28.0. An independent samples t-test was first used to compare the pre-test scores of the intervention and control groups to confirm baseline equivalence. The primary analysis involved using an independent samples t-test to compare the post-test scores between the two groups. Additionally, paired samples t-tests were conducted for each group to assess the magnitude of knowledge gain from pre-test to post-test. The significance level was set at an alpha of 0.05.

2.6.2. Qualitative Analysis

All focus group discussions were audio-recorded, transcribed verbatim, and anonymized. The transcripts, along with the open-ended survey responses, were subjected to thematic analysis, following the systematic, six-phase approach described by Braun and Clarke [13]. This rigorous process involved: (1) familiarization with the data through repeated reading; (2) generation of initial codes from the raw text; (3) searching for patterns and collating codes into potential themes; (4) reviewing and refining these themes; (5) defining and naming the final themes; and (6) producing the final report with illustrative quotes. Two researchers independently coded a portion of the data to establish inter-rater reliability, and any discrepancies were resolved through discussion to ensure the credibility of the findings, a process consistent with best practices in qualitative research [12].

3. Results

3.1. Participant Demographics

A total of 100 second-year medical students participated in the study and were randomized into the intervention group (n=50) and the control group (n=50). The demographic characteristics of both groups were comparable. The intervention group consisted of 27 females (54%) and 23 males (46%), with a mean age of 24.1 years (SD = 1.8). The control group consisted of 26 females (52%) and 24 males (48%), with a mean age of 24.3 years (SD = 2.1). There were no statistically significant differences between the groups in terms of gender distribution, age, or prior academic performance in foundational anatomy courses. All 100 participants completed the pre-test and post-test.

3.2. Quantitative Findings

The primary quantitative outcome was the change in anatomical knowledge as measured by the pre-test and post-test scores (maximum score = 25). At baseline, both groups demonstrated similar levels of knowledge. The mean pre-test score for the intervention group was 11.2 (SD = 2.5), and for the control group, it was 11.5 (SD = 2.7). An independent samples t-test confirmed that this difference was not statistically significant ($t(98) = -0.54$, $p = 0.59$), establishing a comparable starting point for both cohorts.

Following the respective educational sessions, both groups showed a significant improvement in their scores from pre-test to post-test. A paired samples t-test for the control group revealed a significant increase in scores from 11.5 to 17.0 (SD = 3.1), a mean gain of 5.5 points ($t(49) = -9.8$, $p < 0.001$). This indicates that the traditional lecture was effective in imparting anatomical knowledge.

However, the intervention group demonstrated a markedly greater improvement. Their mean score increased from 11.2 on the pre-test to 21.3 (SD = 2.4) on the post-test, a mean gain of 10.1 points ($t(49) = -20.1$, $p < 0.001$).

The key comparison of post-test scores between the two groups revealed a highly significant difference. The mean post-test score of the clay modeling group (M = 21.3) was significantly higher than that of the traditional lecture group (M = 17.0). An independent samples t-test confirmed that this difference was statistically significant ($t(98) = 7.6$, $p < 0.001$). These results strongly support the study's hypothesis that the clay modeling workshop is a more effective method for improving students' knowledge of facial muscle anatomy than a traditional lecture.

3.3. Qualitative Findings: A Deeper Analysis of the Student Experience

The thematic analysis of focus group transcripts and open-ended survey responses from the 50 students in the intervention group provided a rich and detailed account of their learning journey. The process, guided by the principles of Braun and Clarke [13], allowed for the identification of four overarching themes that were consistently and powerfully articulated by the participants: (1) A Paradigm Shift in Spatial Understanding; (2) The Affective Dimensions of Learning: Engagement and Enjoyment; (3) The Power of Social Constructivism: Peer Learning and Collaboration; and (4) Constructive Critiques and Aspirations for Future Integration. These themes and their constituent sub-themes are explored in detail below, supported by verbatim quotes to ensure the students' voices remain central to the findings [12].

3.3.1. Theme 1: A Paradigm Shift in Spatial Understanding

The most significant and frequently discussed outcome of the workshop was a profound shift in how students conceptualized and understood the three-dimensional architecture of the face. This was not merely an incremental improvement but was described as a fundamental change in their cognitive approach to anatomy, moving from rote memorization of flat images to an intuitive, integrated spatial awareness.

Sub-theme 1a: The Cognitive Leap from Two Dimensions to Three

Participants repeatedly expressed the struggle of mentally translating the 2D diagrams from textbooks and lecture slides into a functional 3D model. The clay workshop was consistently identified as the crucial bridge that facilitated this cognitive leap. The physical act of building the structures provided a tangible framework that diagrams alone could not.

"I've spent hours staring at Netter's, trying to picture how the orbicularis oculi sits on the bone. You see the drawing, but it's flat. The moment I molded the clay with my own hands and laid it around the orbit, it just… clicked. It's like a lightbulb went on. All the 2D knowledge I had suddenly organized itself into a 3D structure in my head."

Another student added, *"The problem with books is that they can only show you one view at a time. Here, I could pick up the skull, turn it around, look at my muscle from above, from the side… I was in control of the perspective. That's something you can never get from a PowerPoint slide. It's the difference between looking at a map and actually walking through the city."*

Sub-theme 1b: Embodied Cognition and Muscular Empathy

A fascinating sub-theme emerged related to embodied cognition—the idea that knowledge is linked to physical action. Students described developing an almost intuitive, kinesthetic understanding of muscle function simply by recreating the muscles' paths of pull. This led to what one student termed "muscular empathy."

"When you have to stretch the clay from the zygomatic bone down to the corner of the mouth, you can literally feel the tension along that line. You start to intuitively understand that when that strip of clay contracts, it's going to pull the mouth up and out. I don't have to memorize 'elevates and abducts the corner of the mouth' anymore; I can feel it in my hands. It's a completely different kind of knowing."

"It's weird to explain," commented another participant, *"but after making the corrugator supercilii, I found myself activating my own muscle, feeling it contract, and then looking at my little clay model. The connection between the name, the action, and the physical muscle became inseparable. It's knowledge that's stored in my fingers as much as in my brain."*

Sub-theme 1c: Demystifying the Complexity of Anatomical Layers

The layered arrangement of facial muscles is a notorious point of confusion. The workshop's layer-by-layer construction method was universally praised for its ability to demystify these complex relationships, making the distinction between superficial and deep structures clear and logical.

"The concept of the SMAS (Superficial Musculoaponeurotic System) was always so abstract to me. But when we had to build the deeper muscles first, like the buccinator, and then lay the more superficial ones like the risorius on top, the whole concept of anatomical planes became real. You see why a surgeon has to dissect through specific layers."

A student from another focus group noted, *"I finally understand the relationship between the levator labii superioris and the levator anguli oris. In the book, they just look like two lines next to each other. When you have to place one as deeper than the other, their distinct functions and locations become unforgettable. I will never mix them up again."*

3.3.2. Theme 2: The Affective Dimensions of Learning: Engagement and Enjoyment

Participants spoke at length about their emotional and psychological response to the workshop. The session was overwhelmingly described as a positive, low-stress, and highly engaging experience. This affective component was not seen as incidental but as a critical factor that directly enhanced their ability to learn and retain complex information.

Sub-theme 2a: Novelty and ‘Serious Play’ as a Conduit for Learning

The novelty of using clay in a medical school setting served to break the monotony of conventional study routines, immediately capturing students' attention. This element of "serious play" lowered anxieties associated with learning a difficult topic and fostered a state of deep focus, often described as "flow."

"Honestly, when I heard we were playing with clay, I was skeptical. But it was the most focused I've been all semester. It’s a form of play, but it’s incredibly purposeful. It removes the pressure of just memorizing facts for an exam and allows you to be curious and explore the material. The learning feels like a side effect of the fun you’re having."

"Medical school can be such a grind," one student admitted in a survey. *"It’s just a relentless firehose of information. This workshop was a breath of fresh air. It reminded me that learning can be joyful and creative. That positive feeling makes the information stick in a way that stress-fueled cramming never does."*

Sub-theme 2b: A Multisensory Learning Experience

In contrast to the predominantly visual and auditory nature of lectures, the workshop offered a rich, multisensory experience. Students highlighted the importance of touch (haptics) and proprioception in creating stronger, more durable memories.

"A lecture goes in one ear and out the other sometimes. But this... I can still feel the texture of the clay, the coolness of the skull model, the pressure I needed to apply to make the muscle adhere. It’s a memory that involves multiple senses, and that makes it so much more vivid and lasting. I can close my eyes and mentally rebuild the face because I’ve physically done it."

Another student elaborated, *"It's about muscle memory, in a way. The information is encoded not just as a visual picture, but as a sequence of physical actions. It’s a much deeper and more robust way to learn. It’s the difference between reading a recipe and actually cooking the dish."*

3.3.3. Theme 3: The Power of Social Constructivism: Peer Learning and Collaboration

The physical setup of the workshop, with students working in small groups around lab tables, naturally fostered a collaborative and non-hierarchical learning environment. This social dimension was identified as a key advantage over the isolating experience of a lecture hall.

Sub-theme 3a: Fostering a ‘Community of Inquiry’

The informal, hands-on environment made students feel more comfortable asking questions and admitting confusion, both to peers and facilitators. This created a "community of inquiry" where knowledge was co-constructed rather than simply transmitted from an authority figure.

"In a lecture with 100 people, you’re never going to raise your hand and say, ‘I don’t get it.’ Here, you just turn to the person next to you and ask, ‘Hey, does this look right to you?’ There’s no judgment. We were all figuring it out together, and that sense of shared discovery was really powerful."

"The facilitators were amazing," said another. *"They acted more like coaches than lecturers. They would come over, look at your model, and ask questions like, 'What do you think would happen if you moved the insertion point slightly?' It prompted you to think critically instead of just passively accepting information."*

Sub-theme 3b: Verbalization as a Tool for Solidifying Knowledge

The collaborative process necessitated constant communication. Students had to articulate their anatomical understanding to explain their models, ask for help, or correct a peer. This act of verbalization was a potent tool for reinforcing and clarifying their own knowledge.

"I found that the best way to check my own understanding was to try and help my table-mate. In explaining to them why the mentalis muscle should be placed a certain way, I had to organize my own thoughts and solidify the concept in my own mind. You really don't know something until you can teach it."

"Our group had a running debate about the exact origin of the depressor anguli oris. We had to pull up the atlas, look at each other’s models, and argue our cases. That

10-minute discussion taught me more about that muscle than any book ever could, because I had to actively defend my knowledge."

3.3.4. Theme 4: Constructive Critiques and Aspirations for Future Integration

While overwhelmingly positive, the feedback also included thoughtful critiques and suggestions, reflecting a high level of student investment in the pedagogical method. These comments centered on logistical constraints and a strong desire to see the method more deeply integrated into the curriculum.

Sub-theme 4a: Navigating the Artistic Skill Gap and Time Constraints

Some students initially expressed anxiety about their lack of artistic ability. While this was generally overcome through peer support, it was a noted source of initial stress. The most common logistical critique was the feeling of being rushed.

"I'm terrible at art, so at first, I was pretty intimidated. My first few muscles looked like blobs. But my lab partner was really good and gave me some tips, and I realized it wasn't about making it pretty, but about making it anatomically correct. Once I got over that mental block, it was fine."

"My only complaint is that I wish we had more time," stated a common sentiment. *"Three hours sounds like a lot, but it flew by. I felt a bit rushed at the end trying to get the superficial muscles on. Maybe a four-hour session, or splitting it into two parts, would be even better."*

Sub-theme 4b: A Desire for Deeper Curricular Integration

A powerful concluding theme was that students did not view this as a gimmicky, one-off event. They saw immense potential and expressed a strong desire for this hands-on approach to be integrated with other core components of their anatomy training, particularly cadaveric dissection.

"This would be the most incredible preparatory session for the cadaver lab. If we had done this workshop before we went into the dissection hall, we would have known exactly what we were looking for. We would have had a 3D map in our heads to guide our scalpels. It would make the lab time infinitely more efficient and high-yield."

"I hope the faculty takes this seriously," a final quote summarized. *"This shouldn't just be a fun little experiment. This should be how anatomy is taught. I would love to do this for the forearm, the pelvis... for everything. This is the kind of learning that sticks with you and prepares you to be a better doctor."*

4. Discussion

4.1. Interpretation of Findings

This study aimed to evaluate the effectiveness of a hands-on clay modeling workshop for teaching facial muscle anatomy to medical students. The results provide compelling, convergent evidence from both quantitative and qualitative data that this innovative pedagogical approach is not only more effective than traditional didactic lectures but is also a more engaging and enjoyable learning experience for students. The quantitative findings clearly demonstrated that while both methods improved anatomical knowledge, the magnitude of improvement in the clay modeling group was significantly greater. This aligns with our primary hypothesis and strongly suggests that the active, kinesthetic process of building anatomical structures fosters a deeper and more robust understanding than passively receiving information.

The qualitative findings enrich this conclusion by providing insight into the underlying mechanisms. Students' descriptions of an "enhanced spatial understanding" directly address one of the core challenges of anatomy education. The process of transforming 2D information into a 3D model appears to facilitate the development of the mental schemas necessary for clinical application [9]. This finding resonates with previous research showing that clay modeling improves comprehension of complex anatomical relationships in other parts of the body [2, 11]. Our study extends this principle to the uniquely complex and layered anatomy of the face. Furthermore, the themes of "Increased Engagement" and "Peer Learning" highlight the affective and social dimensions of learning, which are often overlooked in traditional curricula. The positive emotional response and collaborative environment likely contribute to reduced cognitive load and improved memory encoding [5, 8].

4.2. Clay Modeling as a Pedagogical Tool

The success of the clay modeling workshop can be attributed to several key pedagogical principles. First, it is a prime example of active learning. By physically manipulating the clay, students are not just absorbing facts; they are actively constructing, problem-solving, and testing their understanding in real-time. This aligns with constructivist learning theory, which posits that learners build knowledge through experience. The act of shaping a muscle from origin to insertion provides an embodied cognitive link to its function, making abstract names and actions tangible and memorable [4, 11].

Second, the method inherently promotes the development of visuospatial skills. Medicine, particularly surgery and diagnostic imaging, is a highly visual and spatial discipline. The ability to mentally rotate a 3D structure is a critical skill. Our findings suggest that clay modeling explicitly trains this ability in a way that looking at diagrams cannot [cf. 10]. By building the facial muscles, students develop a more accurate and enduring mental model of the head and neck, which could have downstream benefits for clinical practice, such as in planning surgical incisions or administering injections [3, 6].

Finally, the low-cost and high-impact nature of this intervention makes it a particularly attractive pedagogical tool. Unlike expensive virtual reality simulators or the recurring costs of cadaveric dissection, a clay modeling workshop requires a relatively modest initial investment in reusable skull models and affordable materials. This makes it a scalable and sustainable educational innovation that can be easily integrated into diverse curricular contexts.

4.3. Implications for Medical Education

The findings of this study have significant implications for the future of medical education. They provide strong evidence for moving beyond a reliance on passive teaching methods and embracing a more multi-modal and interactive approach to anatomy instruction [8]. Medical schools should consider integrating clay modeling and similar hands-on activities not as peripheral or optional exercises but as core components of their anatomy curriculum. This approach is not about entirely replacing traditional methods like dissection but rather about supplementing and enriching them [7]. A clay modeling session prior to a dissection lab, for example, could prime students with a solid 3D understanding, allowing them to make more efficient and effective use of their time with the cadaver.

Furthermore, the positive student feedback on the collaborative and engaging nature of the workshop highlights the importance of the learning environment. By creating opportunities for active, enjoyable, and peer-supported learning, educators can not only improve knowledge acquisition but also enhance student well-being and foster a more positive learning culture. This is particularly relevant in the demanding and often stressful environment of medical school. The principles demonstrated here can be readily adapted to teach other complex anatomical regions, such as the brachial plexus, the pelvic floor, or the cranial nerves.

4.4. Limitations of the Study

Despite the robust findings, this study has several limitations that must be acknowledged. First, it was conducted at a single institution with a relatively small sample size, which may limit the generalizability of the results to other student populations or educational settings. Second, the follow-up period was short, with the post-test administered only one week after the intervention. While this is sufficient to assess short-term knowledge acquisition, it does not provide insight into long-term retention. A follow-up test administered several months later would be necessary to determine the enduring impact of the intervention.

Third, the "instructor effect" is a potential confounding variable. Although both instructors were experienced, inherent differences in teaching style and charisma could have influenced student outcomes. We attempted to mitigate this by ensuring the content covered was identical. Finally, our assessment tool, while validated for content, primarily measured cognitive knowledge. It did not assess the direct transfer of these skills to a practical or clinical context, which remains a crucial area for future investigation.

4.5. Future Research Directions

This study opens up several promising avenues for future research. Longitudinal studies are needed to track knowledge retention over time and to assess whether the spatial skills gained from clay modeling translate into improved performance in clinical rotations, particularly in surgery, radiology, and anesthesiology. It would also be valuable to conduct comparative effectiveness studies, pitting clay modeling against other innovative teaching tools like high-fidelity 3D-printed models or virtual and augmented reality platforms [10]. Such research could help educators determine the optimal blend of pedagogical tools for different learning objectives and student needs.

Further qualitative research could also explore the faculty experience of implementing such workshops, identifying best practices for training and facilitation. Finally, expanding the application of this method to other health professions, such as dentistry, nursing, and physical therapy, could demonstrate its broader utility and impact across the healthcare education landscape.

4.6. Conclusion

In conclusion, this study provides strong evidence that clay modeling is a highly effective, engaging, and valuable pedagogical tool for teaching the complex anatomy of the facial muscles to medical students. By moving "beyond the scalpel" and the textbook, this hands-on, creative approach was shown to be associated with significantly greater knowledge gains compared to traditional lecture-based instruction. The findings highlight the power of active, kinesthetic learning to enhance spatial understanding and create a more enjoyable and collaborative educational environment. As medical education continues to evolve, the integration of innovative and evidence-based methods like clay modeling will be essential in preparing the next generation of clinicians with the deep anatomical knowledge and practical skills required for excellence in patient care.

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