Sculpting Organs: An Arts-Based Educational Activity for Anatomy Learning

Annika Gupta

*University of South Carolina - Columbia*

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SCULPTING ORGANS: AN ARTS-BASED EDUCATIONAL ACTIVITY FOR ANATOMY LEARNING

By

Annika Gupta

Submitted in Partial Fulfillment of the Requirements for Graduation with Honors from the South Carolina Honors College

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Approved:

Melissa Duffy, PhD
Director of Thesis

Andrew Graciano, PhD
Second Reader

Steve Lynn, Dean
For South Carolina Honors College
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Thesis Summary

This thesis begins with a historical overview of anatomy learning, followed by a discussion of more recent innovations in anatomy education, including educational computerized platforms, such as virtual reality, and arts-based approaches. Several educational theories discussing the role and effects of constructionism, emotions, and multimedia content, are presented in the context of developing an educational protocol for a clay sculpting activity. The primary aim of this thesis is to present the developed, modern, arts-based clay sculpting activity in line with educational learning theory design principles for cardiac anatomy learning. The benefits of this proposed protocol are supported by promising research on similar arts-based methods in anatomy learning and help explain how the use of physical clay models can increase student attention, motivation, and academic performance. The protocol presents instructional recommendations to illustrate the application of a clay sculpting activity of the human heart in an undergraduate, pre-medical classroom with the aid of a slideshow, instructor-led video, instructional guide manual, pre-activity quiz, post-activity quiz, and a lecture plan and should be considered for potential integration into pre-medical anatomy curriculum.
Abstract

As an integral component of healthcare, a comprehensive understanding of anatomy is necessary for accurate clinical diagnoses and medical procedures. Beginning in undergraduate classrooms (premedical), there is a need to explore new ways of teaching and learning anatomy to train healthcare professionals. Traditional methods of attending a lecture and reading a textbook may not be the most effective method to learn about anatomical structures—or to engage learners. However, recent studies have reported promising results in the use of arts-based approaches to enhance anatomy learning. Of these, clay sculpting can provide an opportunity for students to participate in an active and engaging learning experience. Thus, after a thorough literature review of educational approaches in anatomy and discussion of relevant learning theories, this thesis presents an educational protocol on a tactile-learning activity—sculpting the human heart out of clay—to be considered for integration into an anatomy curriculum to enhance attention, positive emotions, and retention of information. To align with several pedagogical principles, a multimedia slideshow, an instructor-led clay sculpting tutorial video, and an instructional guide manual were developed. After completion of a 20-question pre-activity quiz, a 20-minute video tutorial features an instructor illustrating each basic sculpting technique, as well as the key structures of the heart that learners needed to be model the heart. The activity is designed to take approximately 40-60 minutes to complete, although learners may choose to spend additional time improving the quality of their model or technique. The educational protocol and curriculum created in this project provides an example of integrating arts-based methods into medical education and explores the potential benefits of incorporating a tactile activity as a part of the multimodal and hands-on approach to aid pre-medical students’ understanding of anatomy.
Introduction

Understanding human anatomy is the cornerstone of healthcare and fundamental for the effective diagnosis and treatment of human conditions (McCuskey et al., 2005). By definition, anatomy is concerned with the identification and interrelationships of the bodily structures of living things (Britannica, 2018). In the context of medical education, this field has many subdisciplines, each of which physicians must be knowledgeable about. For example, the study of dissection and direct observation without the use of any visual aid is known as gross anatomy while microscopic anatomy is the study of anatomy at the molecular level, (Britannica, 2018; McCuskey et al., 2005) which are both critical in medicine. In surgical branches, the value of anatomy is apparent as Eizenberg states that “fear in surgery is said to be a fear of anatomy, particularly from anatomical variation” (Eizenberg, 2015, p. 376). Additionally, the increasing use of medical imaging, from computed tomography (CT) and magnetic resonance imaging (MRI) to highly sophisticated, surgical robots, calls for a thorough grasp on three-dimensional anatomy knowledge (Lanfranco et al., 2004; McCuskey et al., 2005) to both effectively diagnose and address the effects of a particular disease in the clinical setting.

In an effort to contribute to medical education research of anatomy learning and teaching approaches in the classroom, the objective of this thesis was to develop a clay sculpting activity that could be integrated into the pre-medical curriculum. The literature review component helped to guide the protocol design by aiming to address the following research questions: (1) How is anatomy typically taught in medical and pre-medical classrooms? Are there any innovative educational approaches and activities in this particular discipline, specifically arts-based? (2) Has prior research on clay sculpting in anatomy been conducted and if so, how beneficial was it? (3) Why are the learning theories of constructionism, emotions, and multimedia pedagogical
principles important to academic performance? How do they apply to the proposed clay sculpting activity?

After identifying relevant research questions on this topic, a literature review was conducted using PubMed and Google Scholar. To address the first set of questions, keywords including “anatomy learning”, “innovative anatomy learning”, “hands-on learning in anatomy”, “art in anatomy” were entered. Next, keywords such as “tactile-kinesthetic activities,” and “clay sculpting in anatomy,” were searched to answer the second question. Lastly, to understand the efficacy of certain teaching/learning approaches, several, relevant educational theories, including the control value of achievement emotions, were researched. Keywords such as “teaching methods,” “learning theories,” and “emotions in the classroom,” were analyzed to address the third set of questions. The literature revealed a number of diverse approaches used in anatomy education, which helped in the development of an educational activity and instructional protocol as presented in this thesis.

Since anatomy is a key feature of medical education, anatomy courses, under the STEM (Science Technology Engineering Math) umbrella, are a part of the pre-medical, undergraduate curriculum. However, research from the U.S. Department of Education has revealed an attrition rate of approximately 50% for STEM majors namely due to poor performance (Chen, 2013). In light of this, there is a need to foster learning in pre-medical classrooms through innovative activities to engage students and support learning as these majors comprise the majority of students preparing for future healthcare careers (AAMC, 2020). However, to understand both the current and newly emerging educational tools and approaches in anatomy, it is important to know its history.
The literature review begins with an overview of the history of anatomy teaching and learning. This is followed by reviewing more recent innovations in anatomy education, including educational computerized platforms, such as virtual reality, and arts-based approaches. In an effort to support the promising data of arts-based methods in anatomy learning, several educational learning theories are discussed that help explain how the use of physical clay models supports both learning and engagement. The thesis then presents instructional recommendations in the form of a proposed protocol to illustrate the application of a clay sculpting activity of the human heart in an undergraduate, pre-medical classroom. The final portion of the thesis concludes with a discussion on the potential benefit of the protocol.

**Historical Overview of Anatomy Education**

**Beginnings of Anatomy**

According to Siddiquey’s “History of Anatomy” article (Siddiquey et al., 2009), anatomy is considered one of the oldest sciences as it was first recorded to be taught in ancient Egypt and Greece (300 BCE to 2nd century CE) namely through the mummification process and cadaver dissections. During these early mummification rites to preserve the body after death, Egyptians became familiar with the interior of the human body. Specifically, the abdominal organs were removed, placed in their respective canopic jar, and entombed alongside the sarcophagus (Mark, 2017). Hippocrates, the father of medicine, aided in educating a larger audience by writing several books on anatomy back in 460-377 BCE as he stated this subject was the beginning to understanding medical science. However, most of his work was based on speculation rather than empirical observations. Subsequently, the focus turned to dissections as the most influential anatomist is considered Galen from Rome, who based most of his work on the dissections of animals such as monkeys, pigs, sheep, and goats (Nutton, 2021). Still, the study of human
anatomy was very underdeveloped as it relied on animal anatomy. Thus, it wasn’t until 1091-1161 when the Arabian physician Ibn Zuhr carried out the first documented human dissection and postmortem autopsy. His work was monumental to the field as he described the earliest concepts of the circulatory system and metabolism while discrediting the speculations of previous theories. During the Renaissance, artists Leonardo da Vinci and Michelangelo di Buonarroti helped contribute to the field of anatomy through their realistic sketches and sculptures. Leonardo even performed his own dissections to learn more about the human body. However, Andreas Vesalius, an anatomist from Brussels, is credited for subtracting the fictional aspects of the field of anatomy with his detailed dissections findings. Throughout the 17th and 18th centuries, the use of human dissections as a learning tool was highly sought after in European anatomy schools but was limited due to the availability of cadavers. Thus, cadavers were obtained as they were available, legally or illicitly (Habbal, 2017). The first publication of the world-famous Gray’s anatomy text in 1858 (Gray, 1858) globalized the field as it was a widely popular, single volume on anatomy for the traveling doctor. In the context of anatomy education, a significant change was the shift from the public display of dissecting theaters to classrooms as a form of respect to the deceased. However, this severely limited the educational range of a single cadaver and increased demands (Siddiquey et al., 2009) proving to be a challenge for private and non-hospital associated medical schools. Over time, this radical shift from an apprenticeship model to a professional classroom model solidified into a standard requirement for all to abide by (McLachlan & Patten, 2006). In the 20th century, with the rise of imaging technology and other supporting sciences such as molecular biology and endocrinology,

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1 It is important to note that until 1745 anatomists and surgeons were two distinct professions with the latter stemming from barbers who performed shaves and haircuts. Barber-surgeons were allowed to treat exterior diseases with procedures such as tooth extractions but were not permitted to administer medication for internal complaints (Harold Ellis, 2002).
the development of anatomy subject matter converged into a reliable and accurate discipline. The debate now shifted from the quality of the subject matter to how best to implement effective anatomical pedagogy for medical classrooms.

**Traditional Cadaver Dissection**

Withstanding a millennium, cadaver dissection continues to be a popular approach to teaching anatomy and is considered to be part of the traditional approach alongside lectures. The benefits of dissection include the development of practical skills, human body appreciation, anatomy variability, teamwork, and peer interaction (Elizondo-Omaña et al., 2005). However, the data on its efficacy and use alone has revealed two perspectives on this tool. One perspective remains a strong advocate for cadaver dissection (Aziz et al., 2002; Cahill et al., 2002; H. Ellis, 2001) and has further proposed prosection (the act of observing a dissection performed by an experienced anatomist) as another promising anatomy learning tool as well (McLachlan & Patten, 2006). The other perspective on the general use of human cadavers considers dissections to be dispensable (Elizondo-Omaña et al., 2005; Finkelstein & Mathers, 1990; McLachlan & Patten, 2006). This is mostly due to the several disadvantages of dissections, such as cadaver shortage, especially in private medical schools, emotional distress, health and safety issues in handling, time, cost of maintenance, and construction of large, dissection rooms (Bergman, 2015; McLachlan & Patten, 2006). In the discussion of anatomy in undergraduate courses, these issues are concerning as colleges do not have the safety clearance, funding, and space for cadaver dissections. As a result, undergraduate anatomy courses must turn to other educational approaches to ensure students are both effectively and efficiently learning with the help of modern technology or alternative approaches. The development and application of newer curriculums in anatomy education are still in its infancy. Recent research has identified
promising educational innovations including the use of animal models, medical imaging, interactive online multimedia platforms, 3-D and virtual reality computer-assisted instruction, and physical models of various mediums (Donohue et al., 2016; Losco et al., 2017).

**Animal Models**

Inspired and derived from Galen’s work, the dissection of animal models in order to learn human anatomy is still prevalent throughout undergraduate/pre-medical education, graduate/medical school (Nobis, 2002), and research (Muschler et al., 2009; Rust, 1982). Common choices of animal models in anatomy dissection include the swine, canine, rabbit, and feline (Ericsson et al., 2013) of which the first two are frequently used in understanding cardiology (Camacho et al., 2016). Advantages of this tool include its active learning and hands-on nature as opposed to passive learning by reading a textbook. Additional benefits are exposure to tissue smell, color and texture, and the promotion of confidence in dissection techniques (Nobis, 2002). Interestingly, the use of animal dissections has been reported for specialty training in pharmacology (Shehnaz et al., 2013), otolaryngology (Abou-Elhamd et al., 2010), and endoscopic surgery (Dulguerov et al., 2000). While promising in many aspects, there are a few disadvantages of this educational tool for the purpose of learning anatomy. For one, animal anatomy is only comparable, not equivalent to human anatomy, bringing the transfer of knowledge gain into question. Other disadvantages include costs, proper storage, strict regulations, and profound ethical implications (Shehnaz et al., 2013). Thus, equivalent or superior alternatives to animal dissections have been presented in a meta-analysis when learning structural biology (Balcombe, 2001).
**Medical Imaging**

An essential component of modern healthcare, medical imaging has become a necessity for wellness screenings, early diagnosis, treatment guidelines, follow-ups, triage, and guided procedures (Bercovich & Javitt, 2018). Medical imaging refers to the various images of a human body resulting from multiple technologies and processes to diagnose and treat patients. Due to technical advances, medical images can be publicly accessed via the internet and stored in relatively small files (Bercovich & Javitt, 2018). Medical imaging is a promising addition in anatomy curriculum for many medical schools (Ganske et al., 2006) as this tool is used in the day-to-day clinical practice of physicians (Grignon et al., 2016). Popular imaging includes x-rays, ultrasounds, CT scans, and MRIs (Smith-Bindman et al., 2008). This is most likely due to their inherent nature of providing visualization of soft tissues, the main characteristic of anatomical structures. In conjunction with a traditional lecture, the resulting use of medical imaging showed a significant improvement in students’ performance (Brown et al., 2012; Kondrashova & Kondrashov, 2018; Teichgräber et al., 1996; Tshibwabwa & Groves, 2005) and ability to identify anatomic structures on various diagnostic images both short-term and long-term (Erkonen et al., 1992). Aside from enhanced learning of the human body’s structure and function, other benefits include significant improvement in clinical decision-making skills and greater comfort using medical technology (Hoppmann et al., 2015; Kondrashova & Kondrashov, 2018). Specific to learning cardiac anatomy, one study (Griksaitis et al., 2012) found no significant difference between using cadaveric prosection and ultrasonography, suggesting that this tool could be an equivalent alternative to using cadavers to learn cardiac anatomy. However, certain challenges of medical imaging do exist, including curricular time constraints, high cost of medical equipment, and lack of sufficiently skilled faculty (Mullen et al., 2018). Thus, while
effective in well-funded medical schools, medical imaging may not be a practical or economical option for all schools, particularly at the undergraduate, pre-medical level. Additionally, unless students are able to actively capture imaging on their own, this tool may be more passive than other approaches. Given the challenges in the wide-scale use of medical imagining and the potential lack of active learning, medical educators have looked to other approaches that can complement imaging.

**Online and 3-D Technologies**

Remote learning through interactive online multimedia platforms, such as websites, podcasts (Boulos et al., 2006), computer software, and learning modules, has been an important educational tool for many years (George et al., 2014), especially during the Covid-19 pandemic (Rose, 2020). Major benefits of using this approach are fewer demands for qualified faculty, relatively low costs, scalability, and limitless access and availability without the physical barriers (George et al., 2014). From enhancing traditional educational tools (Marker et al., 2010; Reeves et al., 2004; Shaffer & Small, 2004) to standalone virtual human anatomy dissection platforms (A. W. Phillips et al., 2012), technology in the classroom has shown promising results such efficient lab time, improved learning, and student satisfaction (Granger et al., 2006). Thanks to the modern advances in medical imaging, computer science, and information technology, three-dimensional educational tools have been developed from clinical images and donated cadavers (Pommert et al., 2006; Temkin et al., 2002) and are accessible in convenient forms such as smartphone applications (Zargaran et al., 2020). Approaching anatomy from a three-dimensional learning mode has been of interest to educators given anatomy’s inherent 3-D nature (Grignon et al., 2016). The development of these unique programs has maximized student accessibility while minimizing the student-to-cadaver ratio. Additionally, this approach is more cost-effective as it
bypasses the strict regulations of cadaver storage and dissection halls. Its successful educational use (Yammine & Violato, 2015) has been reported in both graduate and post-graduate education in head and neck anatomy (A. Hu et al., 2009; G. S. Phillips et al., 2012; Yeung et al., 2011), vascular structures (Petersson et al., 2009), and gastrointestinal anatomy (Tam et al., 2010). Interestingly, when directly compared to traditional anatomy textbook usage, students preferred the 3D approach for visualization over the textbook (Petersson et al., 2009) as a result of instant manipulation of a specific structure and a 360-degree visual field. Collectively, the educational approaches discussed represent a move beyond using a textbook alone and suggest that there is value in non-traditional methods that draw on active learning, engaging, and easily manipulable human structures to learn anatomy. This is in line with recent calls to explore arts-based approaches in medical education.

**Interdisciplinary Art-Based Approaches**

**STEAM Education Model**

In an effort to increase student engagement, creativity, and, problem-solving skills, in STEM (Science, Technology, Engineering, and Mathematics) fields, STEAM (Science, Technology, Engineering, Arts, and Mathematics) education emerged around 2007 (Perignat & Katz-Buonincontro, 2019). This has included efforts to integrate the arts into STEM classes. Arts-based curricula were found to be beneficial since they place less emphasis on abstract goals and more emphasis on the creative process that produces tangible projects or pieces (Perignat & Katz-Buonincontro, 2019). During the developmental process, students must independently explore materials, take risks, and problem-solve inevitable mistakes to complete their goal. As a result, skills such as sensory feedback with various mediums, perseverance through failure, self-efficacy, critical thinking, cooperativity (in a group setting), and creativity are all enhanced
With the substantial potential in arts-based approaches in learning, the STEAM education model is an attractive educational shift that can better prepare students for their future professional careers in medicine, as well-rounded physicians must be able to think logically and critically while effectively cooperate with their team and patients (Segarra et al., 2018). Additionally, through the arts and humanistic perspective, students have the advantage of gaining more respect for the human body (Kamensek & Davidson, 2017), which aids in sensitivity training when treating patients.

**Art-Based Physical Models**

Of the numerous supplementary tools to traditional cadaver dissection, the integration of arts and sciences through physical models of various media is particularly exceptional in anatomy medical education. Sharing the advantages of traditional cadaver dissection, this tool allows for the development of tactile manipulation skills and multiple sense engagement. However, in contrast to cadaver dissection, physical models are extremely cost-effective, easier to obtain and store, have no moral or ethical implications, and students reported enjoying this activity over others (Preece et al., 2013). The use of body painting (Finn, 2018; McMenamin, 2008), plastic models (Fredieu et al., 2015b; Mitrousias et al., 2020), and clay sculpting (Motoike et al., 2009b; Noland et al., 2016; Oh et al., 2009a; Segarra et al., 2018) are examples of innovative, hands-on activities that have been investigated.

In one study investigating the use of body painting in medical curriculum (McMenamin, 2008), students were given non-toxic body paints and brushes to paint the anatomy of the respiratory system, musculoskeletal system, and head and neck anatomy on each other. The advantages of this teaching exercise included its tactile-kinesthetic nature, active participation, and peer evaluation. The student feedback form revealed a strong appreciation for the activity
and its value (McMenamin, 2008). Other studies report the use of modern-day plastic models as a supplementary activity in anatomy learning. One specific advantage of plastic models is their clarity in displaying concrete smaller structures. However, the resolution is usually cost-dependent (Fredieu et al., 2015a). In a study comparing cadaver prosection versus the use of plastic models (Mitrousias et al., 2020), no significant difference was found between the two, suggesting that the plastic models were just as effective in teaching anatomy as using a cadaver. However, it is important to note that plastic models cannot truly represent the human anatomy as they lack the interstitial tissues and fluids, which can be found in cadavers. Additionally, the overrepresentation of colors, such as blue corresponding with veins and red with arteries, does not correlate to the true colors of the human anatomy which typically are pink, red, and white. Thus, while useful in learning basic anatomy, the use of plastic models would not be as practical for training surgeons for the reality of the human body. Another major disadvantage of this tool is the likelihood of losing smaller pieces over time (Fredieu et al., 2015b). All combined, these issues were enough for the researchers to suggest using other methods. Resolving the major hindrance of price, clay sculpting has taken a stronghold in medical and pre-medical anatomy classrooms.

**Clay Sculpting in Anatomy**

Several studies integrating art-based activities through the use of clay models (Motoike et al., 2009b; Noland et al., 2016; Oh et al., 2009a; Segarra et al., 2018) have shown promising results in its efficacy for anatomy learning. The initial evidence suggests sculpting anatomical models can improve both anatomy recognition (Oh et al., 2009a) and 3-D spatial knowledge (Yammine & Violato, 2016). Moreover, sculpting provides an opportunity for students to participate in an active and engaging learning experience in a collaborative setting while
developing a deeper appreciation of the complexity of anatomical structures. In an education research study (Krontiris-Litowitz, 2003) on the use of modeling clay in an undergraduate neurophysiology course, students were asked to manipulate the clay into three different structures (an ion channel, nerve cell, and passive membrane). Compared to a control group of students who did not partake in this modeling activity, students that completed the activity scored significantly better on the post-activity quiz. During the instructor-monitored activity, students could receive immediate feedback through question-answer discussion sessions to correct mistakes in their model. By this active line of questioning, akin to an art class critique, some students admitted that they had not understood the material as well as they had thought before attempting to create their models. After the activity, students reported that they finally understood how the arrangement of a particular structure contributes to its function, a critical point to understanding physiology in the biological sciences. Imperative to note, the quality or sophistication of the clay construct did not seem to affect the comprehension level of a student. The researchers identified that a limitation of this particular study could have been a disparity in time to topic exposure as the control group was immediately retested on the subject matter (Krontiris-Litowitz, 2003). Thus, another study (Motoike et al., 2009b) from LaGuardia Community College in Queens, NY compared clay sculpting against cat dissection for human muscle identification in an undergraduate human anatomy and physiology course. Recognizing the moral implications of animal dissection, researchers wanted to explore clay sculpting as an educational tool for its three-dimensional and multisensory characteristics within a group learning environment. Just as dissection revolves around dismantling a structure to learn its components, constructing the structure with a clay medium achieves the same goal. Randomly assigned to either the clay sculpting or cat dissection group, students either modeled a specific
list of muscles and attached them to a plastic human model or completed a traditional dissection following a lab manual, respectively. The overall grades in the course were not significantly different between the two groups suggesting equal efficacy of the tools. However, the third practical muscle examination revealed that students who clay-modeled muscles performed better than those who dissected cats (Motoike et al., 2009b). This same college revised its curriculum in 2014 by replacing cat dissection with rat dissection. Once comparing rat dissection activity scores to clay sculpting activity scores, the results supported their initial findings that clay sculpting was significantly more effective than dissection (Haspel et al., 2014). Similarly, a medical school incorporated clay sculpting into their gross anatomy and neuroanatomy courses as a supplementary tool to understand CT and MRI medical imaging (Oh et al., 2009a). Forty 2nd and 3rd-year medical students were required to make clay models of the heart, liver, carpal, and tarsal bones (hand and foot bones, respectively), the brain, stomach, duodenum, pancreas, spleen, and gall bladder. In this particular study, students were allowed to choose colored clay to distinguish different segments of the organ. Then, they sculpted it part-by-part referencing textbook figures and atlases along the way. Once finished, the sculptures were then boiled to prevent cracking and appropriately cut to reveal cross-sectional surfaces. To investigate the efficacy and long-term retention of the activity, the same 20 question CT examination was administered to students from another medical school after completing the gross anatomy course and then again after six months. While the objective exam scores did not vary enough to be statistically significant, the clay group scores were overall better (Oh et al., 2009a). Two additional surveys revealed that 97% of the students found the activity satisfactory or very satisfactory. By including open-ended questions, a majority of the students reported that they were able to understand the three-dimensional and cross-sectional anatomy more easily after clay
sculpting, slicing, and comparison to CT and MR imaging. Others stated that active participation and interest in model making were reasons for their positive scores. This particular study stands out among the others as it takes both quantitative and qualitative data into account since it is known that the latter significantly affects the former (Harackiewicz et al., 2016).

While the findings of these experiments show great promise, further research is needed as this still remains a fairly novel, underutilized learning tool, particularly among pre-medical, undergraduate students. The typical variables coded for in this genre of educational research are quantitative scoring on examinations with some data on student satisfaction. However, there is a call to obtain more data on students’ motivation, engagement, and emotions during and after the activity to better understand the impact in relation to academic performance.

**Educational Learning Theories**

Of the many benefits of clay sculpting as part of an anatomy curriculum, the intrinsic engaging and hands-on nature of the activity stands out in terms of support a more positive learning experience. Creating an instructional protocol could help educators to implement sculpture learning activities in the pre-medical anatomy curriculum. However, to better understand exactly why and how clay sculpting enhances learning, the following learning theories are considered for their application: Constructionism learning theory, Control-Value Theory of Emotions, and Multimedia and Multimodal learning theories.

**Constructionism and Active Learning Theories**

Papert’s constructionism theory of learning (Han & Bhattacharya, 2001; Papert & Harel, 2002) builds on Piaget’s constructivist theory\(^2\) (Dennick, 2016; Matthews, 1998), which argues

\(^2\) Constructivist perspectives of learning are based on the idea that learning involves the active process of constructing new knowledge by connecting it to prior knowledge and experience (Dennick, 2016; Matthews, 1998)
that meaningful learning is actively constructed by the learner, not simply memorized from teacher to student. Constructionism differs in that it refers to active learning from physical construction of concrete or tangible artifacts that can then be shared within a group setting (Parmaxi & Zaphiris, 2014; Zargaran et al., 2020). By flushing out as many abstractions as possible, learners are able to construct physical experiences or models themselves and take charge of their active learning process (Matthews, 1998). In this context, the educator becomes more of a facilitator rather than an instructor as the students gain control of their own learning, an important component in building student self-efficacy and motivation (Zimmerman, 2000). Additionally, these physical or concrete models, once completed, can be further analyzed and interpreted by the learner, allowing the learner to create and re-create their knowledge even after the construction process has been completed (Parmaxi & Zaphiris, 2014). This is in contrast to the dominant instructionism method of teaching\(^3\) (Wilson, 1996). By considering constructionism teaching approaches within undergraduate anatomy classrooms, pre-medical students can reap the benefits earlier on and carry these well into their medical school and career. Aside from the constructionist perspective on learning, the use of sculpting in anatomy can be supported by another theory namely, the Control-value Theory of Achievement Emotions. This theory addresses the importance of capturing learner interest and enjoyment.

**Control-Value of Achievement Emotions Theory**

Encompassing almost every human thought and activity, emotions in an educational context were historically an overlooked topic, especially in medical education (Artino et al., 2012). However, the importance of learner emotions within the classroom is now considered an

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3 Instructionism is commonly referred to as the *sponge method* of teaching, where learners absorb the information usually through lectures and store it until the respective academic examination. Then, “the information is wrung out of them” (Wilson, 1996, p. 93)
essential variable in educational research. Achievement emotions are defined as emotions tied to academia and academic performance such as enjoyment and boredom. The Control-value Theory of Achievement Emotions is a comprehensive approach to understanding emotions in the educational setting. The main principle of this theory argues that when learners both value an activity and feel in control of their learning, they are more likely to experience positive emotions, such as enjoyment, which influences student motivation and engagement (Artino JR. et al., 2012; Pekrun, 2006). Whereas interest contributes to the initial motivation and attention, enjoyment helps to sustain engagement throughout the learning process (Reeve, 1989). Interest and enjoyment are important to support in learning, as these states not only energizes the learner to be more engaged and attentive, but it is a powerful motivator to learn (Harackiewicz et al., 2016). Research (Hidi & Harackiewicz, 2000) has shown that when students are interested in their field of study, they are more likely to regularly attend class, pay attention, engage with the material, further their education by taking more courses, process new information more effectively and ultimately perform well. Additionally, interest creates a predisposition to reengage with the material over time (Harackiewicz et al., 2016). Curiosity is another positive emotion that is both relevant and essential to this discussion. Fundamental for medical education, curiosity in doctors helps to understand the patient’s perspective, build respectful relationships, deepen self-awareness, and encourage lifelong learning (Dyche & Epstein, 2011). However, identifying novel teaching approaches that spark curiosity, interest and engages students in science to learn dense and complex subject matter can be challenging.

Interestingly, the use of hands-on, active learning approaches has been shown to foster positive emotions. Studies show that science classrooms featuring hands-on activities not only

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4 For the purpose of this thesis, the distinction between enjoyment and interest is minimal as they can be considered related states.
have been significantly correlated with greater engagement but also higher performance in tests (Grabau & Ma, 2017). Furthermore, anatomy students rated experiential learning (learning by doing) strategies significantly more engaging, enjoyable, interesting, and more likely to use this approach in the future (Diaz & Woolley, 2015). In another study (Naug et al., 2011) investigating student modeling of anatomy with plasticine, a putty-like material, the majority of learners reported the activity as “Fun.” Additionally, 48%, 46%, and 61% of students agreed that the activity was “Challenging”, “Stimulating”, and “Made me think”, respectively. In the context of anatomy learning by clay sculpting, previous research (Bell & Evans, 2014; Diaz & Woolley, 2015; Haspel et al., 2014; Noland et al., 2016; Oh et al., 2009a) also supports learning by satisfying the emotional aspect of education. While the constructionist and control-value of achievement emotions theories are reasons to support the use of clay sculpting in this outlined protocol, principles of multimedia learning are also useful to apply.

**Multimedia and Multimodal Learning Theories**

Drawing on several theories the cognitive multimedia learning theory (Mayer, 2014b) argues for teaching materials to contain both verbal and graphical representations (e.g., text and pictures) of the material to best guide the learner’s cognitive processing during learning. To understand the full scope of this theory, it is important to know the key principles for design (Mayer, 2010). The first principle of design is to reduce extraneous cognitive processing as it is recognized there is a limited capacity for processing material and is subjective to overload (Mayer, 2010). An example of extraneous processing could occur when descriptive text on the physiology of the heart is on one slide and the actual image is on another slide. Since the

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5 One theory is the dual coding theory, which essentially recognizes that cognitive processing occurs in two distinct channels. One pathway is the visual/pictorial pathway while the other one is the auditory/verbal pathway. Combining this with the model of working memory and cognitive load theories, it is recognized that each pathway has a limited capacity and should not be overloaded (Mayer 2010).
corresponding information appears on another slide, learners must consume a portion of their cognitive processing capacity to connect the information together. A solution to this specific issue could be solved by simply placing the relevant illustrations and diagrams on the same slide as the respective descriptive text, freeing up cognitive processing capacity. The second principle is to manage essential processing of the material in line with the instructional objectives by aiming to maximize working memory (Mayer, 2010). When teaching inherently complex subject matter, there should be time to process the carefully organized material as to not overload the cognitive capacity. The third principle of design is to foster generative processing and deep learning by engaging and motivating learners (Mayer, 2010). Generative processing refers to the actual process of material in an organized manner so that it makes sense to the learner. Thus, according to the multimedia learning theory, educational material should be prepped and presented with both verbal and graphic components aligned with the educational principles outlined above. The application of these principles of design has yielded positive results in educational settings (Mayer, 2001, 2003a, 2014b). In medical education, it was found that students taught with Mayer’s multimedia design principles in a slideshow statistically outperformed those taught with a traditionally designed slideshow in total scores and retention (Issa et al., 2011). In a recently published article (Mayer et al., 2020), researchers identified five ways to increase the effectiveness of instructional videos through dynamic drawing, gaze guidance, generative activity, perspective, subtitle, and seductive details. Of the five, the instructor-led video in this protocol features a generative activity and some first-person perspective scenes.

Interestingly, when incorporating emotionally appealing and decorative illustrations, learner performance and self-ratings of motivation increased (Mayer, 2014a). Several studies
aimed at teaching immunology concepts to education graduate-level (Plass et al., 2014) and college-level (Um et al., 2012) students showed an induced positive mood after viewing the cartoon-designed image. An example of this type of illustration for cardiac anatomy learning could be a cartoon character version of the heart lifting free weights to represent its characteristic pumping motion. However, there were limitations to using these design elements as it was found that precious cognitive capacity resources were utilized for extraneous processing rather than generative processing. Importantly, the decorative illustrations were particularly harmful for low prior knowledge learners, who are more subject to cognitive overload. Although the findings are not yet clear in terms of how to best integrate emotional design, the overall goal to consider learner emotions and interest is supported in this protocol aimed at introductory-level, undergraduate anatomy students.

Although similar to the multimedia learning theory, the multimodal learning approach differs in that it is the active process of learning information through a combination of multiple sensory modes such as through linguistic, visual, auditory, spatial, temporal, tactile, and kinesthetic sensory routes. For example, a multimodal classroom may feature a lecture with an accompanying slideshow followed by an in-class discussion of the material among the students. In this example, the following modes have been covered: auditory, visual, and linguistic modes, respectively. Highlighted in an extensive review (Moreno & Mayer, 2007; Sankey et al., 2010) of this theory, the major benefit of this approach is that students have the ability to experience the material via multiple modalities. This leads learners to believe that the information is easier to learn and improves attention, which in turn increases academic performance. Research (Mayer, 2003b; Minhas et al., 2012) has also shown that the majority of science students not only prefer and show superior performance when using active or multimodal learning approaches
in undergraduate science courses (i.e., integration of several learning methods) but also foster positive emotions and increased motivation (Park et al., 2015). As discussed earlier, the emotional component of the learner plays a large role in their depth of learning and achievement (Hecht et al., 2019; Pekrun, 2006). Thus, the multimodal approach not only holds its own advantages but simultaneously promotes the positive emotional state of students. Of the literature (Sankey et al., 2010) regarding the efficacy of the multimodal approach, the tactile-kinesthetic modality, in particular, is gaining popularity in educational research (Magana et al., 2019).

Tactile-kinesthetic modalities involve active, physical participation among learners and/or their environment to learn the material. For example, it could mean asking students to walk around the classroom to understand the rotations of planets or creating individual models (Mobley & Fisher, 2014). In medical education, tactile activities hold immense value as healthcare professionals must be in tune with their hands-on skills to manipulate the human tissue with or without tools. Surgeon-physicians, in particular, must be thoroughly trained to use their hands as routine patient checkups and procedures are part of the everyday job. Thus, research has investigated the efficacy of tactile-based activities in medical education as seen by several studies. In 2018, Michigan State University conducted a study (Fenn et al., 2018) in which physiology students learned cardiac electrical rhythms and contractile patterns by physically contracting a squishable heart model in their hands. Another study (Huang et al., 2014) reported significantly higher results for training surgical suture skills via the hands-on approach. Relevant to the modern use of robot-assisted surgery, haptic feedback integrated into the robot has been found to reduce errors due to excessive force by 40% (Lim et al., 2015). Many

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6 Tactile specifically refers to the sensation of touch and fine motor skills while kinesthetic refers to the sensation stimulated by larger bodily movements and gross motor skills (Carpenter, 2008). However, the two terms are typically associated together due to their similarities and can be referred to as tactile-kinesthetic.
other innovative tactile learning activities remain researched for all aspects of medical education. However, for anatomy learning, clay sculpting has been a unique and multi-disciplinary tactile-kinesthetic activity for pre-medical and medical students to learn a tissue or organ’s shape and structure (Krontiris-Litowitz, 2003; Oh et al., 2009a; Motoike et al., 2009b; Bareither et al., 2013; Lombardi et al., 2014; Haspel et al., 2014; Kooloos et al., 2014; Bell & Evans, 2014; Noland et al., 2016; Carlson et al., 2019).

Given my own experience as a pre-medical student, my aspiration to become a physician, and my review of the established literature, I have designed an educational activity in which students can learn the anatomy of the human heart through clay sculpting. The proposed educational protocol was informed by the constructionist theory of active learning, control-value of achievement emotions theory, multimedia learning theory, and overall represents a multimodal learning approach.

**Protocol & Educational Activity**

Inspired by my Art Studio minor with an emphasis on 3D ceramics and my passion for healthcare as a future physician, I have designed a multi-disciplinary protocol for a proposed clay sculpting learning activity for anatomy learning at the undergraduate, pre-medical level. Anatomy professors and laboratory instructors can use this activity as a required experiment in their course during the time students learn about cardiac anatomy. Teaching assistants (TAs) involved in this anatomy experiment can attend a one-hour workshop beforehand to learn the basic sculpting skills and attempt the project themselves. This is more logistical than opposed to requiring ceramic faculty members who are knowledgeable of cardiac anatomy to be present during that laboratory day. The focus of this activity is the human heart as it is the key organ in the body’s circulatory system. This closed system is responsible for transporting blood, nutrients,
chemicals, waste by-products in, around, and out of the body. This system is also one of the life-threatening systems which should be cared for in emergency care\(^7\) (Mistovich & Karren, 2014).

For the purpose of clay sculpting, the heart was focused on as it is a relatively small organ to recreate, comparable to the size of a fisted hand, especially when compared to the other human organs (Elaine N. Marieb et al., 2019).

The first component of this educational protocol is the pre-activity quiz containing 20 multiple-choice questions of varying difficulty to gauge the baseline knowledge of the learners about the anatomy and physiology of the human heart before any teaching instruction (Refer to Appendix A). Both pre-activity ad post-activity quizzes contain questions and illustrations from the *Human Anatomy Atlas 2021 Application* (Visible Body, 2021). Other questions have been created based on the material in the slideshow. This application is uniquely different from others as this learning tool allows students to view a specific anatomic structure based on 3D views of a simulated human body. Using screenshots of these 3D images, learners will be asked to identify the structure from the name, function, or relationship to other structures as a question. This outcome measure is being used as a question type as it should gauge the 3D/spatial knowledge learned through the sculpting activity or lack thereof. The various angles of the heart featured in the images help to challenge learners in their 3D knowledge of the subject. However, not only do the questions vary in format to gauge both non-3D and 3D knowledge, but they are of varying difficulty. Once submitted, learners will view the recorded lecture which has been supplemented by a multimedia designed slideshow\(^8\) (Refer to Appendix B). The learning objectives of the anatomy of the human heart slideshow include the location and orientation within the thorax,

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\(^7\) Airway, Breathing, and Circulation are the three critical components to assess and treat when providing emergency care to patients.

\(^8\) The information and diagrams on the slideshow have been sourced from *Human Anatomy. 9th edition* by Pearson (Elaine N. Marieb et al., 2019) and *Anatomy and Physiology* by OpenStax (Betts et al., 2013), respectively.
layers and structure of the heart, chambers & valves, pathway of blood throughout the heart, cardiac muscle tissue, conducting system and innervation, and blood supply to the heart. The slideshow component of this proposed protocol has been created to contain multimedia design components by placing relevant text and imaging on the same slides to satisfy the multimedia learning theory and reduce extraneous processing. It is also formatted in an aesthetically pleasing theme featuring warm colors.

Following the lecture, learners will then be provided with appropriate materials, an instructor-led video (Refer to Appendix C), and an instructional guide (Refer to Appendix D) to sculpt their own clay model of the human heart. In the instructor-led sculpting video, the instructor simultaneously summarizes key components of the heart structure and teaches the required sculpting techniques step by step in order for the learner to represent these structures in a clay model. The instructional guide manual also lists out the steps needed to complete the project and features multiple anatomically accurate diagrams for learners to reference. Since the video is only 20 minutes long due to editing, the overall activity is expected to take about 40 minutes. However, beginner learners should be provided with an approximately 60-minute window to complete this activity. This time allotment is more than sufficient for the learners to pause the video, take time to review the anatomical diagrams as they work on each stage of the model, and complete the activity at their own pace. They can also utilize any extra time within that window to improve their level of detail on the model, continue to study more detailed aspects of the organ or even create multiple models. The inherent nature of using multiple modes of teaching satisfies the multimodal theory of learning through listening, watching, and engaging with the slideshow, dynamic video, guide manual, and clay medium. This in turn helps to foster learning and positive emotions as supported by the control-value of achievement emotions.
theory. The low-cost materials required for the clay sculpting activity are as follows: 2 lbs. Air-Dry Clay, Clay Sculpting Tool Set, Paintbrush, and Tap water in a cup. The overall cost for materials is less than $20.00 per student.

Referring to Appendix C and D, the first step in the sculpting process requires students to take a portion of their clay, approximately the size of a fist, to sculpt the main body of the heart. Then, the clay should be formed into a sphere and wedged to reduce air bubbles trapped within the clay, which can cause cracking. This basic ceramic technique involves pushing down on the clay and rolling it back in rhythmic motions. Once thoroughly wedged, the clay can then be shaped into the heart which is similar to a mango, featuring both a base and an apex. Next, taking a portion of the remaining clay, one thicker and one thinner column are rolled using a basic coiling technique. This technique is done by rolling a column of clay in between your hands until it elongates into a rope-like structure. The thicker coil represents the ascending aorta, as its diameter is greater, while the thinner one represents the superior and inferior vena cava. The thinner coil can then be cut into two sections with the slicing tool and attached to the heart base using the slip and score technique. The slip and score technique involves using the slicing tool to make diagonal cuts on both surfaces which are to be attached. Then, water is added with the paintbrush and the two structures are pushed together. It is then secured by smoothing the edges down, making the surface of the clay conjoin. This process is repeated to attach the thicker coil in the location of the ascending aorta. Excess length can be sliced off. The bulbous-ended tool can then be used to push divots into the ends of the coils to represent the hollowness of the vessels. Using the coiling technique described above, a thick coil should be sculpted to represent the pulmonary trunk. Once formed, this coil should be sliced in half using the slicing tool. Each slice represents the left and right pulmonary artery and should be reformed into a cylindrical
shape. Next, using the slip and score technique, this structure will be attached in its appropriate location on the heart. The bulbous-ended tool is used again to create divots in each artery opening. Manipulating the clay, the pulmonary trunk should lie underneath the aortic arch of the ascending aorta with the right pulmonary artery protruding towards the right of the heart. Excess length can be then be sliced off. Using the coiling technique, another thin coil should be made, sliced into four sections, and attached to the posterior portion of the heart to represent the left and right pulmonary veins. Using their tools and remaining clay, surface details can then be added to the heart. The sculpture should be allowed to dry and harden for 1-2 days before attempting to be painted.

After the activity, learners will be tested on their anatomy knowledge by answering another 20-question quiz (Refer to Appendix E). It is important to note that while most of the questions from the pre-activity and post-activity quiz will differ in the wording to deter memorization of the questions, the material tested is the same. For additional data, A Likert-scale questionnaire can be used to gauge the emotional outlook and response from the learners after the activity as emotions play a large role in the learner’s academic performance. Thus, by coding the correct/incorrect responses from the quizzes and analyzing the emotional data from the questionnaire, the activity’s overall efficacy can be determined. Findings from this proposed protocol will provide a better understanding of the possible benefits of realistically incorporating a tactile-kinesthetic activity as a part of the multimodal approach to aid medical and pre-medical students’ understanding of anatomy curriculum.

Referring to Appendix F, the ultimate objective of this educational protocol is for learners to obtain new knowledge of cardiac anatomy through a multimodal, multimedia, and tactile-kinesthetic activity. The protocol is created for an introductory, anatomy course as the
sourced materials, such as the textbook, and the learning objectives are all in line with a traditional undergraduate anatomy course. Additionally, Dr. Brasington, an undergraduate anatomy professor from the University of South Carolina, teaches students of this level and approved the designed protocol\(^9\). Students who undertake this course major in one or more of the following: nursing, chemistry, cardiovascular technology, biochemistry and molecular biology, biological sciences, physical education, exercise science, athletic training, biomedical engineering, public health, pharmaceutical sciences, pharmacy, medicine, pre-veterinary, and dental.

While the list of goals may vary, one aspect remains common. That is, of course, to effectively convey the material in such a way so that the student can learn new material. This protocol is expected to improve cardiac knowledge through the use of a generative activity as students must construct an anatomically accurate model. The result of using this highly engaging activity could also enhance long-term retention. While the literature supports these claims, future research on this subject should investigate these claims as educators would all agree on a curriculum that fosters deep learning and long-term retention of the material. Thus, it is important to routinely identify and analyze the efficacy of novel educational activities that can promote learning and positive emotions to best enhance attention, memory, critical thinking, and academic performance (H. Hu et al., 2007; Motoike et al., 2009b; Rowe et al., 2015). After delving into the literature, similar activities to the tactile clay sculpting activity in this thesis stand out for its hands-on learning and positive emotional response.

\(^{9}\) Dr. Brasington, a clinical professor in the Department of Biological Sciences at the University of South Carolina, who teaches courses in human anatomy and physiology, was consulted on the instructional materials (reviewed and approved the content of the pre-activity and post-activity quizzes, instructor-led video, and slideshow).
Discussion & Conclusion

From mummification rituals to virtual reality, the understanding of anatomy and its instructional approaches have remarkably evolved. While traditional tools, such as cadaver dissection still remain a part of the modern curriculum, innovative approaches are being researched. Of those, arts-based approaches are promising as the literature and evidence suggests that they can foster anatomy learning. Several learning theories, the constructionist theory of learning, control-value of achievement emotions, multimedia and multimodal learning theories, were identified for their key pedagogical principles, which were integrated into the design of this clay sculpting protocol. After reviewing a multitude of novel learning approaches in medical education and designing this arts-based educational protocol, this clay sculpting activity should be considered a valuable tool for learning cardiac anatomy at the undergraduate level for pre-medical students.

The positives of this activity are its low cost, high safety, easy clean-up, and small storage space. It is also beginner-friendly and takes much less time to complete than the typical, 3-hour allotted laboratory experiment time in science courses. Additionally, this type of activity is considered generalizable for other portions of human anatomy as it has been appropriately modified and successfully been utilized for learning the anatomy of other organs (Oh et al., 2009b), bones (Naug et al., 2011), and tissues (Motoike et al., 2009a).

While unique in many aspects, the design process of this activity itself is not baseless as it has been grounded in several educational theories as seen from Table 1 and reviewed by several educators. Referring to the instructor-led video (Appendix C) and guide manual (Appendix D) the Constructionist theory of learning is applied due to the active, assembling process. During this sculpting process, learners must pay close attention to the 3D form of the
model by analyzing every angle. Additionally, unlike learning from a textbook, learners can quickly identify their anatomy weaknesses on the spot and build on them, fostering deeper learning. Thus, in the context of this proposed protocol, learners, provided with background knowledge on the topic via a presentation and then allowed to independently sculpt a physical model of the heart with limited monitoring, should be able to successfully create and retain their knowledge. This idea has been supported by the many previously cited successful clay sculpting in anatomy studies and other academic medicine (Rees et al., 2020). An example and beneficial application of this constructionism-based protocol could be in an operating room setting.

Surgeons must have highly trained skills in constructionism-based processes in order to resect damaged tissue and reconstruct the remaining anatomy to a biologically safe spatial form. Additionally, the video is in line with certain multimedia principles to foster generative processing.

### Table 1

*Links between theory principles and clay sculpting design*

<table>
<thead>
<tr>
<th>Theory</th>
<th>Focus</th>
<th>Design Principles</th>
<th>Application of Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructionism &amp; Active Learning</td>
<td>Active learning from physical construction of concrete artifacts</td>
<td>Hands-on activity that results in a tangible item</td>
<td>Hands-on clay sculpting activity</td>
</tr>
<tr>
<td>Control Value of Achievement Emotions</td>
<td>Experience of positive emotions enhances motivation and engagement</td>
<td>Foster: interest, curiosity, enjoyment</td>
<td>Innovative/interesting activity, low stress, provide guidance to enhance control</td>
</tr>
<tr>
<td>Multimedia and Multimodal</td>
<td>Using multiple formats and sensory modes to present information</td>
<td>Reduce extraneous processing and cognitive load, organize material</td>
<td>Organized slideshow with text and graphics; auditory, visual, and tactile modes</td>
</tr>
</tbody>
</table>

Important to note, the heart clay model did not use multi-colored clay. This was intentional as the use of pseudocolors in anatomical diagrams and models may not necessarily
prepare learners for the actuality of the human anatomy as seen by a study that shows decreased academic performance when students were taught in color but tested in black and white (Wichmann et al., 2002). The discrepancy with teaching material through an alternate color scheme may consume cognitive resources. However, further research needs to be conducted on the impact of color use in anatomy learning.

In future research, this educational protocol could be adjusted to require painting of the hardened model to contrast anatomical structure and details more vividly. This requirement could also help students reengage with their model after the sculpting process. Additionally, design principles such as the perspective and subtitle principles for instructional videos could be added to increase the efficacy and accessibility. To gain more information on the efficacy of this activity in terms of deeper learning, students could be asked to retake the quiz portion at a later date to assess for long-term retention. Critical thinking quizzes could also be implemented to investigate the impact on problem-solving skills. Another interesting modification could include assessing the learners’ dissection skills before and after the implementation of this activity. This could reveal more information about the positive impact on tactile skills.

The sculpting process featured in this proposed protocol is most comparable to traditional dissection except learners are assembling versus disassembling anatomical structure to gain information. Additionally, the material section of a clay medium, as opposed to harder materials such as plastic or wood, allows learners to easily manipulate their model and grasp similar tactile sensations to human tissue. Since this simple activity has shown promise at the undergraduate, graduate, and post-graduate levels, it should be considered a valuable tool in training physicians within pre-medical programs, medical schools, residency programs, and fellowships.
However, while there are many beneficial aspects of this activity, a few issues of practicability and implementation of this tool could arise. One potential issue could be the availability of a basic ceramic teacher to aid in this anatomy activity or having an anatomy lab teaching assistant attend a workshop for basic ceramic sculpting skills. Another issue could arise during the sculpting process itself as these beginner skills may take some time to grasp. During a global pandemic and the present-day usage of online learning or e-learning, material availability may also pose a problem as providing students with the required materials or asking them to obtain the materials themselves may not be feasible. While there are recognizable issues with this tool, it is important to note that all educational tools and approaches have positives and negatives. It is up to educators to decide which will best fit their institution, curriculum, and enhance learning for their students. Thus, the beneficial potential in clay sculpting for anatomy learning should not be overlooked.

Ultimately, it still may not be all that clear as to what the perfect solution is for learning anatomy. However, what is clear is the need for continued research on innovative educational approaches and activities. Thus, the purpose of this thesis was not to overhaul the existing curriculum and claim the supremacy of any one methodology. Instead, the purpose of the thesis was to highlight a potentially beneficial activity to supplement existing pre-medical anatomy education. The proposed protocol was developed to aid future researchers and anatomy educators in implementing this activity within their classrooms. Since it is now well recognized that a combination of different approaches must be utilized in the classroom to help to maximize the learning benefits, there is a strong argument for more innovative, multimodal activities within science and pre-health classrooms. That being said, the established literature supporting the efficacy of a tactile clay sculpting activity is promising and should be considered for integration
into the pre-medical anatomical curriculum as it is extremely low-cost, practical, and has potential benefits in terms of knowledge retention, emotions, and development of relevant hands-on skills for their future career.

The inspiration for this thesis is my passion for medicine in combination with my Art Studio minor in 3D ceramics. As an aspiring physician, I recognize the sheer amount of time spent in academia before ever seeing a patient. Additionally, the modern physician must constantly refresh and learn about cutting-edge medical procedures and state-of-the-art technology. Thus, it only makes sense to continually adapt the medical and pre-medical curriculum. Lastly, physicians are responsible for educating peers, students, and the public community. Yet how can we expect our physicians to be both lifelong learners and educators without the discussion of innovative educational approaches within their own curriculum? Thus, through my proposed protocol for an innovative educational activity, I hope to help to contribute to efforts to adopt more engaging and multimodal approaches in pre-medical and medical programs.
Appendix

A. Pre-Activity Cardiac Anatomy Quiz (Key)

*indicates the correct answer

Link: https://annikzg.wixsite.com/website-4

Name: ____________________________________________
Major: ___________________________________________
Email: ___________________________________________

Carefully review the corresponding diagrams and answer each question.

1. Select the letter corresponding to the pulmonary valve.
   a. A*
   b. B
   c. C
   d. D

2. What valve connects the right atrium to the right ventricle?
   a. Mitral Valve
   b. Pulmonary Valve
   c. Bicuspid Valve
   d. Tricuspid Valve*

3. What valve connects the left atrium to the left ventricle?
   a. Tricuspid Valve
   b. Mitral Valve*
c. Pulmonary Valve
d. Aortic Valve

4. Select the letter corresponding to the subendocardial conducting network (Purkinje fibers).
   a. A*
   b. B
   c. C
   d. D

5. What type of cell-to-cell junctions are found in the heart's conducting system?
   a. desmosomes
   b. tight junctions
   c. gap junctions*
   d. plasmodesmata

6. Select the answer choice correctly listing the layers of the heart from the inside to the outside.
   a. epicardium, endocardium, pericardium, myocardium
   b. pericardium, epicardium, myocardium, endocardium
   c. myocardium, pericardium, endocardium, epicardium
   d. endocardium, myocardium, epicardium, pericardium*

7. Which structure(s) lies directly inferior to the heart?
   a. trachea
b. lungs

c. diaphragm* 
d. stomach

8. Select the letter corresponding to the structure which sets the heart rate.
   a. A
   b. B* 
   c. C
   d. D

9. Descending from the aorta, the _______ supplies the _____ side of the heart.
   a. right coronary artery; right*
   b. left coronary artery; left
   c. right coronary vein; right
   d. left coronary vein; left

10. The cardiac veins drain into the ______.
    a. left atrium
    b. inferior vena cava
    c. right atrium* 
    d. right pulmonary artery

11. Which answer shows the correct blood flow through the heart?
    a. Right atrium -> Right ventricle -> Left atrium -> Left ventricle*
    b. Right ventricle -> Left ventricle -> Right atrium -> Left atrium
c. Left atrium -> Left ventricle -> Vena cava -> Right atrium

d. Left ventricle -> Left atrium -> Right atrium -> Right ventricle

12. Heart valves involve one-way blood flow due to ______.
   a. volume differences
   b. temperature differences
   c. weight differences
   d. pressure differences*

13. Select the letter corresponding to the right pulmonary artery.
   a. A
   b. B
   c. C*
   d. D

14. Which vessel carries deoxygenated blood from the myocardium into the right atrium?
   a. pulmonary vein
   b. great cardiac vein*
   c. circumflex artery
   d. pulmonary artery

15. Which is NOT a function of the cardiac skeleton?
   a. prevents overdilation of valves
   b. facilitates the spread of autonomic electric impulses*
   c. attaches cardiac muscle
16. The pericardium is a ______-layered sac covering the heart.
   a. single
   b. double
   c. triple*
   d. quadruple

17. The coronary arteries stem from the ______.
   a. aorta*
   b. left ventricle
   c. left atrium
   d. lungs

18. Select the letter corresponding to the atrioventricular bundle (bundle of His).
   a. A
   b. B
   c. C
   d. D*

19. Which is NOT an extrinsic factor affecting heart rate?
   a. Parasympathetic fibers decreasing heart rate
   b. Sympathetic fibers increasing contraction strength
   c. Sinoatrial node setting heart rate*
d. Visceral sensory fibers conducting sensory impulses

20. Which vessel receives blood from the lower extremities?
   a. superior vena cava
   b. coronary sinus
   c. inferior vena cava*
   d. posterior cardiac vein
B. Multimedia Slideshow & Lecture

1. Location and Orientation within the Thorax
2. Layers and Structure of the Heart
3. Heart Chambers & Valves
4. Pathway of Blood Through the Heart
5. Conductive System and Innervation
6. Blood Supply to the Heart

19.1 Location and Orientation within the Thorax
- The heart lies posterior to the sternum and anterior to the diaphragm.
- Between a person’s 2nd and 4th ribs.
- posterolateral margin is at the level of the 5th intercostal space.
- a space lies in the left of a person’s vertebral column and anterior to the root of the heart.

19.2 Layers and Structure of the Heart
- The outer layer is the epicardium.
- the myocardium layer is the middle layer.
- the inner layer is the endocardium.

19.3 Heart Chambers & Valves
- The heart has four chambers: right atrium, right ventricle, left atrium, and left ventricle.
- Valves separate the atria from the ventricles.
- Atrioventricular valves and semilunar valves.
19.4 Pathway of Blood Throughout the Heart

19.5 Cardiac Muscle Tissue
- Cardiac muscle is composed of cardiac muscle tissue, the muscle responsible for contractions
- Inter muscular muscle cells, cardiac muscle cells are arranged in the sliding filament mechanism
- Contains gap junctions for cardiac conduction
- Nerves stimulate and innervate the heart

19.6 Conducting System and Innervation
- Initiates the rhythm of the heart
- Nerves stimulate and innervate the heart

Autonomic Innervation of the Heart
- Sympathetic fibers affect the heart rate
- Parasympathetic fibers decrease heart rate
- Sympathetic nerves increase heart rate and contractility

19.7 Blood Supply to the Heart
- Heart is supplied with blood by coronary arteries
- The right coronary artery supplies the right atrium, the left coronary artery supplies the left atrium
C. Instructor-Led Clay Sculpting Video

Link: [https://annikzg.wixsite.com/website-4](https://annikzg.wixsite.com/website-4)

Figure 1: The materials for this activity are 2 lbs. air-dry clay, clay modeling tool set, paintbrush, tap water and an optional digital kitchen scale.

Figure 2: The first basic sculpting technique shown is wedging. By pushing the clay forward and rolling it back in a rhythmic motion, air bubbles are removed.

Figure 3: After wedging, the clay shaped by shaped into a mango-like shape to represent the main body of the heart.

Figure 4: To create the arteries and veins, a coiling technique is shown by rolling a piece of clay between your hands and elongating the coil.

Figure 5: A thicker coil and thinner coil are made and then cut to an appropriate length for their representing structure.
Figure 6: A third technique called slip and scoring involves creating diagonal cuts on the clay, adding water with the paintbrush and pushing the two structures together.

Figure 7: This technique is used to attach the vessels in their respective locations.

Figure 8: By using the coiling and slip and score techniques again, more structures are sculpted and added to the body of the heart. Here, excess length is being cut off the pulmonary trunk.

Figure 9: The left and right coronary arteries are added to the posterior side of the heart.

Figure 10: Finally, smaller surface details such as the smaller coronary veins and arteries, ligamentum arteriosum, auricle of the left ventricle, muscle striations, and fatty tissue are added.
D. Instructional Guide

INSTRUCTIONAL GUIDE MANUAL

MATERIALS

<table>
<thead>
<tr>
<th>Material</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 lbs. Air-Dry Clay</td>
<td>$4.59/2.5 lbs.</td>
</tr>
<tr>
<td>Digital Kitchen Scale*</td>
<td>$9.99*</td>
</tr>
<tr>
<td>Clay Modeling Tool Set</td>
<td>$3.49</td>
</tr>
<tr>
<td>Paintbrush</td>
<td>$1.99/6 pieces</td>
</tr>
<tr>
<td>Tap Water</td>
<td>$-.--</td>
</tr>
</tbody>
</table>

*optional

PROCEDURE

1. Approximate and obtain a chunk of the clay about the size of a fist or an open-palm.
2. Prepare the clay for wedging by forming it into a sphere.
3. Wedge the clay by wrapping your fingers around the ball of clay while placing your thumbs on top. Then, roll the clay forward and back in a rhythmic motion and even pressure. (This helps to remove air bubbles which could cause cracking and tears in the clay.)
4. After 1-2 rounds of wedging, begin forming the basic shape of the heart by referring to the diagrams. [Figure 1]
5. Using the coiling technique, form a cylinder to represent the inferior and super vena cava. [Figure 2 on left]
6. Using the same technique, form a thicker cylinder to represent the ascending aorta. [Figure 2 on the right]
7. Make two cuts on the first cylinder [Figure 3] and attach the resulting pieces to the main body of the heart using the slip and score technique.
8. Once attached, smooth down the edges using your fingers or slicing tool to secure the pieces together.
9. Cut off excess length if necessary using the slicing tool.
10. Push in divets/holes using the bulbous-ended tool on each end of the vena cava vessels.
11. Repeating the same technique, attach the thicker cylinder to the main body of the heart. [Figure 5]
12. Using the coiling technique, create a thick cylinder to represent the pulmonary trunk.
13. Longitudinally slice the cylinder to create the right and left pulmonary arteries.
14. Pinch the pulmonary arteries coils together to reform a cylinder form and create divets using the bulbous ended tool at each end. [Figure 6]
15. Attach the pulmonary trunk to the main body of the heart using the slip and score technique. Make sure it lies beneath the aortic arch. Approximate and cut off excess length if needed. [Figure 7]
16. Coil a long and slim cylinder to represent the left and right coronary arteries on the posterior part of the heart.
17. Cut the coil into 4 sections of equal length. [Figure 8]
18. Attach the coils and create divets in each using the bulbous-ended tool.
19. Refer to the diagrams and add in surface details including the smaller coronary veins and arteries, ligamentum arteriosum, auricle of the left ventricle, muscle striations, and fatty tissue. [Figures 9-11]
20. Let the model harden for 1-2 days before painting. (optional)
ANTERIOR VIEW

POSTERIOR VIEW

E. Post-Activity Cardiac Anatomy Quiz (Key)

Link: https://annikzg.wixsite.com/website-4

*indicates the correct answer

Name: ____________________________________________________________

Major: ____________________________________________________________

Email: ____________________________________________________________

Carefully review the corresponding diagrams and answer each question.

1. Heart valves involve one-way blood flow due to ______.
   a. volume differences
   b. temperature differences
   c. weight differences
   d. pressure differences*

2. Select the letter corresponding to the structure separating the ventricles.
   a. A
   b. B*
   c. C
   d. D

3. The _____ drain(s) into the right atrium.
   a. cardiac veins*
   b. aorta
   c. coronary arteries
d. right pulmonary artery

4. Which is NOT a characteristic of a gap junction?
   a. low resistance
   b. rapid exchange of ions
   c. cell-to-cell communication
   d. slow conduction*

5. The subendocardial conducting network (Purkinje fibers) stimulate(s) ______.
   a. ventricle contractions*
   b. atrial contractions
   c. ventricle relaxation
   d. atrial relaxation

6. Select the letter corresponding to the atrioventricular bundle (bundle of His).
   a. A
   b. B
   c. C
   d. D*

7. What valve connects the left ventricle to the aorta?
   a. Tricuspid Valve
   b. Mitral Valve
   c. Pulmonary Valve
d. Aortic Valve*

8. Descending from the aorta, the __________ supplies the _____ side of the heart.
   a. right coronary artery; right*
   b. left coronary artery; left
   c. right coronary vein; right
   d. left coronary vein; left

9. Which structure(s) lies directly lateral to the heart?
   a. trachea
   b. lungs*
   c. diaphragm
   d. stomach

10. Select the letter corresponding to the vessel that carries deoxygenated blood to the right lung.
    a. A
    b. B
    c. C*
    d. D

11. What heart structure sets the pace of the electrical impulses?
    a. subendocardial conducting network
    b. atrioventricular node
    c. sinoatrial node*
    d. bundle of His
12. The pericardium is a ______-layered sac covering the heart.
   a. single  
   b. double  
   c. triple*  
   d. quadruple

13. Select the structure that prevents backflow from the right ventricle to the right atrium.
   a. A  
   b. B  
   c. C*  
   d. D

14. Which answer shows the correct blood flow through the heart?
   a. Right atrium -> Right ventricle -> Left atrium -> Left ventricle*  
   b. Right ventricle -> Left ventricle -> Right atrium -> Left atrium  
   c. Left atrium -> Left ventricle -> Vena cava -> Right atrium  
   d. Left ventricle -> Left atrium -> Right atrium -> Right ventricle

15. Which vessel carries deoxygenated blood from the myocardium into the right atrium?
   a. pulmonary vein  
   b. great cardiac vein*  
   c. circumflex artery  
   d. pulmonary artery
16. The cardiac veins drain into the _______.
   a. left atrium
   b. inferior vena cava
   c. right atrium*
   d. right pulmonary artery

17. Which is NOT a function of the cardiac skeleton?
   a. prevents overdilation of valves
   b. facilitates the spread of autonomic electric impulses*
   c. attaches cardiac muscle
   d. anchoring cusps of valves

18. Select the letter corresponding to the structure which feeds the coronary arteries.
   a. A
   b. B
   c. C*
   d. D

19. Which is NOT an extrinsic factor affecting heart rate?
   a. Parasympathetic fibers decreasing heart rate
   b. Sympathetic fibers increasing contraction strength
   c. Sinoatrial node setting heart rate*
   d. Visceral sensory fibers conducting sensory impulses
20. Select the answer choice correctly listing the layers of the heart from the outside to the inside.

a. epicardium, endocardium, pericardium, myocardium
b. pericardium, epicardium, myocardium, endocardium*
c. myocardium, pericardium, endocardium, epicardium
d. endocardium, myocardium, epicardium, pericardium
### F. Lecture Plan

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<th>LECTURE PLAN</th>
<th>Clay Sculpting Activity/Modeling the Human Heart</th>
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<td><strong>Objective:</strong> Knowledge Acquisition of Cardiac Anatomy</td>
<td></td>
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<tr>
<td><strong>Introduction:</strong></td>
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Upon completion of the pre-activity quiz, learners will sculpt a human heart model from 2 lbs. of air-dry clay and tools in an effort to supplement their cardiac anatomy knowledge through an alternative, active learning activity.

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<th>Strategies/Activities</th>
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<td>✅ Diagnostics</td>
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<tbody>
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<td>Peer-assessment</td>
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<td>Presentation</td>
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<tr>
<td>Graphic Organizer</td>
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<tr>
<td>Collaboration</td>
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<tr>
<td>Homework</td>
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| Assessment Description: |

Questions have been pooled from the *Human Anatomy Atlas 2021 Application* and the content from the slideshow. While the format is in multiple-choice, the difficulty of the questions varies.

<table>
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<tr>
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<td>Project</td>
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<td>Published work</td>
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References


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