

Comparison of the Effects of Clay Modeling & Cat Cadaver Dissection on High School Students' Outcomes & Attitudes in a Human Anatomy Course

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ABSTRACT

Increasing public concern over the use of animal dissection in education is driving development and testing of alternatives to animal use. Clay modeling has proven successful in achieving comparable or superior learning at post-secondary levels, but it has not yet been tested at secondary levels. This study tested the effectiveness and appeal of clay models vs. cat cadaver dissection in teaching human anatomy to high school students. Student performance on a content knowledge assessment increased following both the model and dissection laboratories. The use of clay models produced better short-term learning outcomes in human anatomy for high school students than the use of cat dissection techniques, although this improvement was not retained in students' final examination scores. Students found the clay models both useful and enjoyable. Overall, the majority of students chose dissection as the preferred technique; however, after the laboratory exercises, the proportion of students who chose dissection decreased, for both the clay modeling and cat dissection laboratory sections. In the clay modeling group, the proportion of students expressing preference for clay modeling was slightly higher than the proportion preferring cat dissection.

Key Words: anatomy education; secondary education; anatomy and physiology course; animal alternatives; cat dissection; clay modeling; 3D models; science perceptions.

○ Introduction

Animals historically have been used for teaching anatomy to students from grade school through graduate school. Cadaver dissection is still considered by many to be the “gold standard” in human anatomy teaching at the graduate and postgraduate levels (Preece et al., 2013; Ghosh, 2017), but this view is changing, particularly for educational programs outside of human medical training. Ethical and moral concerns surrounding the use of animals in teaching and research (Balcombe, 2001) have become more prominent. Unlike the situation in many postsecondary academic institutions, where people voluntarily donate their bodies for educational purposes, obtaining animal cadavers generally involves the euthanasia of healthy individuals. As Balcombe (2001) stated,

a “basic ethical principle asserts that if we have a choice between two ways of achieving something – one that causes pain, suffering and death and the other that does not – then ethical conduct dictates using the latter method” (p. 118). Furthermore, some of the species used in dissection, such as domestic cats, are familiar to students as family pets, and this may cause some students discomfort or emotional distress.

Relevant to the training of future scientists are the “three R’s” of Russell and Burch (1959), considered guiding principles for the more ethical use of animals in scientific research (Zurlo, 2009). The three R’s are *replacement* (use of methods that avoid or replace the use of animals in research), *reduction* (any strategy that will result in fewer animals being used, or in maximizing the information obtained per animal without compromising animal welfare), and *refinement* (use of methods that alleviate or minimize potential pain, suffering, or distress and that enhance the welfare of the animals used; see Canadian Council on Animal Care, 2020). Use of models instead of animal cadavers is in line with the three R’s and with the education of future scientists and medical professionals in the humane use of animals in research.

In addition, educators are faced with the decreasing availability and increasing cost of both human and animal cadavers (Hart et al., 2008; Estai & Bunt, 2016), while being offered an increasing range of other options (e.g., reusable, plastinated, and other specimens; Hart et al., 2008) and alternatives to animal use (e.g., computer simulations or three-dimensional models; Losco et al., 2017). Greenfield et al. (1995) suggest that these new approaches, to be considered acceptable, should result in student learning outcomes at least equal to those gained when traditional methods are used. A growing number of studies have identified effective teaching alternatives to cadaver dissection (De Villiers & Monk, 2005; Valliyate et al., 2012).

Successful alternative methods incorporate three important pedagogical benefits of traditional hands-on dissection: a three-dimensional appreciation of structures, a multisensory activity, and active, group learning (DeHoff et al., 2011). In particular, physical,

three-dimensional models may enhance learners' understanding of anatomical structures and the spatial relationships between them (Akle et al., 2018). Clay modeling incorporates these pedagogical benefits and has proven successful in achieving comparable or superior learning for college-level students (e.g., Myers et al., 2001; DeHoff et al., 2011). Models can also facilitate repetition in learning, allowing for the type of repetitive practice not possible when dissecting a cadaver (Saber et al., 2016).

Finally, the ability of clay models to illustrate a human representation, as opposed to that of another species (e.g., cat cadaver dissection), provides an inherent advantage for students of human anatomy. Previous research suggests that "students have a difficult time performing transformations from one representation of anatomy to another" (Waters et al., 2011). That is, they tend to perform better on exam questions related to the species they met within the learning process. When students learn on human models in preparation for exam questions related to human anatomy, this offers a consistency in knowledge domain, thus increasing the chances of successful learning transfer (Barnett & Ceci, 2002; Kulasegaram et al., 2012; Castillo et al., 2018).

Many authors have assessed students' attitudes toward dissection, and the appeal of alternative vs. traditional approaches (e.g., cadaver dissection). Student attitudes have varied. Some reported preferring dissection, which engaged students' interest and was associated with the notion that "science is fun" (Lombardi et al., 2014); others reported preference or support for using alternatives (Oh et al., 2009; Estevez et al., 2010). Balcombe (1997) suggested that many students would prefer not to do dissections, but that they often feel uncomfortable expressing such views. This is important because studies have highlighted a relationship between student engagement and learning outcomes such as improved critical thinking (Carini et al., 2006).

Despite evidence provided by studies at the postsecondary level, use of three-dimensional clay modeling as an alternative to dissection in human anatomy education has not been tested in secondary schools. Animal dissection is traditionally used in the curriculum in secondary school anatomy and physiology courses, and its continued use is supported by the National Science Teachers Association (2008).

This study tested two hypotheses regarding the effectiveness and appeal of using clay models vs. traditional cat dissection for teaching human anatomy to secondary school students. *Hypothesis 1* was that constructing clay models would result in comparable, or better, learning outcomes in human anatomy for high school students, when compared with cat dissection techniques. *Hypothesis 2* was that students in the clay modeling laboratory would report equal or greater enjoyment of the laboratory exercise than students in the cat dissection laboratory.

○ Materials & Methods

This study was conducted over three school years (2015–2018) at a large, diverse, urban public high school in northern California. Students were enrolled in a college-preparatory course in human anatomy and physiology, the learning objectives of which were to gain an in-depth understanding of the structure and function of the human body. Enrolled students were assigned (by school

administrators, based on other course selections and requirements for each student) to one course laboratory section. Laboratory sections were then randomly assigned by the lead instructor, prior to the start of the school year, to one of two study groups for the course unit on musculature: control (cat dissection) or experimental (clay modeling). Students then completed the laboratory exercise in human musculature by either dissecting a cat cadaver or building clay musculature onto a plastic human skeleton model (MANIKEN, Anatomy in Clay; Zahourek Systems, Loveland, Colorado; Figure 1). Given the fixed educational standards in U.S. public schools, researchers could not make substantial changes to the course content or students' learning goals. This course had previously used cat dissection only, although (to the best of our knowledge) the course's learning objectives were not biased in favor of using animal dissection. The course instructor began each period with a topic overview and laboratory exercise instructions, and then circulated among student groups, guiding students and answering questions. Student groups of four each worked on a cat cadaver or clay model. Efforts were made to ensure the comparability of lesson plans between the two groups (e.g., same topics covered and same amount of time allotted to each topic in both laboratory sections). Both groups (in all years) were given identical course lecture content, the same textbook (Thibodeau & Patton, 2006), the same online supplemental resources, and an identical list of muscles to learn (Table 1). The musculature laboratory exercise took five-and-a-half weeks, for both the cat dissection and clay modeling sections.

The intended learning outcomes for this portion of the human anatomy course were muscle naming, identification, and kinesthetic principles. To achieve these outcomes, students were given tasks such as completing a chart showing muscle name, origin, insertion, action, and antagonist for each muscle on the list (Table 1) and then identifying these on the constructed clay model or cat cadaver dissection. Prior to the laboratory, both groups were trained in skills specific to their assigned exercise (cat dissection or clay modeling techniques). Although the MANIKEN models can be used for modeling other systems (nervous, digestive, etc.), for the purposes of this study, only the muscles were constructed on the MANIKEN models. Traditionally, students' learning of this content was assessed through a set of multiple-choice questions nested within a final course examination (see Supplemental Material S1, available with the online version of this article), which took place approximately two to three weeks after the content was covered.

Student participation in the study was voluntary, and students were informed that their opinions and scores on all study assessments and surveys would not impact their course grades. All student scores and survey responses were anonymized using a unique numerical identifier provided by the course instructor prior to the start of each school year. All students, and their parents or guardians, signed consent forms prior to participation.

Learning Outcomes (Content Knowledge Assessment) (Hypothesis 1)

All students completed a pre- and post-exercise assessment consisting of 20 multiple-choice muscle anatomy questions. Pre-assessments were given on the same day that the musculature

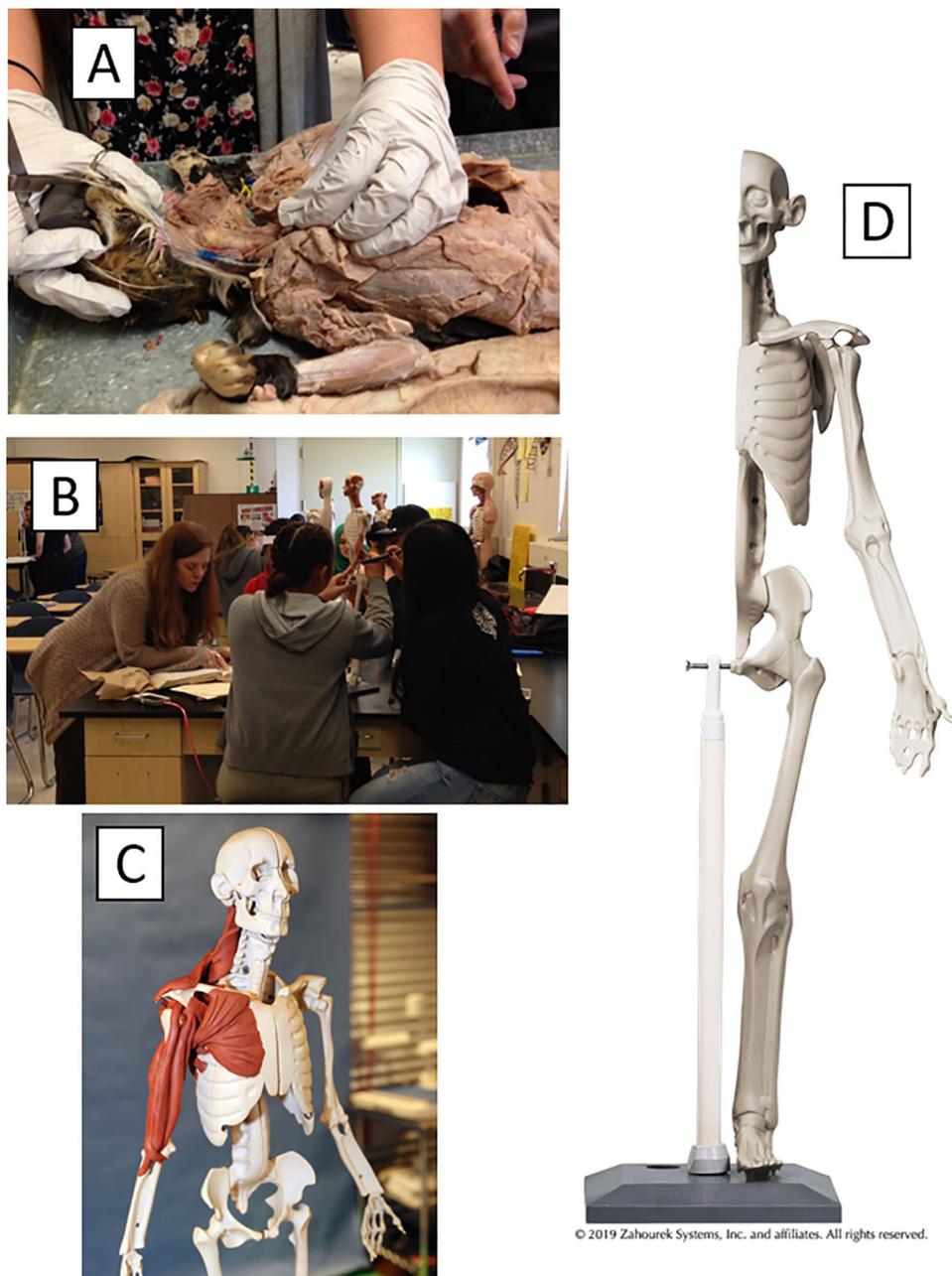


Figure 1. Views of (A) the cat dissection laboratory exercise in progress, (B) students working with the MANIKEN™ clay model, (C) a clay model partially completed, and (D) the human skeleton model. Photo credits: L. Hart (A), E. Grigg (B), Zahourek Systems (C, D).

set of questions prior to the laboratory exercise (i.e., as baseline) and another set immediately after, while the experimental group received the question sets in reverse order. In order to examine retention of the laboratory content over time, students' scores on questions on the course's final exam that were related to the muscle anatomy unit were compared for the two groups.

Attitudes toward Dissection & Enjoyment of the Laboratory Exercise (Hypothesis 2)

All students completed a short, Likert-scale opinion survey before and after completing the laboratory exercises, with responses ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Questions surveyed students' opinions on the ethics and usefulness of dissection, their enjoyment of laboratory exercises in general, and (following the lab) their enjoyment of the dissection or clay modeling in particular (Supplemental Material S3). All students were asked, before and after the laboratory, which type of laboratory exercise they would choose, if given the choice: clay models, cat cadaver dissection, or computer-based/virtual dissection. Note that students in this study did not participate in a computer-based/virtual dissection; this option was included only to assess student interest in this method, as compared to the two approaches studied. The survey was also developed in collaboration with the teaching faculty on the course and tested by a small group of anatomists, who gave feedback on content and overall questionnaire design.

unit was started, prior to beginning the laboratory exercise; post-assessments were given one day after students completed the musculature unit exercise. These questions, which included both simple recall questions ("lower-order" questions) and those requiring understanding and/or application of knowledge ("higher-order" questions), were developed in collaboration with the course instructor, were aligned with course goals and content (Supplemental Material S2), and were comparable to questions used in similar studies (e.g., DeHoff et al., 2011). The assessments were pilot tested by a small group of veterinary and secondary school anatomists who gave feedback on content and structure. A cross-over design was used; the control group of students received one

Statistical Analyses

To investigate outcomes and opinions in the two groups, this study used both within-sample comparisons (of student performance before and after the laboratory exercise; i.e., was student knowledge of the human musculature increased more by one type of laboratory exercise than by the alternative?) and between-group comparisons (of students in the control group vs. the experimental group; i.e., did students using one type of laboratory exercise score higher overall on the post-laboratory knowledge assessment than students using the alternative?). Wilcoxon signed-rank tests for paired samples were used to compare student performance on the knowledge assessment prior to and following the laboratory.

Table 1. Muscle list provided to students enrolled in the high school anatomy and physiology course.

Muscles of the Upper Body			
Body Part and the muscles that move it		Body part and the muscles that move it	
Shoulder	trapezius	Abdomen and chest	external oblique
	pectoralis minor		internal oblique
	serratus anterior		rectus abdominis
			transverse abdominis
			diaphragm
Upper arm	latissimus dorsi	Head	sternocleidomastoid
	pectoralis major		splenius capitis
	deltoid		trapezius
Lower arm	biceps brachii	Face	orbicularis oris
	brachialis		orbicularis oculi
	triceps brachii		zygomaticus major
	brachioradialis		buccinator
	pronator quadratus		masseter
			temporalis
Hand	flexor carpi radialis	Miscellaneous	ligamentum nuchae
	palmaris longus		lumbodorsal fascia
	flexor carpi ulnaris		linea alba
	extensor carpi radialis longus		central tendon of diaphragm
Muscles of the Lower Body			
Body part and the muscles that move it		Body part and the muscles that move it	
Thigh	iliopsoas	Lower leg	quadriceps group:
	rectus femoris		rectus femoris
	gluteal group:		vastus lateralis
	gluteus maximus		vastus medialis
	gluteus medius		sartorius
	gluteus minimus		hamstring group:
	tensor fascia latae		semimembranosus
	adductor group:		semitendinosus
	adductor longus		biceps femoris
	adductor magnus		
	gracilis		

(continued)

Table 1. Continued

Muscles of the Lower Body			
Body Part and the muscles that move it		Body part and the muscles that move it	
Foot	tibialis anterior	Miscellaneous	iliotibial tract
	gastrocnemius		Achilles tendon
	soleus		anterior cruciate ligament
	peroneus longus		patellar tendon

Table 2. Characteristics of student study participants (n = 217).

Variable	Category	Frequency	Percentage
Method	Cat dissection	91	41.9
	Clay model	126	58.1
Study year	1	64	29.5
	2	31 ^a	14.3
	3	122	56.2
Gender	F	143	65.9
	M	74	34.1
Grade level	11 ("Junior")	145	66.8
	12 ("Senior")	72	33.2

^a Only one laboratory section participated in the study in year 2.

Differences in student outcomes for the two groups were also examined, by comparing change in performance (proportion of maximum possible points scored) on the pre- and post-assessments, using Wilcoxon signed-rank tests. To investigate retention of the laboratory content over time, student scores (proportion of maximum possible points scored) on the musculature unit questions on the course's final examination were compared for the two groups, using Mann-Whitney *U*-tests. To assess student retention of the laboratory-related content vs. other course content, the ratio of score on the laboratory-related final examination questions to total score on the final examination was calculated for each student, and compared for the two groups (Mann-Whitney *U*-test).

Wilcoxon signed-rank tests for paired samples were used to compare attitudes toward dissection, perceptions of the exercises as useful and enjoyable, and choice of preferred laboratory method (clay, dissection, virtual) before and after completing the laboratory; and Mann-Whitney *U*-tests were used to compare student attitudes between the two groups (cat and clay). Note that for these analyses, some questions from the attitudes surveys (Supplemental Material S3) were reverse coded, so that in the results (below), lower scores on the "approval of dissection" indicate less approval for, or comfort with, dissection as a teaching tool.

To assess the impact of gender, attitudes toward each type of laboratory exercise, change in performance (pre- to post-exercise), and attitudes toward dissection before vs. after the lab were compared between male and female students (Mann-Whitney *U*-tests).

Because student score data were not normally distributed (Shapiro-Wilk test, $P < 0.05$), nonparametric tests were used for all comparisons. Statistical analyses were performed using XLSTAT 2019.1.1 (Addinsoft, Boston, Massachusetts) for Microsoft Excel 16.0. Significance for all analyses was set at $\alpha = 0.05$.

○ Results

Over the three school years, 217 students completed all assessments and surveys required for this study (Table 2). The majority (65.9%) of students in the study were female; however, the proportion of male to female students in each group was comparable (clay modeling: 65% F, 35% M; cat dissection: 67% F, 33% M). All students present on assessment days completed the survey instruments (i.e., all enrolled students consented to participate in the study). Students who did not complete all study instruments (e.g., due to absence from class) were not included in the analyses.

Learning Outcomes (Content Knowledge Assessment) (Hypothesis 1)

Baseline scores on the knowledge assessment did not differ significantly between the two groups ($P = 0.37$; Table 3). Following completion of the laboratory exercise, however, students in the clay modeling group did significantly better on the knowledge assessment than students in the cat dissection group; mean percentage scores (\pm SD) were 52.6 ± 17.1 for cat dissection ($n = 91$) and 58.9 ± 14.1 for clay modeling ($n = 126$) ($U = 4459$, $P = 0.005$). This difference was also seen when considering only the lower-order questions; mean percentage scores (\pm SD) were 58.6 ± 20.3 for cat dissection ($n = 91$) and 65.9 ± 17.1 for clay modeling ($n = 126$) ($U = 4459$, $P = 0.004$). Although students in the clay modeling group scored slightly higher on the higher-order questions than students in the cat dissection group, this difference was not significant ($P = 0.24$).

As expected, students in both groups significantly improved in their knowledge assessment scores, before vs. after the laboratory exercise (both cat and clay groups, $P < 0.0001$; Table 3). Students in the clay model laboratories, however, showed a significantly greater improvement in knowledge than students in the cat dissection laboratories ($U = 3636$, $P < 0.0001$). The effect size (difference between the two teaching methods in improvement in student scores) was modest (mean improvement: cat, 24.4%; clay, 31.3%; net 6.9% greater improvement when using clay modeling) but was strongly statistically significant. Improvement in knowledge ranged from zero to 68.7% improvement (cat dissection) and

Table 3. Results of the student knowledge assessments, before and after completion of the lab exercise using either the cat dissection or the clay modeling technique.

	Percent Score Pre-laboratory (Mean ± SD)	Percent Score Post-laboratory (Mean ± SD)	Percent Improvement, Post – Pre (Mean ± SD)	Difference (Pre vs. Post)?
Cat dissection students	28.2 ± 0.1	52.6 ± 0.2	24.4 ± 0.2	Yes ($P < 0.0001$)
Clay modeling students	27.6 ± 0.1	58.9 ± 0.1	31.3 ± 0.2	Yes ($P < 0.0001$)
Difference (cat vs. clay)?	No ($P = 0.37$)	Yes ($P < 0.006$)	Yes ($P < 0.0001$)	–

Table 4. Student attitudes reported prior to and following the laboratory exercise, for both the cat dissection and clay modeling groups, on a Likert scale of 1–5 (with 1 being “strongly disagree” and 5 being “strongly agree”).

Survey Item	Cat Dissection Exercise			Clay Modeling Exercise		
	Median	Mode	Mean ± SD	Median	Mode	Mean ± SD
<i>Lab was enjoyable</i>						
Pre-lab	NA	NA	NA	NA	NA	NA
Post-lab	4.0	4.0	3.6 ± 0.9	3.7	4.0	3.7 ± 0.9
<i>Lab exercise was useful in learning material</i>						
Pre-lab	NA	NA	NA	NA	NA	NA
Post-lab	4.0	4.0	3.8 ± 0.7	4.0	4.0	3.9 ± 0.7
<i>Approve of dissection as a teaching technique</i>						
Pre-lab	3.7	4.0	3.6 ± 1.0	3.3	3.3	3.3 ± 1.0
Post-lab	3.0	4.0	3.2 ± 1.3	3.0	3.0	3.2 ± 1.3
<i>Value student ability to choose laboratory technique</i>						
Pre-lab	4.0	4.0	4.1 ± 1.0	4.0	4.0	4.3 ± 0.9
Post-lab	4.0	5.0	4.4 ± 0.6	4.0	5.0	4.3 ± 0.9

from zero to 72.7% improvement (clay models). Improvement in knowledge assessment score, pre- vs. post-laboratory, did not differ by gender ($P = 0.932$), student grade level ($P = 0.367$), or study year ($P = 0.096$).

By contrast, students in the cat dissection group did significantly better on the final examination than students in the clay modeling group, both on questions related to the laboratory exercise ($U = 7555$, $P < 0.0001$) and on questions related to other topics covered in the course ($U = 7101$, $P < 0.004$).

Attitudes toward Dissection & Enjoyment of the Laboratory Exercise (Hypothesis 2)

Following the laboratory, the two groups did not differ significantly in opinions related to the usefulness ($P = 0.10$) or the enjoyment ($P = 0.94$) associated with the laboratory exercise (Table 4). Among students in the clay modeling group who expressed an

opinion (i.e., selected a response other than “no opinion”), 88% found it useful and 85% found it enjoyable.

Groups differed significantly in their pre-laboratory approval scores related to dissection; students in the cat dissection laboratory expressed higher approval ratings than students in the clay modeling group (cat: median = 3.7; clay: median = 3.3; $U = 8607$, $P < 0.007$). Following the laboratory, however, dissection approval scores did not differ significantly between the two groups ($P = 0.922$; Table 4). When comparing students’ attitudes before and after the laboratory exercise, approval scores for dissection declined slightly for both groups, but the cat group showed the greatest change in opinion ($U = 3793.5$, $P < 0.0001$). Combining student data from both groups, pre- vs. post-laboratory approval scores for dissection approached significance ($P = 0.08$), with mean post-approval scores for use of dissection being slightly lower.

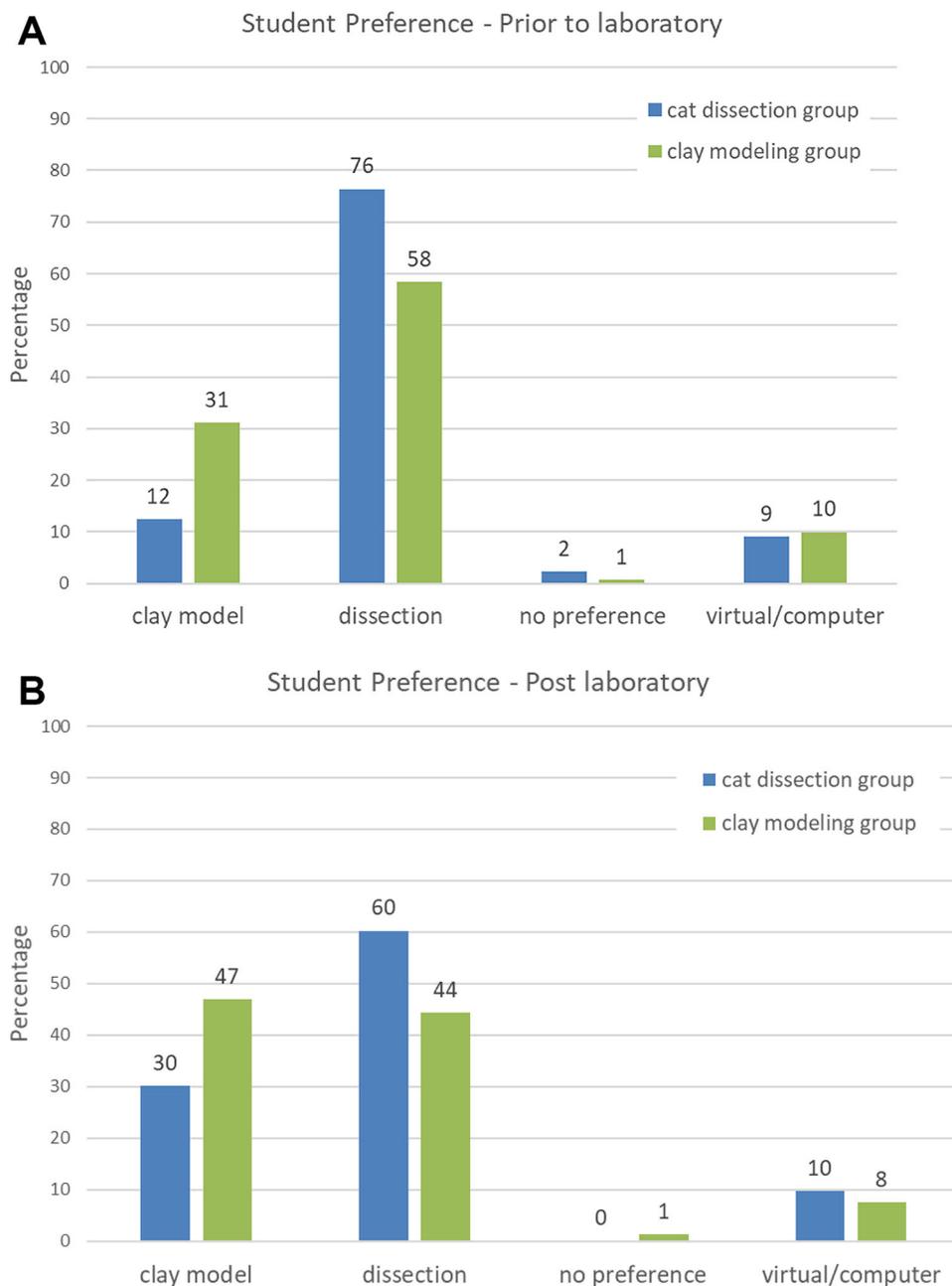


Figure 2. Stated laboratory technique preferences of students in the cat dissection group vs. the clay modeling group, (A) before undertaking the laboratory exercise and (B) after completing the laboratory exercise. Percentage of responses in each category is also shown. *Note:* Students in this study did not complete a virtual/computer-based dissection exercise; this was offered as a hypothetical option on the pre- and post-exercise surveys.

Concerning which technique they would choose to use in the anatomy laboratory, dissection was listed as the preferred laboratory method by most students in the course as a whole (Figure 2). Combining both groups, pre-laboratory preferences were 24.7% for clay, 65.6% for cat dissection, and 9.7% for virtual/computer-based exercise; post-laboratory preferences were 41.0% for clay, 50.6% for cat dissection, and 8.4% for virtual/computer-based exercise. Preference for dissection decreased after the laboratory among students in both groups ($\chi^2 = 15.165$, $df = 2$, $P = 0.001$); correspondingly, preference for the clay modeling alternative increased. In the clay modeling group, after the

laboratory exercise, slightly more students expressed a preference for clay modeling (47%) over cat dissection (44%).

In examining gender-related attitudes toward dissection before the laboratory exercises, there was no significant difference by gender in approval of dissection; the mean approval rating for dissection was slightly higher in male students, but not significantly so ($P = 0.192$). After completion of the exercises, however, a significant difference emerged, with male students rating dissection more favorably than female students ($U = 6075$, $P < 0.05$). The gender-related change in approval rating for animal dissection from pre- to post-laboratory exercises differed significantly, with

female students showing a larger decline in approval than males ($U = 3840, P < 0.0001$).

○ Discussion

Students' content knowledge increased significantly following both the clay modeling and cat dissection laboratories. In the short term, the improvement was significantly greater for students using the clay model as a tool for learning about human muscle anatomy, especially for students' performance on lower-order questions (such as muscle identification). These results partially supported *hypothesis 1*: clay modeling produced better short-term learning outcomes in human macroscopic anatomy for high school students, when compared with cat dissection, based on content knowledge. Differences between the two pedagogical approaches could be due to the reduced cognitive load students face in building human clay models, as compared with dissecting a cat cadaver (Chan & Cheng, 2011). Alternatively, they could be due to more direct transfer of anatomical knowledge using the human skeletal model than using the cat cadaver, in studying human muscle anatomy (Khalil et al., 2005). These results are similar to those of previous studies in which use of clay models produced comparable or superior learning at postsecondary levels (e.g., Waters et al., 2005; Motoike et al., 2009; DeHoff et al., 2011).

Contrasting with assessments conducted immediately following the laboratory exercise, students in the cat dissection group did better than students in the clay modeling group on laboratory-related questions on the final examination, perhaps due to inherent differences in the content of the final exam questions in comparison to the pre- and post-laboratory assessments. The muscle unit questions on the final exam (written by the course instructor to align with educational standards) had broader scope than the questions on the assessments created for this study, encompassing topics of microscopic anatomy and physiology (such as structure and function of muscle fibers) that are less directly taught by the hands-on cat dissection and clay modeling exercises, which focused more on macroscopic anatomy. Performance on the final exam may be more dependent on learning from other course resources, such as textbooks and lecture notes. Thus, these results could indicate that clay modeling facilitates some types of content learning (e.g., identification and location of muscles, spatial relationships) better than others (e.g., microscopic anatomy and function). Conversely, it is possible that the cat cadaver dissection, with all systems present in situ, might allow students to understand spatial relationships between different body systems, which may have improved student performance on some final exam questions (particularly those on topics beyond the musculature lab itself).

Additionally, the time interval of two to three weeks between the study laboratory exercise and the final examination may have contributed to extraneous variables; for example, students may have engaged in diverse and individual approaches (e.g., review sessions, study groups) to prepare for what they perceived as a high-stakes final examination.

Finally, some reported benefits of using clay models may not have been utilized within the course, or may not have been differentially beneficial to students' scores on the final examination. For example, use of clay modeling (vs. cadaver dissection) facilitates

replication in learning (Valliyate et al., 2012), as students can build, rebuild, and exchange clay models. Students in this study could access the clay models only during scheduled laboratory periods and were not able to take the models home to practice independently.

Students who completed the laboratory exercises using the clay models predominantly viewed these models as useful and enjoyable, yet most students in the course as a whole still listed dissection as the preferred technique after the laboratory exercise. However, the proportion of students who chose dissection decreased after the laboratory, for both groups. Students in the cat dissection group (i.e., who had actually participated in dissection) showed a greater decrease in approval for dissection than students in the clay modeling group, resulting in equivalence in approval between the two methods. In the clay modeling group, after the laboratory exercise, a slightly higher proportion of students chose modeling over dissection as their preferred method (Figure 2). *Hypothesis 2* was partially supported by these results: no significant difference was found in student perceptions of enjoyment or usefulness between laboratory exercises with clay models and cat dissection.

Students' attitudes on animal dissection vary. At this high school, cat dissection had long been in the course curriculum; students thus expected to do this dissection when choosing to enroll in this elective course and may have perceived animal dissection as the "best" method for learning the material (Oakley, 2012). This expectation may have influenced their opinion survey responses, especially prior to actually experiencing the cadaver dissection exercise; the decline in approval for dissection after the exercise may reflect the influence of experience over expectations.

Female students in this study showed a larger decline in approval for dissection than male students. Consistent with previous research, exposure to dissection activities may have had a differential effect on male and female students. Studies of both high school and undergraduate cohorts have indicated that female students tend to hold more negative attitudes toward dissection activities (e.g., higher levels of disgust and increased anxiety, compared to male students; Holstermann et al., 2012; Fančovičová et al., 2013; Wisendin et al., 2018).

These students strongly valued the ability to make choices about what methods are used in their classrooms. However, as Keiffer (1979) notes, simply allowing students to choose between animal dissection and an alternative does not resolve the ethical issue; instead, this may foster moral relativism, suggesting that there are many versions of "right and wrong" and, thus, that any choice is as good as any other (De Villiers & Monk, 2005).

These results support the use of clay models as an effective, engaging tool for teaching (macroscopic) human anatomy to high school students, avoiding the ethical issues associated with animal dissection, although the question of retention remains open. Many authors have recommended that anatomy instructors employ multiple teaching techniques for maximum learning, ensuring that students with different learning styles and innate spatial abilities have their educational needs met (e.g., Johnson et al., 2012; Estai & Bunt, 2016). Incorporating alternatives into the classroom allows greater flexibility to meet varying student needs. In particular, three-dimensional physical models can greatly improve spatial understanding of anatomical structures (e.g., Akle et al., 2018).

Others have suggested that alternative techniques such as clay modeling may best serve as a supplement to, rather than replacement for, more traditional teaching tools such as dissection (Oh et al., 2009). The two techniques here were tested separately, so these results cannot shed light on whether student learning outcomes would have improved further with combined dissection and clay modeling techniques. Replacing cat dissection with clay modeling would also help secondary school science curricula model Russell and Burch's three R's of animal use in scientific research (Russell & Burch, 1959) for their students. In addition, although initial costs of purchasing high-quality clay modeling systems may be high, costs in subsequent years of use are minimal, making models more cost-effective, while eliminating the ongoing challenge of obtaining animal cadavers. Taken as a whole, students' enjoyment of the exercise, combined with improved performance on the post-laboratory assessment by the clay modeling group in this study, alongside the reduction of ethical concerns when using clay models vs. animal cadavers, supports the use of clay modeling as one part of a multimodal curriculum in high school human anatomy classes. Instructors in secondary education classrooms can take advantage of the documented benefits of clay models over cat dissection, specifically in the areas of repetitive learning and enhancing understanding of spatial structure and relationships. Future research could focus on clarifying the question of differential retention of new information by students using clay modeling vs. animal cadaver dissection.

○ Limitations of the Study

There are two important limitations of this study. (1) The study was conducted in a single context (school, course, and instructor). This helped control for the confounding variables of teacher skill level and teaching style, but caution is required in making generalizations based on these results. Our encouraging findings regarding the use of an alternative to dissection in secondary school classrooms were largely congruent with similar studies in postsecondary classrooms. (2) Researchers were unable to assign students to study groups or make changes to the course curriculum in these classrooms; hence, the two groups (cat dissection and clay model) are not matched in terms of student number, gender proportions, and grade level (Table 2). Student data (such as overall grade point average) were not available, except from this course. Prior to laboratory exercises, the baseline scores of the two groups' knowledge assessment showed no significant differences ($P = 0.37$), supporting comparability of the two groups on the topic of human musculature. Nonetheless, this discrepancy between group sizes should be taken into consideration when drawing conclusions from the study findings.

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