Are all hands-on activities equally effective? Effect of using plastic models, organ dissections, and virtual dissections on student learning and perceptions

Sara A. Lombardi,1,2 Reimi E. Hicks,3 Katerina V. Thompson,4 and Gili Marbach-Ad4

1Marine Estuarine Environmental Sciences, University of Maryland, College Park, Maryland; 2Department of Environmental Science, American University, Washington, District of Columbia; 3Department of Biology, University of Maryland, College Park, Maryland; and 4College of Computer, Mathematical, and Natural Sciences, University of Maryland, College Park, Maryland

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Lombardi SA, Hicks RE, Thompson KV, Marbach-Ad G. Are all hands-on activities equally effective? Effect of using plastic models, organ dissections, and virtual dissections on student learning and perceptions. Adv Physiol Educ 38: 80–86, 2014; doi:10.1152/advan.00154.2012.—This study investigated the impact of three commonly used cardiovascular model-assisted activities on student learning and student attitudes and perspectives about science. College students enrolled in a Human Anatomy and Physiology course were randomly assigned to one of three experimental groups (organ dissections, virtual dissections, or plastic models). Each group received a 15-min lecture followed by a 45-min activity with one of the treatments. Immediately after the lesson and then 2 mo later, students were tested on anatomy and physiology knowledge and completed an attitude survey. Students who used plastic models achieved significantly higher overall scores on both the initial and followup exams than students who performed organ or virtual dissections. On the initial exam, students in the plastic model and organ dissection treatments scored higher on anatomy questions than students who performed virtual dissections. Students in the plastic model group scored higher than students who performed organ dissections on physiology questions. On the followup exam, when asked anatomy questions, students in the plastic model group scored higher than dissection students and virtual dissection students. On attitude surveys, organ dissections had higher perceived value and were requested for inclusion in curricula twice as often as any other activity. Students who performed organ dissections were more likely than the other treatment groups to agree with the statement that “science is fun,” suggesting that organ dissections may promote positive attitudes toward science. The findings of this study provide evidence for the importance of multiple types of hands-on activities in anatomy laboratory courses.

anatomy and physiology; higher education; model-assisted activities; science perceptions; structure visualization

THE GREAT VALUE of using models in instruction is that they enable objects, events, or ideas, whether they be complex or abstract, to be rendered into forms that are either simpler or visually more concrete (15). As students actively work with models, they are more likely to remember and transfer their learning to new situations (2, 22). While it is generally accepted that incorporating model-assisted activities into classrooms is beneficial (4, 7, 13, 14, 24), educators must choose from among multiple active learning options to find the approach that best suits the subject that they teach and the objectives of their courses. Not all active learning approaches have the same outcomes, but rather there are gradations of benefit (12, 31, 32).

Within anatomy and physiology classrooms, activities that involve plastic models and organ dissections have historically been the most common tools used to incorporate active learning and promote structure visualization. However, in recent years, virtual dissection software has become increasingly popular (9, 17, 34). In the past decade, there has been an array of studies documenting the academic contributions of these model-assisted activities. For instance, in 2005, Waters et al. (36) found that anatomy students studying muscular, digestive, and cardiovascular systems who performed cat dissections scored lower than students who sculpted clay models of the body systems. Similarly, DeHoff et al. (8) found that when studying peripheral nerves, students who used clay models scored higher on low-order questions than students who performed cat dissections. Nicholson et al. (27) found that medical students studying the inner ear using a tutorial accompanied by interactive three-dimensional virtual models scored 18 points higher than students who performed the tutorial alone. Similarly, Oh et al. (28) found that students using clay models of cross-sectional anatomy did better on computerized tomography examinations than students who did not use models. Whereas Nicholson et al. (27) and Oh et al. (28) demonstrated that learning was enhanced with model-assisted activities, these studies did not compare multiple models and thus do not yield insights into which model-assisted activities are best at promoting learning. Furthermore, Nicholson et al. (27) created three-dimensional interactive model software in their laboratory, which may not be feasible for many educators. Therefore, while these studies contribute to our understanding of the value of model-assisted activities and there is much discussion of the value of these model-assisted activities (25, 26, 27, 30, 35, 40), there is no clear consensus on which are best for learning anatomy and physiology, and there are few studies comparing all three approaches simultaneously. Furthermore, of the few studies that do compare multiple approaches, many include anecdotal evidence, emotional bias, or observational data (3, 39) and typically address only student learning and skills but not attitudes (39). Identifying both the learning and attitude benefits derived from these model-assisted activities is valuable as positive attitudes have been associated with higher student retention rates (1, 10, 11, 18, 20).

The overarching goal of this study was to inform higher education curricular and pedagogical change, since previous studies (14, 19, 33) have found that altering curriculum and pedagogy to include effective active learning activities in-
creased student knowledge acquisition, content retention, and critical thinking. We experimentally tested the benefits of three types of model-assisted activities (plastic models, organ dissections, and virtual dissections) commonly used to teach the cardiovascular system in anatomy and physiology classrooms. Our study was designed to isolate the benefits of these model-assisted activities on 1) short- and long-term student learning, 2) student attitudes regarding the value of the activity, and 3) student attitudes toward science.

**MATERIALS AND METHODS**

**Recruiting participants.** Students enrolled in the Human Anatomy and Physiology I (BSCI 201) course were invited to participate in an optional research study. Students in the Human Anatomy and Physiology course come from diverse backgrounds; many of the students are sophomore, junior, or senior Kinesiology majors, but the course also enrolls students of all majors who are interested in entering nursing programs, postbaccalaureate programs, and the medical professions, which may require this course. Heart anatomy and physiology, the content focus of our study, is not covered until the second course in the sequence (Human and Anatomy Physiology II), so study participants had not yet encountered heart anatomy content in the course.

We solicited volunteers through a class announcement and an e-mail inviting students to participate in a 2-h supplemental activity and followup examination. We explained to the students that the supplemental activity was independent of their course and that their decision whether or not to participate would not affect their grades. As an incentive to participate, we offered students a review session for an upcoming exam. Additionally, students were offered 0.1% extra credit if they participated in the study or completed an alternative assignment.

**Treatments.** Volunteers were randomly assigned to one of three treatments: plastic model, organ dissection, or virtual dissection. Participants were unaware of the treatment group to which they had been assigned until after they arrived at the study site. Each participant provided written informed consent to participate in the study. Each treatment group met separately for a 2-h session that began with the same 15-min PowerPoint lecture providing background in heart anatomy and physiology followed by a 45-min hands-on activity with either plastic models, organ dissections, or virtual dissections. In each treatment group, students worked in teams of 2–4 students/group. For all treatments, each team was given instructions on how to complete the activity and a list of structures to learn, and two instructors circulated the classroom helping students with the activity and answering questions.

In the plastic model treatment, each team of students was given a life-size model of a human heart. A larger, labeled plastic model was shared among all teams. In the organ dissection treatment, each team was given gloves, dissection tools and trays, and a sheep heart. Students were instructed to remove the pericardium and to make an incomplete coronal cut from the apex toward the base but to leave the vessels intact to allow vessel manipulation and identification. Students were encouraged to insert plastic tools into vessels to visualize vessel-chamber connections in order to identify each vessel. Additionally, there were labeled dissected sheep hearts available for students to examine. In the virtual dissection, each team performed virtual heart activities using physiology software programs (Practice Anatomy Lab, Pearson Education, and Interactive Physiology, Pearson Education), virtual dissection websites, and an online video of a sheep heart dissection. After the lecture and hands-on activities, students filled out a Likert-style survey (on a scale of 1–4, where 4 = “yes/strongly agree” and 1 = “no/strongly disagree”) regarding their perceived value of the activity, activity preference, and perceptions of science. Students also took a 30-min examination (initial exam) on the anatomy and physiology content presented during the supplemental activity (see Fig. 1 for example questions). The initial exam consisted of 22 questions, of which 14 questions tested anatomy knowledge and 8 questions tested physiology knowledge. Approximately 2 mo later, students were given another examination (followup exam) to test their retention of content knowledge. The followup exam was a shortened version of the initial exam, consisting of 10 questions testing anatomy knowledge and 6 questions testing physiology knowledge.

Twenty-nine students participated in the supplemental activity and completed the initial exam (22 women and 7 men; 48.3% sophomores, 20.7% juniors, 13.8% seniors, and 17.2% postbaccalaureate or adult learner students). Sample sizes for each treatment group were 13 for organ dissection, 8 for virtual dissection, and 8 for the plastic model. Twenty-six of these students completed the followup exam (11 students in the organ dissection group, 8 students in the virtual dissection group, and 7 students in the plastic model group). Sample sizes varied among treatment groups because some of those initially scheduled to participate in the study did not attend.

Students had access to their anatomy and physiology course scores through the course learning management system and were asked to self-report their current grade as well as their major. The median self-reported score across all treatments was a B (virtual dissection: 82.5%, plastic model: 85.0%, and organ dissection: 85.0%), and individual scores ranged from A to C. Ordinal regression analysis showed no preexisting differences in student self-reported current course grade among treatments (treatment pair-wise comparisons $P > 0.10$) or in their actual final course grade ($P > 0.10$). Furthermore, $\chi^2$-analysis revealed no difference in the distribution of science and nonscience majors between treatments ($P > 0.99$). In the organ dissection treatment, only two students (15.3%) were nonscience majors (Government and Education). The plastic model and virtual dissection groups each had one nonscience major (12.5%). Marketing

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1. **Open Ended.** Which side of the heart has thicker myocardium? Why does that side have thicker myocardium?

3. Identify the correct label for the following features. Please mark the letter associated with the feature on the diagram.

   Papillary muscles....................
   Bicuspid valve.....................
   Interventricular septum.............

   ![Diagram of heart with labels](image)

   Fig. 1. Example questions from initial and followup exams. Shown are examples of the types of questions asked on each of the exams. Students were given 2 min to answer each question on the initial exam but were not timed on the followup exam.

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4. **Identify the correct label for:**

   Myocardium............
   Semilunar valve...
   Tricuspid valve.....
and Economics, respectively). We defined a science major as any degree leading to a Bachelor’s of Science. Across all treatments, 52% of the science majors were Biology and Kinesiology students.

Data analyses. All statistical analyses were performed in Statistica 6.0 (Statsoft, Tulsa, OK) or R 2.11.1 (R Core Team, Vienna). We used Kruskall-Wallis one-way ANOVA and Mann-Whitney U-tests to test for and identify differences between learning approaches (i.e., plastic models, organ dissections, or virtual dissections) on initial and followup exam scores. In addition to looking at overall scores on these exams, we also assessed if students in any treatment group performed better on specific subsets of questions (i.e., anatomy questions, physiology questions, or questions using images of real human hearts). P values are reported; all tests were two tailed.

To investigate the effect of treatment group on student perceptions about the activity and science in general, descriptive statistics were used. We analyzed students’ open-ended responses qualitatively using an inductive approach, in which related responses were grouped into subcategories that could be quantified. Two of the researchers categorized the responses separately and then discussed their categories until they reached agreement. The interrater agreement was >90% (23).

This study was reviewed and approved by the Institutional Review Board of the University of Maryland (no. 11-0045).

RESULTS

Initial exam. There was a significant effect of treatment group on the initial exam scores ($P = 0.009$; Fig. 2). Students in the plastic model treatment group had the highest overall scores on the initial exam (median: 95.4%) and scored similarly high or higher than the other treatment groups on each of the initial exam subsections. Specifically, students in the plastic model treatment had an overall median score of 95.4%, which was significantly higher than the median score of students in the organ dissection treatment (77.3%, $P = 0.006$) or the virtual dissection treatment (70.4%, $P = 0.007$; see Table 1 for all medians and interquartile range scores). When tested on their anatomic knowledge, students in the plastic model treatment and organ dissection treatment performed equally well (92.9%), and both groups had significantly higher scores on this subsection than students in the virtual dissection treatment (71.4%, $P = 0.02$ and $P = 0.03$, respectively). When tested on their knowledge of physiology, students from the plastic model treatment scored significantly higher (93.7%) than those in the organ dissection treatment (75.0%, $P < 0.001$), whereas the students in the virtual dissection treatment (75.0%) did not differ significantly from students in either of the other two groups. The virtual dissection treatment group had the lowest scores on the subsection of the initial exam that used images of a real human heart, although the differences did not reach significance ($P = 0.07$).

Followup exam. There was a significant effect of treatment group on followup exam overall scores ($P = 0.007$) and anatomy subsection scores ($P = 0.007$) but not on physiology ($P = 0.12$) or real heart image ($P = 0.09$) subsection scores (Fig. 2; see Table 1 for medians and SEs). Specifically, on the followup exam, the overall score of the students in the plastic model treatment (67.9%) was higher than both the median scores of students in the organ dissection treatment (45.8%, $P = 0.003$) and virtual dissection treatment (37.5%, $P = 0.017$; Table 1). Students in the plastic model treatment also earned a higher median score (80.0%) on questions testing anatomic knowledge than those in the organ dissection treatment (50.0%, $P = 0.03$) and virtual dissection treatment (40.0%, $P = 0.001$).

Attitude survey. Across all treatments, every student provided an answer to every Likert-style and content test question. Students also had the ability to provide a written explanation for their answer, but they did not always do so. When asked their opinion on the statement “science is fun,” two (of thirteen) organ dissection students and one (of eight) virtual dissection student failed to provide a written explanation for their answer. For the question about the impact of the activity in preparing them for their future career, two students in the organ dissection treatment and one student in the virtual dissection treatment did not provide a written explanation. When asked about their preference for a future activity, only one student (in the organ dissection treatment) did not provide a written explanation. While small sample sizes precluded formal statistical analyses, learning approach appeared to affect attitudes regarding science (Table 2). All of the students in the organ dissection treatment and plastic model treatment “agreed” or “strongly agreed” that science was fun compared with only 62.5% of the students in the virtual dissection treatment. In the open-ended responses justifying their choice, students in the organ dissection treatment wrote “I am a government major and activities like this make me wish I did something in biology” and “It is the basis for understanding everything. The more you understand, the more fun it is.” When we summarized all students’ explanations, across all treatments, we found the most common explanations could be grouped into two broad categories of reasoning: 1) science promotes experimentation and is hands on and 2) science teaches how the world or bodies work. In the organ dissection group, the most common reason that students provided to support their agreement that “science was fun” was the experimental and hands-on nature of science (27.3%), whereas in the plastic model and virtual dissection groups, the most common reason was that science promotes learning how the world and the body works (37.5% of plastic model responses and 50% of virtual dissection responses). Furthermore, when asked “Did this activity help prepare you for your future career?,” 77% of organ dissection students strongly agreed or agreed compared with 62.5% of plastic model students and 62.5% of virtual dissection students.

Students were asked, “In the future would you rather have an additional plastic model, a virtual dissection, or an organ dissection?” and then asked to provide an open-ended explanation of their choice. Organ dissection was requested as a future activity twice as often (across all treatments) as any other activity. The majority of student explanations could be grouped into four categories: 1) the activity allows good visualization of anatomic structures, 2) the activity allows good visualization of blood flow or physiology, 3) the hands-on nature of the activity, and 4) the activity illustrates the variation between individual organs without oversimplifying. The two most common reasons that students requested more organ dissections were that they believed it highlighted variation between individuals rather than being an oversimplification (33.3% of responses) and it helped students visualize anatomic structures (33.3% of responses). The next most common reason (16.6% of responses) for requesting organ dissection was because of its exploratory and hands-on nature. One student in the virtual dissection treatment group reflected that “Seeing
Fig. 2. Median scores on the initial and followup exams. This box plot illustrates the median, minimum, and maximum as well as 25–75 percentile ranges of student test scores for the initial exam and followup exam for each treatment (plastic model, organ dissection, or virtual dissection). In addition to providing student scores on the overall exam, we also show the scores of anatomy and physiology subset questions. Within each plot, when the same letter is above two or more medians, this indicates that these test scores were not different, whereas different letters denote significant differences among medians ($\alpha = 0.05$).
something isn’t the same as actually touching it and understanding it. It would be nice if each individual got an organ to dissect.” Another student (a student in the plastic model treatment) noted that “[Having an organ to dissect] would allow me to see an actual heart that is not overly simplified, plus it is more hands on and keeps you in lab longer, rather than just leaving after quickly reviewing a model or two.” Students who requested virtual dissections did so because they believed virtual dissections were good for visualizing anatomic structures (50%) and physiology (50%). One student (a student in the virtual dissection treatment) remarked “…I like to see the movement/travel of the blood traveling through the heart…” Among the students who requested activities with plastic models, half did so because they liked its tactile/hands-on nature, e.g., “I like having a [plastic] model in front of me to touch and identify” (student in the virtual dissection treatment). The responses of the remaining students could not be classified into any of the above categories.

It is noteworthy that organ dissection was the only activity that most of the students asked to perform again; for example, 68.2% of students in the organ dissection treatment requested additional opportunities for organ dissection, whereas only 12.5% of students in the virtual dissection treatment expressed a desire to engage in more virtual dissection activities. Virtual dissections were the only treatment that was perceived as having the ability to assist students with visualizing physiology, whereas organ dissection was the only treatment that was perceived as having the ability to highlight the variation and complexity in living structures.

**DISCUSSION**

Our results indicate that the type of model used to illustrate heart anatomy in classrooms, specifically, plastic models, organ dissections, or virtual dissections, may have a significant effect on student attitudes, learning, and retention of heart anatomy and physiology content. In general, students in the plastic model treatment group outperformed students in both virtual and organ dissection groups. In none of our test metrics (initial and followup exam overall scores, anatomy scores, physiology scores, and real heart images scores) did students who performed virtual dissections score significantly higher than students who performed either plastic models or organ dissections. When asked which type of instruction they would like to see added to the course curriculum, students requested organ dissections more often than any other treatment. Furthermore, students who performed organ dissections generally had more favorable opinions of science. In summary, plastic models may be more effective than organ dissections or virtual dissections for teaching heart anatomy and physiology content, but organ dissections may have the highest perceived practical value and may be superior for improving students’ attitudes toward science. Ultimately, this research adds to the existing body of knowledge on science pedagogy through a direct, experimental comparison of three common teaching practices on not only conceptual understanding but also attitudes regarding science.

Students who examined plastic models scored much higher (e.g., 95.4%) than we expected. We hypothesize this may be due to a combination of our study design and the nature of the activity. The simplicity of the plastic models (e.g., relative ease to assess orientation and differentiate arteries and veins) may have maximized the students’ studying time. Furthermore, the use of plastic models required virtually no set up (e.g., opening computer programs or putting on gloves). Thus, while we required all students to stay and participate the entire 45 min, there may have been more quality time devoted to learning in

**Table 1. Initial and followup exam scores**

<table>
<thead>
<tr>
<th></th>
<th>Plastic Model</th>
<th>Organ Dissection</th>
<th>Virtual Dissection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial exam</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatomy</td>
<td>Median 92.9</td>
<td>92.9</td>
<td>71.4</td>
</tr>
<tr>
<td>Physiology</td>
<td>93.7</td>
<td>75.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Real heart image</td>
<td>83.9</td>
<td>85.7</td>
<td>69.6</td>
</tr>
<tr>
<td>Overall</td>
<td>95.4</td>
<td>77.3</td>
<td>70.4</td>
</tr>
<tr>
<td><strong>Followup exam</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatomy</td>
<td>Median 80.0</td>
<td>50.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Physiology</td>
<td>50.0</td>
<td>33.3</td>
<td>33.3</td>
</tr>
<tr>
<td>Real heart image</td>
<td>66.7</td>
<td>50.0</td>
<td>33.3</td>
</tr>
<tr>
<td>Overall</td>
<td>67.9</td>
<td>45.8</td>
<td>37.5</td>
</tr>
</tbody>
</table>

Values are in %. After a heart anatomy and physiology lesson augmented with a plastic model, organ dissection, or virtual dissection activity, student learning was assessed. Median and interquartile range scores on the initial exam (immediately after the lesson) and a followup exam (2 mo after the lesson) are shown for each treatment group. In addition to the overall raw score, we assessed student performance on questions that focused on anatomy or physiology or were based on images of a real heart.

**Table 2. Summary of student attitude survey responses**

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Is science fun?</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic model</td>
<td>50.0</td>
<td>50.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Organ dissection</td>
<td>84.6</td>
<td>15.4</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Virtual dissection</td>
<td>25.0</td>
<td>37.5</td>
<td>25.0</td>
<td>12.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Did this activity help you prepare for your future career?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic model</td>
</tr>
<tr>
<td>Organ dissection</td>
</tr>
<tr>
<td>Virtual dissection</td>
</tr>
</tbody>
</table>

Immediately after the model-assisted activity (plastic model, virtual dissection, or organ dissection), students were given Likert-style survey questions probing their attitudes toward science and the model-assisted activity they performed. The percentage of students in each treatment who strongly agreed, agreed, disagreed, and strongly disagreed with each are shown.

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the plastic model treatment than with the other model-assisted activities.

Although our study indicates many benefits of using plastic models in teaching cardiovascular anatomy and physiology, they also have inherent limitations. A disadvantage to plastic models, compared with virtual and organ dissections, is that learning with plastic models may be less inquiry-based than dissections, as there is less opportunity for discovery when students are presented with a color-coded, fixed plastic model. Furthermore, plastic models necessarily oversimplify complex systems. Plastic models lack the pericardium, provide distinct color differences for oxygenated and deoxygenated blood flow, and present a typical, pristine heart lacking any abnormalities. While the inherent simplicity of the models may promote learning (5, 36) and lead to higher exam scores compared with dissections, the more realistic and complex organ dissections may be a better choice to achieve some course objectives. For instance, in addition to providing a more accurate depiction of tissues and allowing students to develop dissection skills, organ dissections may better demonstrate the inherent variation between individuals. Thus, the simplicity of the plastic models may actually be an oversimplification for some higher education courses, and therefore incorporating more complex activities to augment plastic model use may be necessary. Furthermore, our results indicate that students appreciate more complex model-assisted activities since organ dissections were the most commonly requested treatment, and one of the most common reasons reported for this preference was that organ dissections highlighted variation and complexity.

A possible explanation for the success of plastic models and organ dissections compared with virtual dissection is that these activities offer tactile feedback, whereas tactile manipulations are not possible with virtual dissections. Plastic models and organs provide a concrete hands-on structure that can be manipulated in a way that is not possible for virtual dissections. Additionally, as noted by Richardson (30), even the best virtual dissection activities have inherent contradictions to the fundamental nature of anatomy, physiology, and science in general, as they do not as effectively convey the distinction between living organisms and machines and the unpredictability of living organisms and systems. Richardson (30) warned that virtual dissections may promote misconceptions and lead to overgeneralization.

Virtual dissections are an attractive alternative to organ dissections, which are, at times, controversial and expensive; however, in this study, they did not lead to increased knowledge acquisition compared with the other treatments and typically resulted in the lowest scores in each category tested. Virtual dissections were also unpopular among students. Students in the virtual dissection treatment group were only half as likely to request that virtual dissections be added to course curricula as students in the plastic model and organ dissection treatment groups. This leads us to believe that the idea of heart virtual dissections is appealing to students, but, in practice, students are disappointed. The preference for a tangible organ dissection is further confirmed by student open-ended responses. Overall, our findings lead us to believe that the software, websites, and online tutorials used for the virtual dissection treatment are not a viable alternative to organ dissections or plastic models for either increasing student content knowledge or perceptions about science. However, as the technology and software options improve and become more interactive and realistic (highlighting the variation and diversity of life), then computer activities may hold greater academic value when teaching the human cardiovascular system.

Waters et al. (37) suggested that student exam scores are related to transformation demands (i.e., students who study a model may be better at identifying hand-drawn images than students who perform dissection, whereas dissection students may be better able to identify organ structures from a species similar to that which they dissected). However, our data, although limited by small sample size, do not support the transformation demands hypothesis, as we found that students who performed a sheep heart organ dissection or virtual dissections (which included both sheep and human heart images) were not better able to answer a question identifying features on a human heart dissection image compared with students in the plastic model treatment.

This research can be used to inform curriculum development in anatomy and physiology classrooms. Incorporating activities that promote learning and engagement as well as have perceived practical value are important, as these have been linked to higher student retention rates (1, 10, 11, 18, 20). It has been estimated that only 40% of freshman science majors graduate with a science degree (29); hence, it is not surprising that retaining student interest, especially in science, technology, engineering, and medical fields, has become a high priority for research and discussion (6, 16, 21, 38). Our research, which identifies cardiovascular model-assisted activities that promote learning, retention, and positive attitudes toward science, contributes to this discussion and provides guidance in designing curricula to promote student academic success and retention.

In classrooms, a variety of hands-on and model-assisted activities should be used, as this may accommodate students of varied learning styles, and different activities are best suited to achieving different goals. In the case of heart anatomy and physiology, our study suggests that using plastic models may promote knowledge acquisition and retention, whereas organ dissection may promote student interest and enjoyment of science. When teaching the cardiovascular system, we recommend using both plastic models as well as organ dissections as combined these activities may promote learning, student engagement, and positive attitudes. While further studies are needed to provide conclusive evidence, when designing anatomy curriculum it may be advantageous to use plastic three-dimensional models as a standard laboratory tool and augmenting model use, on occasion, with organ dissections. This varied approach may prioritize learning but also take into account student perceptions and attitudes while minimizing the classroom time and resource investment associated with organ dissections. Furthermore, it is possible that organ dissections may better capture the essence of science by preventing oversimplification and promoting experimentation and inquiry-based learning that may not be easily replicated by the use of plastic models or currently available virtual activities. This study contributes to a growing body of knowledge on the impact of different teaching practices, which ultimately will aid in reforming higher education science laboratory courses to promote the overarching goal of effectively educating science students, retaining students in the sciences, and preparing students for science careers.
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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS


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