Using Paper Models to Teach Basic Concepts of the Human Musculoskeletal System

Susan J. Rehorek, PhD, Paul G. Falso, PhD, and Justin R. Siebert, PhD, MS Med Ed
Department of Biology, 300N Vincent Science Center, Slippery Rock University of Pennsylvania, 1 Morrow Way, Slippery Rock, PA 16057-1326
Corresponding Author, susan.rehorek@sru.edu

Abstract
Traditionally, human anatomy is taught using cadaveric human or animal specimens, however such materials are not always available or are quite costly. Alternate instructional methods can include software, models, clay models, and illustrations. Unfortunately, while cost effective, these methods lack the ability to demonstrate the in situ three-dimensional relationships between anatomical structures. This study examined one alternative method of instruction, the construction of three-dimensional paper models, which are currently limited in availability, and mostly designed for teaching medical anatomy programs. This study set out to determine 1) if a paper model system could be used to highlight the anatomic complexity of specific anatomic regions, 2) if a model system primarily designed for medical anatomy programs could be customized to topics and made appropriate for undergraduate anatomy courses, and 3) if this low-technology and inexpensive form of instruction is an effective tool in teaching musculoskeletal anatomy. Students were given a series of four models to assemble during a time period of 4-weeks. Students were assessed with a series of paired questions before and after the model exercise relating to: number of muscles, plane of muscle, depth of structure, name and function of muscle. Comparison of the pre and post-test data demonstrated a gain in knowledge. Thus, the utilization of paper models are a viable and cost effective pedagogical tool for undergraduate anatomical education.

Key Words: paper models, 3D anatomy, musculoskeletal system, undergraduate

Introduction
Anatomy and Physiology is a popular course taught at many undergraduate institutions, and is often a prerequisite for graduate-level professional health programs. Cadaveric dissection (human or animal) has been the traditional paradigm of anatomical pedagogy since the days of the Renaissance (McLachlan and Patten 2006; Gosh, 2015). While teaching methods have varied over the years, anatomy and physiology courses continue to primarily utilize animal or human cadaver dissection to teach anatomic structure. However, the primacy of cadaver-based anatomy instruction has not gone unchallenged. These challenges include: questioning the educational value of the time spent in the dissection laboratory rather than studying the material, the usefulness of utilizing embalmed tissues, the environmental hazards involved with formalin fixation, the financial and infrastructural costs associated with the use and storage of formalin fixed cadaveric material, as well as the ethical, moral, and other practical issues that arise with the use of cadaveric material (McLachlan et al., 2004; McLachlan and Patten 2006; Wright, 2012).

While cadaveric dissection is still a primary method of anatomical pedagogy, many traditional dissection-based laboratories are transitioning to more cost and time effective methods of instruction (McDaniel and Daday, 2017). Moreover, cadaveric material may not always be available or affordable, especially at smaller undergraduate institutions. As a result, alternative pedagogical methods are sought in the anatomical sciences. Common and currently utilized alternative methods of anatomical instruction include: anatomy software packages (Wright, 2012), plastic models (Preece et al., 2013), clay models (Motoike et al., 2009), and anatomic illustrations (Bell and Evans, 2014). Unfortunately, while more cost effective than cadaveric dissection, these alternative methods of anatomy instruction lack the flexibility of the human cadaver and eliminate the student’s ability to visualize three-dimensional structures in situ. Comparative strengths and weaknesses of each type of anatomical education are briefly summarized in Table 1.
There is an additional method of instruction for anatomy education, which is the construction and use of three-dimensional paper models. Paper model systems currently exist. However, these models are designed specifically for medical students, include complex details, and require reading a complicated set of instructions in order to assemble the model (Weber, 1979; Locket et al., 2012). In undergraduate introductory level courses where students have limited course time to devote to anatomical descriptions, limited resources, and variable levels of pre-requisites, the utilization of the current paper model system would be inappropriate. However, the utilization of a paper model system is intriguing because it can address several of the previously mentioned weaknesses presented by other forms of anatomical instruction. First, because it is a paper model, it is inexpensive and pre-prepared. Second, because it allows for the study of anatomic structures at different layers and depths, it generally preserves the three-dimensional relationships between various anatomic structures. Third, the students have to assemble the paper models, resulting in an active hands-on interactive learning activity. Finally, because this is a paper model system, there are no ethical concerns, environmental hazards, or need for expensive technological or other institutional infrastructure.

**Table 1. Current Utilized Methods of Anatomic Instruction**

<table>
<thead>
<tr>
<th>Method</th>
<th>Strength</th>
<th>Weakness</th>
</tr>
</thead>
</table>
| Cadaveric dissection | Dissection Skills  
Active form of Learning  
Exposure to a vertebrate body  
3D relationships easily observed  
Anatomic variation is appreciated | Requires low student to faculty ratio  
Dissection is time intensive  
Environmental Hazards  
Cost Intensive to Institutions  
Ethical and Moral issues |
| Clay models  | 3D structure  
Students make their own body  
Highly interactive | Intensive training of faculty and students  
Requires low student to faculty ratio  
Requires self-motivated students |
| Illustrations | Allows for easy to identify coloration, and isolation of structures  
Can show depth with multiple illustrations  
Relatively inexpensive  
Easy to study | Artistic stylization of anatomy  
Illustrations may be incorrect  
Copyright/legal issues  
Loss of 3D visualization & relationships  
Loss of anatomic variation  
Passive form of learning |
| Plastic models | Easy to handle  
3D structures  
Can enlarge structures too small to adequately study *in situ*  
Easy to study  
Interactive (depending on the model) | Expensive  
Loss of associations between muscles and bones  
Cannot show deep muscles  
Model Keys may be incorrect  
Artistic stylization of anatomy  
Loss of anatomic variation |
| Software     | Uses technology  
Can be accessed outside class room  
Real time quizzing  
Interactive programs | Expensive programs  
Access to Computer Technology  
Loss of 3D visualization & relationships  
Limited interaction with specimens  
Technological ability of Faculty  
Loss of anatomic variation |
To address the need for alternate instruction methods, in this study we set out to investigate three primary questions:

1. Could the paper model system effectively highlight and teach the complexity of the musculoskeletal system for four different regions of the human body?
2. Could a paper model system designed to teach medical students be adapted to a complexity level appropriate for undergraduate students?
3. Could this inexpensive, low tech, hands-on model system achieve a significant gain in student learning on a complex topic like the musculoskeletal system?

This study also investigated whether specific demographics (major, SAT score, etc.) had an impact on the effectiveness of this teaching tool.

Materials and Methods

The research protocol (protocol # 2016-045-17-A) for this study was submitted to the Slippery Rock University Institutional Review Board. It was determined to be exempt for the requirement for IRB review and approval, per exemption according to 45 CFR 46.101(b)(1) for research conducted in established education settings involving normal education practices such as research on the effectiveness of curricula.

Population

The paper model system was tested on six sections of Biology 217, Anatomy and Physiology II, at Slippery Rock University for a total sample size of 140 students. As illustrated in Figure 1A, the vast majority of students, 76.43%, were female. As shown in Figure 1B, a majority of the students, 48.57%, had declared exercise science as their major, while 45% of the students were public health majors. The remaining 6.43% of students were other declared majors such as biology, histotechnology, and cytotechnology. The class year of students varied from underclassmen to upperclassmen, and included students who were first-experience students as well as course-repeating students. Students SAT scores were acquired through the office of institutional research.

Paper Models

Four different regions of the human body, the abdomen, brachium, face, and anterior thigh, were studied over a four-week period during one semester. The paper models used in this study were derived from two different sources. Paper models for the brachium and anterior thigh were from Locket et al. (2012). The nerves and arteries of the two paper model systems were omitted from this study. Since the brachium and anterior thigh models were originally designed to teach anatomy at a medical school level, they were developed to be anatomically proportional, contain a high degree of fine detail, and be accompanied by a complex set of assembly instructions. Moreover, due to the fine level of anatomic detail, the names of the muscles were written on the paper adjacent to the pieces of the model, that were eventually to be cut out (Locket et al. 2012).

Models for the abdomen and face, although inspired by the Locket et al. (2012) paper model system, were created by one of the authors (S. Rehorek) and specifically designed for undergraduate level instruction. Thus, the S. Rehorek models were intentionally designed to be simple and clear with less concern for anatomic proportionality and a lesser degree of fine detail. They included a set of assembly instructions that were simple and easy to follow. More importantly, the names of the muscles were either written on the model pieces (abdominal model), or the muscle abbreviations were written on the models pieces (face model). Each set of models included a key to the abbreviations in the model activity packet. Models were printed on normal weight copy paper, left uncolored, and an instruction sheet on model assembly was provided. Lines indicating muscle fiber directionality were sketched on all of the models.

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**Figure 1.** Demographic data of the anatomy and physiology II class. The demographic break down of the student population in the Biology 217: Anatomy and Physiology with Lab II course. (A) The percent of students by identified gender. (B) The percentage of student in declared majors. ES = exercise science, PH = public health, Other = students enrolled in the biology major, or one of the many pre-health profession programs (e.g. biology, histotechnology, and cytotechnology).

**Figure 2.** The abdominal muscles model. This partially deconstructed picture of the model components shows the elements used and the simplicity of the design.
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Activity
During the musculoskeletal portion of the course, students were given one of the four different paper models (abdomen, brachium, face, or anterior thigh) based upon the specific body region being covered that week. Students were given a packet that included the pieces of the paper model and the instruction sheet, along with the scissors and glue sticks necessary to complete the activity. Students were then instructed to color the individual pieces of the paper model for easy identification and to follow the instructions for cutting out the individual pieces of the model. The instructions for assembling the models were given after the students had cut out the pieces of the model. A completed model was available for students to observe. Students were given an hour to complete construction of the model. Students were asked to compare their newly constructed three-dimensional paper model to the plastic anatomical models available in the anatomy lab.

Assessment of Knowledge
Prior to the beginning of the musculoskeletal unit in the Anatomy and Physiology II course, students were given a pre-test to assess their base knowledge. The scored pre-tests were not returned to students, and the correct answers to the pre-test questions were not reviewed or discussed, so that students could not memorize the questions and answers. The assessment of base anatomical knowledge was done because students majoring in exercise science had already taken an introductory musculoskeletal anatomy course, whereas students majoring in public health and the other majors had not. Following the conclusion of the study of each body region in class, student knowledge was again assessed on each of the body regions, using the same pre-test questions. As shown in Table 2, the assessment questions were designed to cover five basic areas of knowledge:
1. The number of muscles learned.
2. The names of structures.
3. The function of structures.
4. The plane of the muscles.
5. The depth of the structures.
All tests, pre and post, consisted of five multiple choice questions, and were therefore graded and reported out of five points.

Assessment of Student Confidence
A total of three questions were designed to determine student confidence in their own knowledge of the material. Confidence was assessed for the abdomen, brachium, and face utilizing a Likert scale of 1 to 5, with 1 designated as not confident, and 5 designated as very confident. As indicated in Table 3, the three questions assessed ability to identify muscles, ability to understand the layering of the muscle, and the ability to connect the structure of the muscle to its function. Unfortunately, because of the timing of the lab activities in the semester, confidence data for the anterior thigh could not be assessed because the post-test items for this anatomic region were covered on the final exam, and not available for inclusion in this study.

<table>
<thead>
<tr>
<th>Topic of question</th>
<th>Rationale for questions</th>
<th>Example question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of muscles</td>
<td>To test to see if students understand that there are multiple muscles in any given region</td>
<td>How many pairs of abdominal muscles are there?</td>
</tr>
<tr>
<td>Plane of muscle</td>
<td>To test to see if students understand that muscle fibers are orientated in a specific manner</td>
<td>The fibers of which muscle are perpendicular to the sagittal plane?</td>
</tr>
<tr>
<td>Depth</td>
<td>To see if students understand that muscles are arranged in a 3D manner</td>
<td>Which muscle is the deepest?</td>
</tr>
<tr>
<td>Name of structure</td>
<td>To see if students understand that muscles are associated with names and structures.</td>
<td>Which muscle forms part of the radial groove?</td>
</tr>
<tr>
<td>Muscle function</td>
<td>To see if students understand the function of a given muscle</td>
<td>Which muscle causes hip flexion?</td>
</tr>
</tbody>
</table>

*Table 2. Topic Questions Designed to Test Anatomic Knowledge*

<table>
<thead>
<tr>
<th>Topic of question</th>
<th>Rationale for question</th>
<th>Question asked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional Muscle identity</td>
<td>To determine student perception of regional muscle identity confidence</td>
<td>How confident do you feel about being able to identify facial/abdominal or arm muscles?</td>
</tr>
<tr>
<td>Layering</td>
<td>To determine if students understood that muscles are layered</td>
<td>How confident do you feel about understanding the different layers of muscles?</td>
</tr>
<tr>
<td>Connecting structure to function</td>
<td>To determine if students understand that muscle fibers orientation dictates muscle function</td>
<td>How confident do you feel about understanding the role of planes in muscle function?</td>
</tr>
</tbody>
</table>

*Table 3. Questions Designed to Assess Confidence of Student’s Knowledge*
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Student Perception of the Paper Models
At the end of the semester, as part of the student course evaluation process, students were asked three questions designed to assess the student perception of the paper model activity. The student course evaluation process is anonymous so the responses to the questions regarding student perception of the paper model activities could not be used to identify individual students or cohorts. As seen in Table 4, the questions assessed whether the students liked the activity, which model the student found to be the most helpful, and which model the student found to be the least helpful.

Data Analysis
All the data were analyzed using SigmaPlot 13.0. The significance for all tests was determined to at least a P-value of <0.05. The specifics of each statistical analysis can be found in the results and analysis section.

Results and Analysis
Students demonstrated an overall gain of knowledge utilizing the paper model system
One of the main objectives of this study was to determine if a paper model system initially designed for students in a medical anatomy program could be appropriately customized and used to teach anatomy in an undergraduate setting. To determine the effectiveness of the paper models as a teaching tool, students were given a pretest to assess their base knowledge prior to building and studying the paper model and a post-test following construction and studying of the paper model. Student performance on the post-tests was compared to determine on which post-test students performed the best.

First the post-test for the four different paper models were analyzed using the Kruskal-Wallis one-way analysis of variance. This analysis showed a significant (P<0.001) difference between the results of the post-tests. Further post-hoc testing revealed that the students’ post-test performance on the abdomen was significantly better than their post-test performance on any of the other anatomical regions. Post-hoc testing did not find any significant post-test performance difference between the face, brachium, or anterior thigh anatomic regions.

Analysis of the pre and post-test data began with the Shapiro-Wilk test for normality, which generated a value of P<0.05, indicating that the data was not normally distributed. Therefore, the data was analyzed utilizing the Wilcoxon signed rank test, revealing a significant (P<0.001; Figure 3a) difference between the pre and post-test data for all four of the models studied. In order to determine which of the paper model systems demonstrated the largest learning gain, the difference between pre and post-test results was analyzed using a Kruskal-Wallis one-way analysis of variance on ranks. Overall, a significant (P<0.001) difference in student learning gain was observed between the different anatomical model systems. Tukey post hoc testing revealed no difference when comparing the learning gain between the two Locket models

Table 4. Questions Designed to Assess Student Perception of the Paper Model Activity

<table>
<thead>
<tr>
<th>Topic of question</th>
<th>Rational for question</th>
<th>Question asked</th>
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<tbody>
<tr>
<td>Helpfulness of paper</td>
<td>To determine if the students felt this approach enhanced their learning experience</td>
<td>I found the use of paper models helped me learn the muscles of the body</td>
</tr>
<tr>
<td>model activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most Helpful Model</td>
<td>To determine student preference of specific models</td>
<td>I found _____ to be the most helpful</td>
</tr>
<tr>
<td>Least Helpful Model</td>
<td>To determine student preference of specific models</td>
<td>I found _____ to be the least helpful</td>
</tr>
</tbody>
</table>

Figure 3. Pre and post-test performance on anatomical knowledge questions. (A) Student acquisition of knowledge was assessed using a series of pre-test questions, administered prior to using a paper model, and a post-test following using a paper model. Pre-and-post-test results were reported out of a score of five. (B) The learning gain was determined by taking the post-test score and subtracting the pre-test score to determine the overall difference. The gain in student learning was then compared between the different model activities. Error Bars = SEM, ** = Significance (P<0.001), # = Significance (P≤0.05)

continued on next page
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In preserving the three-dimensional relationships of the anatomic areas of study. The pre and post-test data for the individual task areas (name, function, depth, plane, and number) were analyzed utilizing a Kruskall-Wallis one-way analysis of variance, and as illustrated in Figure 4, a significant (P<0.001) increase in overall student performance was observed for each task area. The overall student post-test data was again analyzed to determine which of the task areas had the greatest increase utilizing the Kruskal-Wallis one-way analysis of variance on ranks, followed by a Tukey post-hoc analysis. Analysis of the data revealed a significant (P<0.001) difference in task performance, with the results of the post-hoc testing being shown in Table 6. Three of the four comparisons utilizing the task area of depth (Table 6) were found to be significant (P≤0.002), strongly indicating preservation of the three-dimensional anatomical concepts. Comparisons using function and plane were also found to be significant when compared to other non-three-dimensional task related areas (Table 6). However, further analysis into the performance on specific questions revealed no consistent relationship between the anatomical regions and the task area questions.

**Table 5. Comparison of Learning Gain Performance by Anatomic Region**

<table>
<thead>
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<th>Comparison</th>
<th>P value</th>
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<tr>
<td>Abdomen vs. Brachium</td>
<td>0.03</td>
</tr>
<tr>
<td>Abdomen vs. Anterior Thigh</td>
<td>0.05</td>
</tr>
<tr>
<td>Brachium vs. Anterior Thigh</td>
<td>0.998</td>
</tr>
<tr>
<td>Face vs. Abdomen</td>
<td>0.077</td>
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While learning the identification of anatomic structures was important, it was only one component of the intended activity. Other learning goals included the understanding of applications (function, depth, plane, and number). The data demonstrates that the paper model system is an effective pedagogical method for teaching anatomy, especially in preserving the three-dimensional relationships of the anatomic areas of study. The pre and post-test data for the individual task areas (name, function, depth, plane, and number) were analyzed utilizing a Kruskall-Wallis one-way analysis of variance, and as illustrated in Figure 4, a significant (P<0.001) increase in overall student performance was observed for each task area. The overall student post-test data was again analyzed to determine which of the task areas had the greatest increase utilizing the Kruskal-Wallis one-way analysis of variance on ranks, followed by a Tukey post-hoc analysis. Analysis of the data revealed a significant (P<0.001) difference in task performance, with the results of the post-hoc testing being shown in Table 6. Three of the four comparisons utilizing the task area of depth (Table 6) were found to be significant (P≤0.002), strongly indicating preservation of the three-dimensional anatomical concepts. Comparisons using function and plane were also found to be significant when compared to other non-three-dimensional task related areas (Table 6). However, further analysis into the performance on specific questions revealed no consistent relationship between the anatomical regions and the task area questions.

**Figure 4. Pre and post-test performance on task area questions. Student acquisition of anatomical concepts was assessed (for all paper models) using a series of task specific designed pre-test questions, administered prior to using a paper model, and followed by a post-test after using a paper model. Pre-and-post-test results were reported out of a score of five. Error Bars = SEM, ** = Significance (P<0.001)**

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Potential Factors Impacting the Learning Gain
A large majority (93.57%) of students in the Anatomy and Physiology II class had declared either exercise science or public health as their primary major (Figure 1). Therefore, an analysis was conducted to see if there was an effect of the student’s declared major on the post-testing results. First, the data was analyzed utilizing the Shapiro-Wilk normality test, resulting in a calculated test statistic of 0.093; indicating the data demonstrated a normal distribution. Following the normality test, the post-test data between the exercise science majors and the public health majors was analyzed utilizing a 1-tailed t-test. As illustrated in Figure 5, a significant (P<0.001) difference in the post-test performance was found, with the exercise science majors outperforming the public health majors in all four of the anatomic areas that were studied. The results of this analysis clearly demonstrated that the declared major has a significant effect on student post-test performance.

A majority of students enrolled in the Anatomy and Physiology II course identify as female, Figure 1a. Therefore we wanted to determine if student gain was influenced by the identified gender of the student. First, the data was analyzed with the Shapiro-Wilk test for normality. This analysis determined (P<0.05) that the data were not normally distributed. The data were further analyzed by the non-parametric Mann Whitney test, which demonstrated that the gender of a student had no significant (P=0.051) effect on the learning gain from this paper model system.

Finally we wanted to determine if there was a correlation between student SAT scores and their performance on the paper model activity. When the pre-test data was analyzed against the student SAT scores there was no significant correlation. However, when post-test results were compared to student SAT results, we found a significant (P=0.004) correlation with the coefficient of determination ($r^2$) to be 0.058, meaning that a student’s SAT scores can explain 5.8% of the variation observed in the data.

These findings indicate that declared major had the greatest impact on the overall learning gains. SAT scores have a correlation with the learning gains and identified gender had no impact on the learning gains observed in this activity.

### Table 5. Comparison of Post-test performance by Question Task Area

<table>
<thead>
<tr>
<th>Comparison</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth vs. Function</td>
<td>0.403</td>
</tr>
<tr>
<td>Depth vs. Name</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Depth vs. Number</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Depth vs. Plane</td>
<td>0.002</td>
</tr>
<tr>
<td>Function vs. Name</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Function vs. Number</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Function vs. Plane</td>
<td>0.26</td>
</tr>
<tr>
<td>Name vs. Number</td>
<td>0.981</td>
</tr>
<tr>
<td>Plane vs. Name</td>
<td>0.013</td>
</tr>
<tr>
<td>Plane vs. Number</td>
<td>0.002</td>
</tr>
</tbody>
</table>

### Figure 5. Influence of a student’s declared major on post-test performance. A student’s declared major was found to have a significant influence on the post-test outcomes. Two majors (public health and exercise science) make up an overwhelming majority of the Biology 217 class population. The overall pre-test and post-test results between these two majors were directly compared. ES = exercise science, PH = public health. Error Bars = SEM, *** = Significance (P<0.0001)

The Paper Model System altered student Confidence
Student confidence level with the anatomical information was assessed using the series of questions posed in Table 3. First, the data was analyzed with the Shapiro-Wilk test for normality, which determined (P<0.05) that the data was not normally distributed. Therefore, the Wilcoxon signed rank test was used to analyze the pre-test/post-test data for the abdomen, brachium, and face. As illustrated in Figure 6a, there were significant (P<0.001) increases in student confidence for content regarding the abdomen, brachium, and face. When it came to the three-dimensional task area questions (Figure 6b), there were significant (P<0.001) increases in student confidence for content regarding muscle layering and anatomical planes.

With the increase in student confidence, a Spearman rank order correlation analysis was conducted to see if increased confidence results in better academic performance on the post-tests. Interestingly, this analysis demonstrated that even though the students showed a significant increase in confidence with the material being taught in the paper models activity, a Spearman rank order confirmation test revealed...
that no correlation (abdomen P=0.389; brachium P=0.234; and face P=0.234) to academic success was demonstrated. So, even though using the paper model system demonstrated significant gains in student learning and had a positive effect on student confidence, the increase in student confidence with the material did not correlate to a better or worse academic performance in any specific anatomical region studied.

Student Perception of the Paper Model Activity
In order to assess student perception of the paper model laboratory activity, and which model system they found the most and least helpful, students were surveyed at the end of the course. Student satisfaction with the paper models was evaluated by posing the questions that are presented in Table 4, and then having the students respond using a Likert scale of 1 to 5, with 5 designated as strongly agree, and 1 being strongly disagree. As seen in Figure 7a, a large majority 71.7% of students agreed or strongly agreed that the paper models helped them learn, while a relatively smaller portion of the students 28.3% stated that the paper models were not helpful to their learning.

Students were also asked which model was the most and least helpful in their studies. As seen in Figure 7b, 43.5% of the students surveyed (N=140) found the face musculature model to be the most helpful, with the abdominal musculature model coming in a close second at 38%. Interestingly, the two Locket models came in a distant third and fourth with 15% of the students finding the brachium model helpful, and only 3% finding the anterior thigh model helpful (Figure 7b). With regard to the model that was the least helpful, the data was much more split. 14.5% of students surveyed found both the face and abdominal muscle models to be least helpful. As expected, based on the previous assessment, the Locket models were found to be the least helpful of the paper models, with 28.2% of students identifying the anterior thigh model as least helpful, and 22.1% of students identifying the brachium model as least helpful.

Figure 7. Student’s perception of the paper model activities. (A) Assessment of the overall student perception on how helpful the paper model activities were in learning anatomy. (B) Body region specific assessment on which paper model activities were the most helpful in learning anatomy, and which models were the least helpful in learning anatomy. SA = Strongly Agree, A = Agree, D= Disagree, SD = Strongly Disagree

Figure 6. Paper models systems effect on student confidence. Questions assessing student confidence with anatomical knowledge were asked on both the pre-tests and post-tests. (A) Student confidence with general anatomical knowledge in three of the four body regions studied. ** = Significance (P<0.001)
Discussion
Our data revealed that there was a gain in student learning, and that regardless of pre-requisite there was the same absolute level of knowledge gain. Therefore, this study demonstrates that not only can a paper model system be designed to a complexity level appropriate for an undergraduate student, but also that paper models are an inexpensive viable pedagogical tool for anatomical education.

One of the more challenging issues that face anatomy educators is which combination of pedagogical systems (images, models, cadaveric) is the most appropriate to teach anatomical concepts. More importantly, to teach the anatomical concepts at a level of detail appropriate for college undergraduates, many of whom are taking undergraduate anatomy and physiology courses as prerequisite classes for entry into health professions training programs. Studies have focused on the success of using a multimodal approach (e.g.: using models, clays, digital media, body painting etc.) to best teach students (Sugand et al., 2010; Higazi, 2014) and accommodate a multitude of learning strategies (Soon, 2015). To our knowledge, this study is the first of its kind to examine the effects of a three-dimensional paper model system on undergraduate anatomical sciences education, as another pedagogical technique.

The first question of this study was, could a paper model system effectively highlight and teach the complexity of the musculoskeletal system for four different regions of the body? Overall the results from this study clearly indicate that a significant amount of student learning occurred when this model system was used to teach the complexity of detail that is involved with musculoskeletal anatomy. Typically, the three-dimensional attributes of musculoskeletal anatomy are better appreciated in cadaveric dissections (Papa and Vaccarezza, 2013). However, when it comes to pedagogical effectiveness, students do not necessarily find cadaveric dissection to be the best teaching tool (Bergman et al., 2011). Evaluation of student knowledge in the task areas designed to assess the complex three-dimensional anatomical relationships revealed a significant gain in student knowledge in the concepts areas of muscle depth, plane, and function (Figure 4, Table 6). Significant gains in student knowledge of muscle depth, plane, and function all indicate that a paper model system can be an effective pedagogical tool to teach three-dimensional anatomic relationships.

The second question this study set out to answer was, could a paper model system originally designed to teach medical students, be adapted to a complexity level appropriate for undergraduate students? The results of this study demonstrate that a) this paper model system can be modified for instructional purposes at an undergraduate level and b) data from this study offer suggestions on how to adapt these models for use at an undergraduate level. Students found both of the Locket models (brachium and anterior thigh) to be the least helpful, while finding the two models designed by Dr. S. Rehorek (abdomen and face) to be the most helpful (Figure 7). The face and abdominal models were designed to be simpler, and composed of larger pieces, which allowed for easier to manipulation. Additionally, the assembly instructions for the face and abdomen models were concise and clear preventing confusion and frustration, resulting in an overall more enjoyable activity. The brachium and anterior thigh models adapted from Locket had many small pieces, and complex assembly instructions, which increased student frustration and confusion during the assembly of the models.

The ability to simplify the paper models to a level more appropriate for undergraduate education is important, because as has been documented in the pedagogical research, students respond better to activities if they are more fun (Higazi, 2014). Additionally, placement of the muscle names was also found to affect student learning, with labels on the actual muscles (Rehorek models) being more helpful than those labeled outside of the muscles (Locket), which would often get lost during construction. Repetition and engagement with the material is key to any successful learning strategy (Dunn-Lewis et al., 2016).

The last question this study examined was, can this inexpensive, low tech, interactive model system achieve a significant gain in student learning for a complex topic like the musculoskeletal system? There were significant learning gains in all four anatomic regions studied (Figure 3) and functional task areas (Figure 4). This seems to indicate that significant learning gains took place using a relatively simplistic, inexpensive, and more importantly, an environmentally safe model system. Additionally, allowing students to take these models home opens up additional self-study time for that would otherwise not be available. Self-study time is becoming more of a necessity as the amount of material that needs to be taught is outpacing the amount of time available for study, thus making self-study an increasing viable form of learning (Bergman et al., 2011).

One of the most dramatic findings in this study was the impact that a student’s declared major had on the learning gain with this paper model system. Here at Slippery Rock University, there are no official prerequisite courses for a student to register for the Anatomy and Physiology II course. Most of the students in the class are either exercise science majors or public health majors. The students enrolled in exercise science are required, as an unofficial prerequisite, to take an a semester-long exercise science course titled “Applied Anatomy” which is a basic musculoskeletal anatomy class, whereas the public health majors typically are not required to take this course. There was a significant difference between the exercise science students, who had taken the applied anatomy class, and the public health students who had not taken the course. The results of the study demonstrated that the exercise science students outperformed the public health
majors on three of the four paper models (face being the exception) in both pre-and-post testing (Figure 5). When the pre-test data for the face was examined, both exercise science and public health majors showed equivalent levels of performance. However, when the post-test data for the face was examined, while both the exercise science and public health majors showed a significant increase in their performance, the exercise science majors significantly outperformed the public health students (Figure 5). This model system would suggest that exercise science majors are better prepared to process and retain the information with regard to muscle anatomy and the three-dimensional aspects of the muscular anatomy. This would be a reasonable conclusion, based on the fact the course on “Applied Anatomy” teaches not only the basic linguistic jargon that accompanies musculoskeletal anatomy, but also primes the students at a basic level in some of the other concepts of muscle planes, actions, and regional relationships. The effect of a prerequisite course on anatomy and physiology grades has been noted (Russell et al., 2016), but those were for general science courses, not specifically human anatomical courses. The precise mechanism for why the exercise science majors outperform the public health majors has yet to be precisely elucidated. However, it is very clear from the data presented in this study, that the declared major of a student has a profound effect on their performance in Anatomy and Physiology II.

This finding while interesting also has a confounding variable that needs to be taken into consideration. Did students underperform in the brachium/anterior thigh model? If so, why? The “Applied Anatomy” course focuses most of its time on the musculoskeletal anatomy of the upper and lower extremity. Since exercise science majors form the majority of students registered in the Anatomy and Physiology II course, there is a chance that this finding could be biased by the fact that exercise science majors are already somewhat familiar with the anatomy of the extremities. This familiarity with the anatomy of the extremities, may have given the students a false sense of confidence (figure 6a), thus tempering their study of a body region they already felt comfortable with. This is called the overconfidence effect, when there is a disparity between what students know and what they think they know (Nowell and Alston, 2007). This is an issue of retrieval of information, not learning, in which students have learned the material and thus no longer feel the need to actively remember it (Karpicke and Grimaldi, 2012). This results in under preparation and subsequently underperformance (Nowell and Alston, 2007). Muscles of the abdomen and face are not the focus of study in the applied anatomy course, thus the abdomen and face models presented in this study would present a novel learning opportunity to the students. Therefore, the novelty of the learning experience would tend to increase the student’s focus and study of the new region.

Regardless of the reason for the variable performance in the different models, one thing was clear, that is that the amount of class time dedicated to the models needs to be proportionate to the complexity of building the model. For example, the face model which is fairly simplistic to color, cut, and assemble does not need the same amount of laboratory time as the construction of the anterior thigh or brachium model. The major reason the time dedicated to model building must be tailored to the complexity of the model is that if too much time is allotted to a model that is simple to build, the students will get bored and their attention will wander. On the other hand, if there is not enough time allowed for building a complex model, the students will rush through it and get frustrated, which decreases the overall effectiveness of the activity.

Different pedagogical methodologies have been used for anatomic science education. While the cadaver or cadaveric materials historically represents the best teacher of anatomy, there are still the institutional infrastructure costs to run such laboratories, and environmental hazards, such as formaldehyde exposure, that need to be considered. The paper models presented in this study provided an inexpensive, nontoxic, and mostly hazard free system in which to teach anatomy. Moreover, because these anatomic models are three-dimensional in nature, the anatomic relationships that are best appreciated in the cadaveric teaching material is preserved to a large degree. Additionally, because the students are actively building these models, not just passively observing anatomic models, this is a much more active learning pedagogical practice that involves a tactile component not just a strictly cognitive component.

This study clearly demonstrates that a paper model system that was originally designed for students in medical training programs can be used to teach undergraduate anatomy. However the models have to be adapted for students at the undergraduate level in order to have a successful result.

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About the Authors
Susan Rehoerk, PhD, is a Professor in the Department of Biology at Slippery Rock University of Pennsylvania, Slippery Rock, Pennsylvania. She teaches anatomy and physiology and histology to undergraduates. Her research interest is in the development of the vertebrate nasolacrimal apparatus, and anatomy education.

Paul Falso, PhD, is an Associate Professor in the Department of Biology at Slippery Rock University of Pennsylvania, Slippery Rock, Pennsylvania. He teaches anatomy and physiology and physiology to undergraduate students. His research interest is in environmental toxicology and its effects on endocrine and immune processes in amphibians.

Justin Siebert, PhD, MS Med Ed, is an Assistant Professor in the Department of Biology at Slippery Rock University of Pennsylvania, Slippery Rock, Pennsylvania. He teaches clinical anatomy and physiology in the Slippery Rock University Physician Assistant Program. His research interests include medical education and neurologic injury and repair.

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