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THE EFFICACY OF INTRODUCING THREE-DIMENSIONAL DIGITAL IMAGES TO SIMULATED HUMAN SKELETAL ANATOMY LABORATORIES.

by

Christian Petersen

A dissertation

submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy in the Department of Education

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To the Graduate Faculty:

The members of the committee appointed to examine the dissertation of Christian Petersen find it satisfactory and recommend that it be accepted.

____

Dorothy Sammons, Ed.D.

Major Advisor

____

Karen Wilson Scott, Ph.D.

Committee Member

____

David Coffland, Ed.D.

Committee Member

____

Elizabeth Cartwright, Ph.D.

Committee Member

____

Curt Anderson, Ph.D.

Graduate Faculty Representative

Human Subjects Committee Approval

IRB-FY2016-271 - Initial: Letter of Approval (exempt) Inbox x

baerralp@isu.edu 10/28/16

to me

October 28, 2016

Christian Petersen
Anthropology
MS 8005

RE: regarding study number IRB-FY2016-271: The educational impact of threedimensional digital files in an online environment.

Dr. Petersen:

I agree that this study qualifies as exempt from review under the following guideline: Category 1: Normal educational practices & settings. This letter is your approval, please, keep this document in a safe place.

Notify the HSC of any adverse events. Serious, unexpected adverse events must be reported in writing within 10 business days.

You are granted permission to conduct your study effective immediately. The study is not subject to renewal.

Please note that any changes to the study as approved must be promptly reported and approved. Some changes may be approved by expedited review; others require full board review. Contact Tom Bailey (208-282-2179; fax 208-282-4723; email: humsubj@isu.edu) if you have any questions or require further information.

Sincerely,

Ralph Baergen, PhD, MPH, CIP
Human Subjects Chair

Dedication

I would like to dedicate this study to my wife and son. Without their love and support I would not have been able to complete this project. You two are the reason I achieved this goal and I am so very grateful for both of you.

Acknowledgement

I would not have been able to complete this study without the advice, assistance and support of my graduate committee. To Dr. David Coffland, your advice and clear explanation of the statistical requirements of my study were incredibly useful to me and our off-topic discussions in your office were a blast. To Dr. Wilson-Scott, having known you for so many years, it was a joy to enter into this new relationship with you. You opened my eyes to the complexity and the utility of the qualitative analysis. Thank you so much for that. To Dr. Cartwright, it is always a tricky transition when a colleague becomes a committee member. You made that transition so effortless and your advice and encouragement meant so much to me during this process. To Dr. Anderson, your enthusiasm and sense of humor were an incredible addition to my committee. Your point-of-view as an academician outside of the education department was much needed in keeping my project on track and focused. Finally, to Dr. Sammons, you spent so much time with me. You read and reread everything that I sent to you tirelessly. You were patient beyond measure and your insights have made me a better academician. Words cannot express how much that means to me.

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Abstract

This dissertation studied the impact of the inclusion of three-dimensional digital images of the human skeleton on the educational outcomes and perceptions of novice learners studying introductory skeletal anatomy. A group of students with little or no knowledge of human skeletal anatomy completed an online educational module, with the treatment group receiving additional instruction from three-dimensional digital images of the bone covered in the instructional module. The results of an in-person, practical posttest described the compared achievement differences between the two groups. In addition, participant motivation was measured using a course interest survey and participants were asked about their experience and perception concerning online education and three-dimensional digital images through two open-ended questions at the end of the posttest. The statistical analysis did not show a statistically significant difference in performance on the posttest, between the treatment and control groups. While there was a significant difference between the groups specific to motivation as measured by the course interest survey, emergent themes suggested from the open-ended questions suggest that while the instructional material was engaging, the participants did not see the 3D files creating an authentic learning experience.

Chapter I

Introduction

College level courses are increasingly being moved into the digital or online environment. Currently, nearly one third of all college students in the United States take at least one online class during their college career (Allen & Seaman, 2014). The transition to online is seen not only in lecture courses, but also in laboratory courses, most commonly in engineering fields (Auer & Ursutiu, 2003; Feisal & Rosa, 2005; Ma & Nickerson, 2006) and health related professions (Brenton et al., 2007; Chittaro & Ranon, 2007; Dee, 2009; Li, Brodlie, & Phillips, 2000; Nicholson, Chalk, Funnell, & Daniel, 2006; Ong & Mannan, 2003). As with lecture style classes, the reasons for moving laboratory classes online have to do with both lowering costs (Auer & Ursutiu, 2003; Balakrishnan & Woods, 2013; Dee, 2009) and perceived advantages to student learning (Auer & Ursutiu, 2003; Chittaro & Ranon, 2007; Dee, 2009; Li et al., 2000; Ong & Mannan, 2003) (Tang & Byrnes, 2007). The purpose of this study is to describe the impact of three-dimensional digital files on learner performance and motivation in an online laboratory course.

Context

The laboratory class is a common fixture in post-secondary education. Biology, chemistry, physics, and even anthropology often require laboratories as part of their introductory classes. It is not uncommon for students to take two or three laboratory courses in their first years of college regardless of their major. This is not surprising considering that science educators have considered the laboratory course an essential part of general science education for over a century (Fay, 1931). Laboratory teaching is considered critical to science education because such courses are a primary mechanism for training students in observational skills, supplying topic-specific information, and shaping positive perceptions of learning (Travers, 1978). Although laboratory courses are a long-standing educational tradition, in the last two and a half decades, there has been a rapid change in laboratory educational technologies, especially with the advent of online learning (Hiltz & Turoff, 2005; Saba, 2011).

Online courses have become a common part of the educational process in the United States. By the early 1990's, the Internet was explored as an avenue for providing education (Saba, 2011). By 2011, over 32% of college students in the US were taking at least one online course, representing over 6.7 million students, an increase of more than 9% from the year before (Allen & Seaman, 2014). The ongoing transition from the traditional face-to-face course to the online makes sense given the advantages inherent to the online environment, which include a reduction in facilities costs and the ability to reach geographically disparate students. Further, research supports the idea that well-designed online courses are as effective as more traditional face-to-face courses (Ni, 2013).

However, some types of courses pose unique challenges in translation to the online environment. Traditional face-to-face laboratory courses, for instance, are designed to simulate the real world, allowing the student to learn through an authentic learning experience (McLachlan & Patten, 2006). It has been suggested that the very act of transitioning a laboratory course to an online environment eliminates the authentic experience of the laboratory course (Ma & Nickerson, 2006). Further, researchers and industry leaders claim the move has led to lowered educational outcomes in a number of fields (Cottam, 1999; Ma & Nickerson, 2006; Sugand, Abrahams, & Khurana, 2010). Unfortunately, traditional laboratory courses tend to be very expensive, consuming valuable time, personnel, and resources (Sugand et al., 2010; Turney, 2007), which makes the online versions of such courses attractive to resource-strapped learning institutions. Thus, this transition of laboratory classes from the traditional face-to-face environment to the online environment is likely to continue.

Currently, online laboratory courses are taught using a variety of methods, designed to simulate the face-to-face laboratory experience. These methods might include 2D graphics, animation, audio files, and text-based material. Research supports the use of multiple forms of media in the online environment as a means of increasing educational outcomes (Mayer & Moreno, 1998). Still, researchers and industry leaders (Ma & Nickerson, 2006) claim that these methods are not sufficient to overcome the challenges of teaching complex concepts in an online environment.

As technology continues to improve, it has become possible to create and display three-dimensional (3D) images. From engineering applications created to design and create mechanical objects (Auer & Ursutiu, 2003) to medical imaging used to visualize complex three-dimensional anatomy (Brenton et al., 2007; Li et al., 2000), 3D digital images are seen as having significant educational potential: as an authentic learning exercise (Furness, 1997), as a simulation of actual anatomy (Harrell, Hatcher, & Bolt, 2002), or as an example of the multimedia approach to online education (Clark & Mayer, 2011). The 3D technology is still relatively complex to maintain and expensive to use. Given that online laboratory courses, utilizing two-dimensional multimedia resources, have a long but uneven history (Lohse, Schlader, & Sammons, 2002; Ma & Nickerson, 2006), the question that now arises is whether the integration of 3D images into online laboratory classes will have a significant effect on student achievement.

A secondary issue is the matter of the student perception of the online environment. Data suggest that learners' perception of the environment can significantly impact their achievement (Ma & Nickerson, 2006). In an early study on student engagement in an online environment, Sheridan (1994) described the idea as the perception that the learner is engaged with the learning environment, and dubbed this engagement *presence*. Various researchers have expanded on Sheridan's concept, noting that if sufficient attention is given to the learning environment, a level of suspension of disbelief can be attained, greatly aiding in learning (Nunez & Blake, 2003).

Before going further, it is necessary to understand how the various forms of online laboratory courses are categorized. For the purposes of this study, the categorization system put forth in Ma and Nickerson (2006) was used. Though this categorization system was first advanced by Auer and Usurtiu (2003), the system received little attention. Nearly two years later a similar categorization was presented by Feisal and Rosa (2005). Then, in 2006, Ma and Nickerson refined and described the categories in detail after an extensive literature review (over 70 articles) and these categories have begun to see use in engineering literature such as Yan et al. (2006). No common categorization system is currently used in the literature from chemistry or human anatomy, which appear to be the other laboratory sciences with the most interest in the use of three-dimensional files in the education process.

According to Ma and Nickerson (2006), there are at least two separate kinds of laboratory courses: the traditional, face-to-face laboratory class, referred to by Ma and

Nickerson as the hands-on laboratory class; and by contrast, any laboratory courses where the students' complete tasks in a digitally-mediated setting. However, not all digital laboratory courses are the same. Ma and Nickerson recognize two categories of digital laboratory courses: simulated and remote. The remote lab allows students to access and remotely control actual, physical machinery to complete lab tasks, and is commonly found in engineering, chemistry, or physics courses. However, since the remote lab is not a format addressed in this study, no further examination of its functions or benefits will be offered. The characteristics of the traditional, hands-on lab and the simulated lab are discussed below.

Hands-on laboratories. The traditional laboratory format is seen as inherently superior to the online laboratory in that the hands-on laboratory takes place in the real world. The process of manipulating objects, dealing with different materials and instruments, and simultaneously gathering data teaches the student to deal with an unpredictable environment (Magin & Kanapithipillia, 2000). Students learn effectively by carrying out the tasks they will be expected to carry out once they have finished their education, what Lave and Wenger (1991) have termed *situated learning*.

The disadvantages of the hands-on lab, however, are the main reasons for the rapid translation of laboratory courses into an online environment. In a word, hands-on labs are expensive (Cottam, 1999; Ma & Nickerson, 2006; McLachlan & Patten, 2006; Ridgway et al., 2007; Sugand et al., 2010; Turney, 2007). Hands-on labs require physical space, often a great deal of space compared to a course taught in a classroom; and even more than space, a laboratory often requires considerable infrastructure such as water and gas lines, floor drains, storage, and safety equipment. Hands-on laboratory courses also require specialized materials, many of which are consumable and must be frequently replaced or manufactured in-house, such as deionized water or petri dishes of agar. Then there are the personnel required to teach and supervise the laboratory course. While graduate students using highly codified lessons can teach lower division courses, more complex lab courses require one or more senior level faculty to properly teach and supervise the lab activities. Finally, lab courses take a lot of student time. This time must be scheduled, impacting the student's ability to attend other courses. Indeed, time can negatively impact the student's perception of the value versus the cost of the course and thus impact the student's performance in the course (Sugand et al., 2010).

Simulated labs. The type of lab that is the focus of this study is the simulated lab. The following description is relatively common in engineering literature (Auer & Urstiu, 2003; Feisal & Rosa 2005; Ma & Nickerson, 2006). This description as well as the associated advantages, is also common in the biological sciences (Li, et al., 2000; Ong & Mannan, 2003; Brenton, et al., 2005; Chittaro & Ranon, 2005; Nicholson, et al., 2006; Dee, 2009). A simulated laboratory course is asynchronous, in that the students can access the laboratory at their convenience. All the equipment and materials needed to complete the laboratory are simulated and the simulation is generally accessed through the Internet. As the student completes the tasks associated with the specific lesson, the results are also simulated. Ideally, the simulation closely approximates the results that would be obtained in a physical laboratory setting.

The primary advantage of the simulated lab is the decreased cost of running the lab. A simulated lab is certainly very expensive to create, and purchasing the software necessary to run a simulated lab can be expensive initially. However, a simulated lab, due to the nature of the digital environment, avoids many of the costs associated with a traditional laboratory class. These cost savings are found in materials, the physical space of the lab, and personnel.

A simulated laboratory does not require physical materials in the traditional sense. Certainly, a digital infrastructure is needed, but universities already have such an infrastructure in order to offer online courses. Since the lab course exists in a digital environment, no physical space is needed to run a simulated lab course. As no physical lab space is needed, a single instructor can monitor the performance and guide the behavior of many more students (Auer & Ursuitu, 2003; Balakrishna & Woods, 2013; Dee, 2009). Finally, such labs are asynchronous, allowing students to access and perform the tasks at a time and place of their choosing, within given time restrictions (Auer & Ursutiu, 2003; Balakrishnan & Woods, 2013; Chittaro & Ranon, 2007; Dee, 2009; Li et al., 2000; Ong & Mannan, 2003) (Tang & Byrne, 2007).

Further, research suggests that simulated labs are at least as effective as traditional, hands-on labs (Corter et al., 2007; Finkelstien et al., 2005; Lindsay & Good, 2005; Zacharia et al., 2015). Indeed, research adds to the list of advantages in several ways. Unlike a live situation, simulated labs allow the student to freeze reality in order to better assess the process and results (Parush, Hamm, and Shtub, 2002). Corter and colleagues also came to this conclusion, adding that simulation labs eliminated the necessity of setting up and breaking down the equipment necessary to complete the lab. Parush et al. also suggest that since the students most commonly completed the simulation lab alone, they had the opportunity to stop the process and think about what they were learning without the constraint inherent in a traditional laboratory setting.

Taken together, these two studies suggest that the students could spend more time on task, with fewer distractions, in a simulated lab.

Finally, a number of authors have pointed out that the difference in costs between the hands-on and simulated labs is not always significant. Canizare and Faur (1997) examined the cost of creating and supervising a simulated lab, showing that the costs for technologically demanding simulations are nearly as high, if not higher than the cost of the hands-on lab. Papathanassiou et al. (1999) examined a number of poorly designed and constructed simulations, making the point that a piece of expensive software can still be a poor approximation of reality.

Theoretical framework

The multimedia approach. The multimedia approach is a method of enhancing learning by presenting information in multiple formats such as text, graphics, audio, animation, or video. By combining two or more media formats, the instruction is more engaging, encouraging the learner to become an active participant in the learning process (Clark & Mayer, 2011, p. 57). This combining of media formats has been shown to increase the achievement of educational goals. The specific combination of text and graphics has been shown to increase learner achievement by as much as 121% over text or traditional verbal lecture alone (Clark & Mayer, 2011, p. 66).

Clark and Mayer (2011) claim that by presenting information and the proper graphical representation of the information, the learner is encouraged to internally construct information and link relevant concepts presented in the text and graphic. Thus, the graphic is used to guide or scaffold the learner’s acquisition of important concepts and the relationships between them.

However, Clark and Mayer (2011) argue that simply providing graphics related to the information presented in the text is not enough to successfully increase student achievement. The process, like any other educational process, must be deliberate. The relationship between the text and the graphics used must be obvious. If the graphic is not tightly related to the material presented in the text, or if the placement of the graphic is not spatially appropriate, such as placing the graphic on a previous or subsequent page, the learner is be subject to unnecessary cognitive load (Clark & Mayer, 2011, p. 58). In other words, the learner is required to keep information in active memory while he or she navigates from the text to the graphic. Coining the term *Split Attention Effect*, Tarmizi & Sweller (1988) found that the improper placement of a graphic could diminish any increase in student achievement and in some cases, such incorrect placement could actually confuse the learner, leading to a decrease in achievement. Contiguity, the proper placement of conceptually appropriate graphics to support information presented in text, has been demonstrated to promote achievement (Clark & Mayer, 2011).

Finally, contiguity is useful in a very specific learner context. Mayer and Gallini (1990) found that contiguity was responsible for considerable increases in learner achievement among novice level learners. However, the same increase in learner achievement was not seen in learners who were already well versed in the subject. Arguing that expert learners had already internalized their own graphical representation, Mayer and Gallini suggested that such learners received no extra guidance from the contiguous graphics presented with the textual information.

The 3D graphics used for this study embody the multimedia approach in the classic sense that text and graphical representation of the material are paired. Given that the images can be rotated and that it is possible to zoom in and out, the student was able to examine the image in detail unavailable to student examining static images in a traditional textbook. Further, the student was able to choose from the six standard anatomical orientations, each with all of the standard anatomical features clearly identified, embodying the concept of contiguity.

Authentic learning. There is a common view in educational research that, in modern schools and universities, there is a separation between the act of learning about something and the act of doing that thing (Resnick, 1987). The general idea is that schools and universities are focused on identifying the central concepts of a discipline and then teaching the student these concepts in an “abstract and decontextualized form” (Herrington, Reeves, & Oliver, 2000). According to Herrington and Oliver, this approach ignores the connection between the knowledge gained about a specific task and the actual performance of the task. Thus, the knowledge gained during the educational experience becomes the goal instead of the ability to perform the job for which the student is receiving training.

As this issue has been recognized in the literature as early as the beginning of the last century (Whitehead, 1932), researchers have been involved in mitigating this problem for some time. In their 1989 article, Brown, Collins, and Duguid created a framework for dealing with this problem by focusing on learning in the context of the eventual environment of practice for which the learning ultimately takes place. This model is now most closely identified with the cognitive anthropologists Jean Lave and Etienne Wenger (1991), who shifted the focus of the model toward the creation of a community of practice, where the practitioners of a specific craft interact professionally, learning from each other. Thus, the learners begin as peripheral members of the group and, as their education progresses, gradually become full-fledged members of their profession. This pedagogical approach has been labeled *situated learni*ng (Lave & Wenger, 1991) and differs from the more general *authentic learning* by its focus on the movement of the learner from legitimate peripheral participation to inclusion in the community of practice.

Given the limitations of the simulation lab experience, the use of high resolution, three-dimensional images in the study of the human skeleton is, in effect, approximating both the use of skeletal material in the physical lab setting and the handling of human skeletal remains in the professional setting. Thus, the three-dimensional images are a situated learning activity. The overall problem to be addressed is whether the inclusion of three-dimensional images in a simulated lab can create an authentic learning experience.

Purpose of the Study

The purpose of this study was to describe the effect of the addition of three-dimensional digital files in an online laboratory course on both learner performance and learner attitudes.

Research questions

Four research questions were specifically addressed for the purpose of the study.

1. Is there a significant difference in student knowledge of skeletal anatomy as measured by an in-person practical examination, between students who receive 3D digital bone images in addition to the regular online 2D instruction, and those students who receive the regular online 2D instruction only?

2. If there is a significant difference in the posttest results of the treatment and control groups, can the difference be attributed to the preexisting skeletal knowledge of the participants?
3. Is there a significant difference in student attitude toward learning skeletal anatomy as measured by the Course Interest Survey, between students who receive 3D digital bone images in addition to the regular online 2D instruction, and those students who receive the regular online 2D instruction only?
4. Is there a qualitative difference in student attitude toward learning skeletal anatomy between students who receive 3D digital bone images in addition to the regular online 2D instruction, and those students who receive the regular online 2D instruction only, as indicated by the response to two open ended questions?

Research design

The research followed a quasi-experimental, posttest only control group design. It is recognized that the control of a true experimental situation is difficult in an educational setting. Specific to this study, the participants were volunteers, from preexisting college courses and not randomly selected from the general student body of the university at which the study took place. In situations where the researcher lacks selection control, the quasi-experimental design is generally used (Gall, Gall, & Borg, 2007). However, the participants were randomly assigned to the treatment and control groups.

Table 1.

Posttest only control group research design.

Groups	Knowledge Test	Treatment	Attitudinal Survey	Posttest
R_1	O_1	X	O_2	O_3
R_2	O_4	C	O_5	O_6

Note: O1, O4: Test of skeletal anatomy knowledge; O2, O5: Course Interest Survey Posttest; O3, O6: Posttest of skeletal anatomy knowledge. Treatment (X) is traditional instruction with 3D images; control (C) is traditional instruction only.

The target sample consisted of students from the seven sections of ANTH1100: General Anthropology during the fall semester of 2016 and the seven sections of ANTH1100: General Anthropology taught during the spring semester of 2017. The students who volunteer were administered a Test of Prior Knowledge (ToPK) to assess prior knowledge and then randomly assigned to treatment or control groups. The students assigned to the control group were asked to complete an online learning module focused on one of the bones of the lower leg, the tibia. The students assigned to the treatment group completed the same educational material with the addition of an illustrated, three-dimensional file of the tibia. The week after the students complete the learning module, both groups took an in-person exam on the material. The examination was delivered in the skeletal anatomy lab of the Department of Anthropology. After the examination, the participants answered two open ended questions focused on their experience during the study.

In addition, a Likert scale attitudinal survey was conducted through the study Moodle pages at the end of the module, but prior to the examination. The Course Interest Survey (CIS) (Keller, 2006) is designed to elicit the students' perception of the value of the educational materials they have received. The questions used in the CIS survey are available in Appendix A.

Definition of terms

Asynchronous learning. A student centered teaching method where educational activities take place at the time of the individual learners' choosing and thus outside of the constraints of a specific time and place (Mayadas, 1997).

Contiguity. Placing graphics and the text that corresponds to the graphics in close physical proximity in educational materials (Clark & Mayer, 2011).

Control group. In a study, a group of participants who do not receive the treatment condition and whose performance, the performance of the treatment group is compared(Gall et al., 2007).

Online course. An educational course, where the instructional materials are delivered through the World Wide Web, accessed through a web browser on a personal computer or other digital device.

Online environment. Any learning environment that exists wholly as information stored on a computer, accessible through the World Wide Web.

Presence (cognitive presence). Defined as "the extent to which the participants in any particular configuration of a community of inquiry are able to construct meaning through sustained communication" (Garrison, Anderson, & Archer, 2001).

Remote Laboratory course. In remote laboratory courses, the learner accesses and uses real, but geographically distant, equipment to accomplish educational tasks (Ma & Nickerson, 2006).

Simulated Laboratory course. The instruments, all materials and the results are simulated on a computer (Ma & Nickerson, 2006).

Split attention effect. When corresponding words and graphics are spatially or temporally separated, the learner is forced to use cognitive resources to keep information in working memory longer than necessary, leading to increased cognitive load (Ayers & Sweller, 2005).

Three-dimensional (3D) images. Digital graphics that represent three-dimensional objects and can be rotated in order to see all sides of the represented object.

Treatment group. In a study, the group receiving the intervention or treatment in order to determine its effect on the dependent variable(Gall et al., 2007).

Limitations

Campbell and Stanley (1963) identified eight common threats to internal validity in their 1963 article. Later, Campbell and Cook (1979) identified four more possible threats to internal validity. Each possible threat is discussed in detail below.

History. Over the course of a study it is possible for events beyond the scope of a study to influence the results of a study. Thus, the longer the duration of the study the more likely it is that a variable outside the scope of the study will impact the outcomes of the study (Cook & Campbell, 1979).

The study duration was only two weeks. This is a relatively narrow timeframe considering the length of a single term or school year. By limiting the study’s time frame, historical variables outside the scope of the study should not have a significant impact on the results.

Maturation. People change over the course of time. Students become more adept at dealing with the educational environment due to natural changes in cognitive ability as they age or through experience with the educational environment. Such changes can have a significant impact on the results of a study. However, due to the relatively narrow time frame of this study (two weeks), it was considered unlikely that change sufficient to impact the results of the study took place. In addition, the participants were adults and were unlikely to physically, emotionally or cognitively "mature" during the duration of this study (Cook & Campbell, 1979).

Testing. It is a common practice in educational research to administer a Test of Prior Knowledge (ToPK) to characterize participant knowledge prior to the start of the study. After the treatment has been administered, the participants take a posttest and the difference between the two tests illustrates the effect of the treatment. However, if the ToPK and the posttest are similar, the ToPK can, in effect, prepare the participants to better deal with the posttest, artificially increasing the result on the second test. This increase could then be mistaken for a result of the treatment (Cook & Campbell, 1979). This potential threat was controlled in this study two ways: first, the ToPK was a knowledge-based, selected-response quiz taken through the Moodle course page, while the posttest is a practical exam using actual human bone. Second, the ToPK covered features of the radius and provided a rough understanding of participants' previous knowledge of anatomy. The posttest covered features of the tibia and provided an exact measure of students' knowledge gained from the instructional module.

Instrumentation. Any change in the nature of the measuring instrument can have an impact on the results of a study. There are a variety of ways this threat to internal validity can manifest. In educational research, one of the most common ways this threat manifests are in the expectations of the personnel administering the ToPKs and posttests. The simple expectation that the treatment will lead to an increase in learning can bias the way the instrument is applied and how the results are recorded (Cook & Campbell, 1979).

The ToPK was administered through Moodle. Moodle is a commonly used course management system, so it was assumed that the students enrolled in courses at this university, from which the target population is drawn, were able to easily access the Moodle page from the computers available on campus as well as the computers the participants commonly use off campus. Further, since the participants were randomly assigned to the treatment and control groups, any technical difficulties should also be randomly distributed, and thus impact the two groups equally.

While two different research assistants and the primary investigator delivered the posttest, the delivery was scripted and uniform. Further, to avoid any complications, the posttest was administered in only one physical lab space. The practical exam format was one with which both research assistants and the PI were familiar and protocols were enforced in order to maximize the uniform nature of the administration and grading of the posttest.

Statistical regression. Research has shown that in a test-retest experimental design, participants who score near one or the other extreme on the ToPK tend to score nearer the mean on the posttest. This tendency can be confused with a change based on the impact of the treatment (Cook & Campbell, 1979). However, as with differential selection, given the differences between the ToPK and the posttest, this threat was not considered to be relevant to the study.

Differential selection. The random selection of participants for a study and the random assignment of the selected participants to the treatment and control groups allow the researcher to generalize the results of the study, beyond the participants in the sample to the population at large. This is known as generalizability. However, this is not always possible. In educational research, it is often necessary to use volunteer students as participants. The self-selected nature of volunteer students allows the introduction of any number of confounding variables and compromises generalizability (Cook & Campbell, 1979).

The participants consisted of volunteers who were drawn from preexisting, introductory level courses. Thus, generalizability could have been compromised. However, in this study, the participants were randomly assigned to either the treatment or the control group, thus minimizing the threat.

Experimental mortality. During the course of any research project, it is likely that some participants will miss important portions of the study such as the ToPK or posttest or the educational materials. Participants who fail to complete or participate in vital assessment tools can become incomplete or confounding data points in the final analysis (Cook & Campbell, 1979).

In order to mitigate this threat, a course with large numbers and multiple sections was chosen in order to gain access to large numbers of potential participants. In addition, the majority of the study was administered through a Moodle website. This was done for two reasons. First it would allow the participants to access the study materials at their convenience, thus lowering the chances that a scheduling conflict would lead to a participant withdrawing from the study. Secondly, Moodle allows enrolled user activity to be tracked allowing the researchers to assist participants in successful completion of the study. In addition, the short study duration (two weeks) was seen as a feature that would decrease participant withdrawal. Finally, an extra credit reward was offered to all participants who successfully completed the study.

Selection-maturation interaction. This threat deals with the intersection of differential selection and maturation. If the duration of a study allows for the participants to mature, any differences between the two groups based on problems with bias-free selection can create a threat to internal validity (Cook & Campbell, 1979). However, the participants for this study were adults, so maturation was not seen as an issue and the participants were randomly assigned to the treatment and control groups.

Experimental treatment diffusion. If the treatment is perceived as being superior to the materials available to the control group, it is possible that the participants in the control group will seek access to the materials designed for the treatment group. It is even more likely that this will happen if the control and treatment groups are in close proximity to each other (Cook & Campbell, 1979).

This was not seen as a significant threat to this study. The voluntary nature of the participation coupled with the fact that the participants were not currently enrolled in a class dealing with human anatomy obviated any need the control group may have had to gain access to the 3D files. In addition, Moodle offered some protection against this limitation. Each participant had a unique account requiring a user name and password each time they access Moodle. Moodle also allows the instructor in charge of the page to limit or allow access to any materials housed on the page. Finally, the short nature of the study limited the chance that the differences between treatment and control groups would become common knowledge among the participants.

Compensatory rivalry by the control group. Commonly called the John Henry effect in educational research, this limitation occurs when members of the control group come to see themselves as being in competition with a better-equipped treatment group. In effect, the control group works harder to make up for the perceived advantage of those students who are receiving the treatment. Thus, any actual difference in performance based on access to the treatment materials is diffused by the increased efforts of the control group (Cook & Campbell, 1979).

As with Experimental Treatment Diffusion, this threat was not seen as significant with respect to this study. The participants were voluntary and received the completion reward (extra credit) for participating regardless of their performance on the posttest. Further, each participant accessed the study Moodle page using his or her unique user name and password. Finally, the short study duration should have mitigated the chance of the differences materials available to the two groups from becoming common knowledge.

Compensatory equalization of treatments. In studies where instructors or even educational administrators see the treatment materials as advantageous, treatment materials can be made available to the control group against the instructions of the researcher (Cook & Campbell, 1979). It is fair to say that instructors and lab teaching assistants could see three-dimensional files of the skeletal system that can be accessed outside of class and lab as advantageous. However, since the participants' scores on the posttest was not part of the grade for the class from which they were drawn and all participants received equal extra credit points, there was no incentive for researcher to provide compensatory equalization of treatments.

Resentful demoralization of the control group. In this case, members of the control group may develop the perception that they are disadvantaged by their lack of access to the treatment materials. This could lead to an increase in the differences between the scores of the treatment and control group based on the participants' perception and not the nature of the treatment materials (Cook & Campbell, 1979). Again, as with the previous three limitations, this limitation was not seen as a credible threat. The participants received the extra credit reward regardless of their posttest performance and the participants were not receiving a grade for their efforts, as the materials were not for the class in which they are enrolled.

Delimitations

External validity, in research, is the extent to which the results of the study can be applied beyond the participants and specific setting of the study (Bracht & Glass, 1968). This is known as generalizability and has two distinct contexts. First, can the results of the study be applied to people beyond those individuals represented in the study sample? This is known as Population Validity. Second, can the results of the study be applied to people in settings other than the specific setting in which the study took place? This is known as Ecological Validity.

To paraphrase Bracht and Glass (1968), one of the central goals of experimental research is to learn something about a large group of people, by making detailed observations of a relatively small, but representative group of people. The challenge is to carry out these observations in such a way as to allow the results to be used to describe the large group of people. This is the crux of population validity. For this study, it was necessary to use a sample of convenience, delimiting the results to students taking the specific class in the specific semester the study was carried out at the university used for the study. Information was gathered on the participants of the study (Chapter III) in order to demonstrate that this sample of convenience was representative of the larger population of students at this university; however, generalization beyond the participants of the study is speculative.

This study also contained two credible threats to ecological validity. The first threat was based on the fact that the participants were aware that they were part of a study, commonly known as the Hawthorne effect (Bracht & Glass, 1968; Campbell & Stanley, 1963). If students know that they are the focus of a study, it is reasonable to conclude that this knowledge may impact their behavior. Thus, there may be a difference in the impact of the treatment on learning outcomes between volunteers who are participating in a study and later students using the treatment materials as part of an established class. This threat also negatively impacts the ability to generalize the results of this study beyond the participants.

The novel nature of the instructional materials used in this study may also have had an impact on participant behavior. New experiences have a disruptive effect on human behavior (Bracht & Glass, 1968). In a study this disruptive effect can artificially impact learning in both positive and negative ways. Thus, a new type of instructional materials could cause the volunteer to pay particular attention, as the new material is intriguing, like a new toy received on one's birthday.

The materials used in this study utilized technology that is common in video games and animation but relatively new to education. Thus, it is reasonable to assume that the novelty of these materials was disruptive to some of the participants in the study, particularly those individuals who were unconformable with technology. The treatment materials provided a tutorial on the use of the materials and some suggestions to help the participant integrate the materials into their own study methods. Otherwise there was little that could be done to mitigate this problem.

It is reasonable to assume that, as technology changes, there are other, newer, better file formats for 3D images. Therefore, the results of this study may not be generalizable to all 3D image files or formats. Further, as this study is focused on human skeletal anatomy, the results may not be generalizable to simulated labs in other educational contexts such as engineering, chemistry or other biological foci.

Significance of Study

The topic of the effectiveness of online labs versus the more traditional variety is very complex. Ma and Nickerson (2006) indicated, in their review, that there is little agreement in the literature with respect to a common list of educational goals or how different online laboratory formats should be classified. In addition, research has yet to illustrate the specific educational differences between a face-to-face and an online laboratory course. However, based on the trends detailed earlier in this chapter, as well as the economic advantages previously discussed, the simulated lab is now a permanent part of our collective educational arsenal.

Chapter II

Literature Review

The purpose of this study was to explore impact of the addition of three-dimensional digital files on both educational effectiveness and learner attitudes toward an online laboratory course. Specifically, this study examined whether 3D files can simulate an authentic learning experience when coupled with text based information and static two-dimensional images, and be effective both in terms of student performance and student attitudes. As introduced in the previous chapter, the framework for the study is based in the multimedia principles of Clark and Mayer (2011) and theories of authentic learning (Herrington et al., 2010).

The multimedia approach is a method of enhancing learning by presenting information in multiple formats such as text, graphics, audio, animation, or video. By combining two or more media formats, the instruction is more engaging, encouraging the learner to become an active participant in the learning process (Clark & Mayer, 2011, p. 57). Known collectively as the Multimedia Principles, this combining of media formats has been shown to increase the achievement of educational goals. The specific combination of text and graphics has been shown to increase learner achievement significantly over text or traditional verbal lecture alone (Clark & Mayer, 2011, p. 66).

In addition, the 3D materials can offer an authentic learning experience. There is a separation between the act of learning about something and the act of doing that thing (Resnick, 1987). The general idea is that schools and universities are focused on identifying the central concepts of a discipline and then teaching the student these concepts in an “abstract and decontextualized form” (Herrington et al., 2010). According to Herrington, Reeves and Oliver (2010), this approach ignores the connection between the knowledge gained about a specific task and the actual performance of the task. Thus, the knowledge gained during the educational experience becomes the goal instead of the ability to perform the job for which the student is receiving training.

Like any other review of literature concerning a complicated subject, the search for relevant studies was involved a number of different resources. First, time was spent at the university library, where the relevant search engines, involving the journals on the subject of education were queried. The search began with the phrases *online laboratory courses*, *digital laboratory courses*, and *traditional laboratory courses*. These phrases were then combines with words like *education, research* and *learning theory*. These searches provided basic background on the educational theory behind the laboratory course as well as a lot of information on best-practices. The phrase *transitioning traditional labs online* provided a great deal of research and helped frame the subjects within which most of the research has taken place specific to online labs. It was at this point that a common naming scheme became apparent and because of this the next set of searches involved the terms *simulates, remote,* and *traditional labs research*. The term simulated laboratory is the common name for the type of lab course chosen for this study. Following this discovery, a series of searches using the phrases *2D graphics/images/files* combined with *simulated lab* was carried out to determine what research, specific to simulated labs, had been carried out using 3D graphics. All of the searches were then repeated in Google Scholar. Patterns in the research had become obvious as well as the major researchers involved in these areas of research. The bibliographies of the most influential articles were then gleaned for more applicable studies and the works of specific authors were also searched.

The Simulated Laboratory

While the educational outcomes of simulated labs are comparable to those of the traditional, face-to-face lab, differences between the two learning environments can and have led to significantly different experiences between the two types of labs.

In 2000, two researchers from the University of Toronto investigated experiences among students using a simulation designed to mimic the application of anesthesia to a human patient (Morgan & Hogg, 2000). While both students and faculty involved in the study agreed that simulation was a useful tool for teaching associated concepts and as a tool for evaluating student mastery of the subject, the participants also agreed that a level of familiarity with the lab interface was necessary to successfully utilize the simulation.

In a more recent study by Balakrishnan and Woods (2013) involving a comparison between traditional and simulated electronic engineering lab courses, the researchers failed to find a significant difference between the treatment and control groups. The participants were concerned that the simulation was not providing real world experience. Further, the participants reported a dissatisfaction with the lack of collaborative opportunities. In addition, some participants also reported problems with successfully completing the lab due to an unfamiliarity with the software and or the interface.

However, Balikrishnan and Woods (2013) also found that students preferred the simulation in two distinct ways. First, the participants felt that the simulation was more successful in dealing with concepts, and the predictable nature of the results minimized the frustration and confusion the participants felt when extraneous variables beyond the control of the learner produced erroneous results.

Simulated labs have also proven to be flexible and adaptive learning environments. In 2010, researchers in the chemistry department at Carnegie Mellon University designed an application that allowed students to design and carry out their own chemistry lab experiments (Yaron, et al., 2010). The participants' comments focused on the value of the complex feedback provided by the authors when they designed the application. The authors were also focused on using the flexibility of their application to avoid giving the learner a simple linear lesson so the learner was less likely to focus on solving problems without mastering the associated concepts.

3D Simulation Laboratories

Over the past 15 years, research on the effectiveness of simulation labs, and specifically 3D simulation labs, has been limited. Only a few publications were found which address the issue.

In 2000, Ying Li, Ken Brodlie and Nicholas Philips discussed the development of a piece of software designed to help medical students perform a very difficult procedure: inserting a needle into the base of a human skull (Ying, et al., 2000). The authors described the development of their software, citing specific design features based on the requirements of the surgical procedure for which the software was developed. While the authors did not explore the impact of the software, the article served as one of the earliest documented software packages incorporating 3D digital images, with the goal of creating an experience that mirrors the task for which the learner is being trained.

In 2007, Harry Brenton and his colleagues at the Imperial College London designed a piece of software to teach student about the brachial plexus, a nerve bundle in the upper arm (Brenton et al., 2007). Their research provided a comprehensive discussion of the available medical imaging technologies and their impact on the educational process, placing three-dimensional images at the end of a logical progression in educational technology. The authors also provided a detailed description of the process of designing and developing this kind of software. However, as with Ying et al. (2000), Brenton and his colleagues failed to actually test their software beyond a brief mention of a proof of concept test using faculty and graduate students. No data were gathered beyond informal discussion and no statistical analyses were reported.

In 2006, the first known study in the biological sciences to test the impact of the 3D digital image on the educational process was published (Nicholson, Chalk, Funnell & Daniel, 2006). Nicholson et al. created a three-dimensional model of the inner and middle ear in order to assist first year medical students in their mastery of the anatomy of that area. They recruited sixty, first year medical students from the university at which the study was conducted, and randomly assigned thirty students each to the treatment and control groups. To begin, both groups were put through an online tutorial covering the inner ear, consisting of text and 2D graphics. This was to provide each student with basic information on the subject. Then both groups attended a one-hour lecture on the more detailed anatomy of the inner ear followed by a lab session where students from both groups were allowed to complete a lab assignment on the inner ear. During the lab, the control groups had access to the regular online materials. The treatment group had access to the same materials as the control group, but also had access to three-dimensional images of the inner ear with relevant featured identified in the 3D image. After the lab was complete, all the students took the same final test and the results were compared. The authors found a nearly 20% increase in test scores for the treatment group.

Overall, this study was well designed. The sample size was appropriate and the participants were randomly assigned to the treatment and control groups. The procedures also seemed appropriate for the study. Further, care was taken to make sure that the participants had the background knowledge necessary to successfully complete the instructional material. However, the authors fail to mention how access to the 3D materials was controlled (Nicholson, Chalk, Funnell & Daniel, 2006). There is also very little detail in the description of the lab section of the study, so any differences in the lab experience of the two groups is impossible to identify.

Ng et al. (2015) also created a three-dimensional model of the inner ear. Seventy-two graduating medical students at a medical school in Singapore were randomly assigned to a treatment group and a control group. The participants were physically segregated but learned inner ear anatomy from the same text and 2D graphics. The treatment groups also had access to the three-dimensional model developed for the study. After the treatment, both groups took the same online exam and completed a detailed questionnaire. The questionnaire gathered demographic information as well as the participants' perception of their comfort level with technology and previously existing knowledge of the subject matter was gathered prior to the treatment. The authors found that there was an increase in the positive perception of the technology as well as a significant increase in the educational outcomes of the treatment group.

Like the previous study, Ng et al. (2015) also has a solid research design. While it is not explicitly stated, graduating medical student should all have a roughly equivalent knowledge base specific to the inner ear. The brief duration of the study, in comparison to Nicholson et al. (2006), mitigated a number of possible threats to validity. Further, the use of the questionnaire added another dimension to the study.

The same year, Salajan, Mount, and Prakki (2015) published a study focused on the impact of the use of a digital, dental atlas in the training of first year dental hygiene students. Prior to beginning the First-Year Dental Anatomy course or FYDA, the students were given a comprehensive survey to gauge the students' perception of their own familiarity and comfort with the software used in the course as well as their overall perception of the value of technology in education. The survey used in this study was many orders of magnitude more complex than those used by the previous studies. This allowed the authors to mine the survey data in complex and informative ways. The authors found a statistically significant increase in student perception based on the use of the 3D models.

The study by Salajan, Mount, and Prakki (2015) differs significantly from the others previously discussed in that their study only examined the students' perception of the software. No control groups were used to examine differences in perception between possible groups. However, the survey used for the study was comprehensive and the analysis was exhaustive. Unfortunately, the authors did not provide any information on whether or not a power calculation was performed, so the adequacy of the sample size cannot be ascertained. Further, while the student perception of the software would suggest that the educational material had a significant and positive impact on student educational outcomes, the methodology used does not allow for the claim to be credible.

Summary

Two significant gaps have been identified by the review of the literature. First, none of the studies on the subject investigated both student outcomes and perception of the experience. Second, while the literature covering simulated labs does involve the novice learner, the participants of the studies specifically concerned with the introduction of three-dimensional images into the simulated lab experience were either graduate level students or members of the faculty. The current study dealt solely with novice learners and examined student outcomes, learner motivation, and learner perceptions.

Chapter III

Methodology

The purpose of this study was to explore the impact of the addition of three-dimensional digital files on both educational effectiveness and learner attitudes toward an online laboratory course. In order to accomplish this, the study employed a posttest only control group design to answer the four questions posed in Chapter I.

1. Is there a significant difference in student knowledge of skeletal anatomy as measured by an in-person practical examination, between students who receive 3D digital bone images in addition to the regular online 2D instruction, and those students who receive the regular online 2D instruction only?
2. If there is a significant difference in the posttest results of the treatment and control groups, can the difference be attributed to the preexisting skeletal knowledge of the participants?
3. Is there a significant difference in student attitude toward learning skeletal anatomy as measured by the Course Interest Survey, between students who receive 3D digital bone images in addition to the regular online 2D instruction, and those students who receive the regular online 2D instruction only?
4. Is there a qualitative difference in student attitude toward learning skeletal anatomy between students who receive 3D digital bone images in addition to the regular online 2D instruction, and those students who receive the regular online 2D instruction only, as indicated by random participant interviews?

The project design followed quasi-experimental, posttest only control group design. First, the study was designed to measure the impact of a series of three-dimensional files of the human skeleton on the educational outcome of students. Due to the complexity of the skeleton as a whole, it was decided to focus specifically on the tibia. This goal was measured by comparing student performance between the control and treatment groups. Second, the study was designed to investigate the impact of these files on learner motivation as defined by Keller's ARCS model. This second goal was measured using a combination of the Course Interest Survey (Keller, 2006) and two open-ended questions. In this chapter, the participants, treatment, instruments, and data collection and analysis are described.

Population and Sample

The population of interest for this study consisted of college undergraduate students. A number of disciplines commonly include courses with a skeletal anatomy component within their undergraduate curricula. The disciplines include, but are not limited to, Biology, Anthropology, Physical Therapy, and Massage Therapy, as well as undergraduate programs in health sciences. The sample of convenience for this study consisted of student currently enrolled in the fourteen sections of ANTH1100: General Anthropology during the fall semester of 2016 and spring semester of 2017. This sample was chosen due to the relatively large number of students enrolled in ANTH1100, and the relatively low likelihood that these students would have had advanced training in human skeletal anatomy. Combined, the separate classes had an enrollment of over 400 students. Historical data were obtained from the university to establish that there was no significant difference between fall semester 2016 and previous semesters in terms of gender, class standing, or age (see Appendix D). While these characteristics are not the focus of the research questions, the data were gathered in order to compare the study participants with the “typical” student who takes this class.

According to the results of a preliminary power analysis (Table 2), the total sample size would need to be 60 participants to have 95% power. Given the large number of available students, an ample pool of participants was expected. However, this goal was not achieved. The final sample size was 47. The reasons for this and the possible threat to internal validity this low sample size represents will be discussed further in Chapter V.

Table 2.

Power calculation

Anticipated effect size (Cohen's *d*):	0.95
Desired statistical power level:	0.95
Probability level:	0.05
Minimum total sample size (two-tailed hypothesis):	60
Minimum sample size per group (two-tailed hypothesis):	30

Treatment Materials

Due to the complexity of the human skeleton, it was not possible to cover a significant portion of skeletal anatomy in a single week. Further, the participants were unlikely to have even minimal knowledge of the human skeleton. Because of this, the study focused on one bone, the tibia, which is the larger of the two bones in the lower leg.

The instructional materials consisted of a series of video lectures and a set of study slides. The focus of the instructional material was twofold. First, the instructional material was designed to give the participant a basic grasp of gross skeletal anatomy, which would include the basic names of features common to all human long bones as well as the directional terms used to discuss a long bone. Second, the instructional material was designed to teach the participant to recognize a human tibia and to name the relevant features of the tibia as well as tell from which side of the body (left or right) a specific tibia originated.

The instructional materials were housed on a Moodle site which was accessible through the website of the university at which the study was conducted. The instructional materials for the control groups contained 2D, static graphics of the tibia with the relevant features labeled. The treatment material contained the same information as the instructional material for the control group, but in addition to the 2D static graphics, the treatment material contained 3D manipulable graphics. Figure 1 displays the main Moodle page that a participant would see just prior to being added to the treatment or control groups.

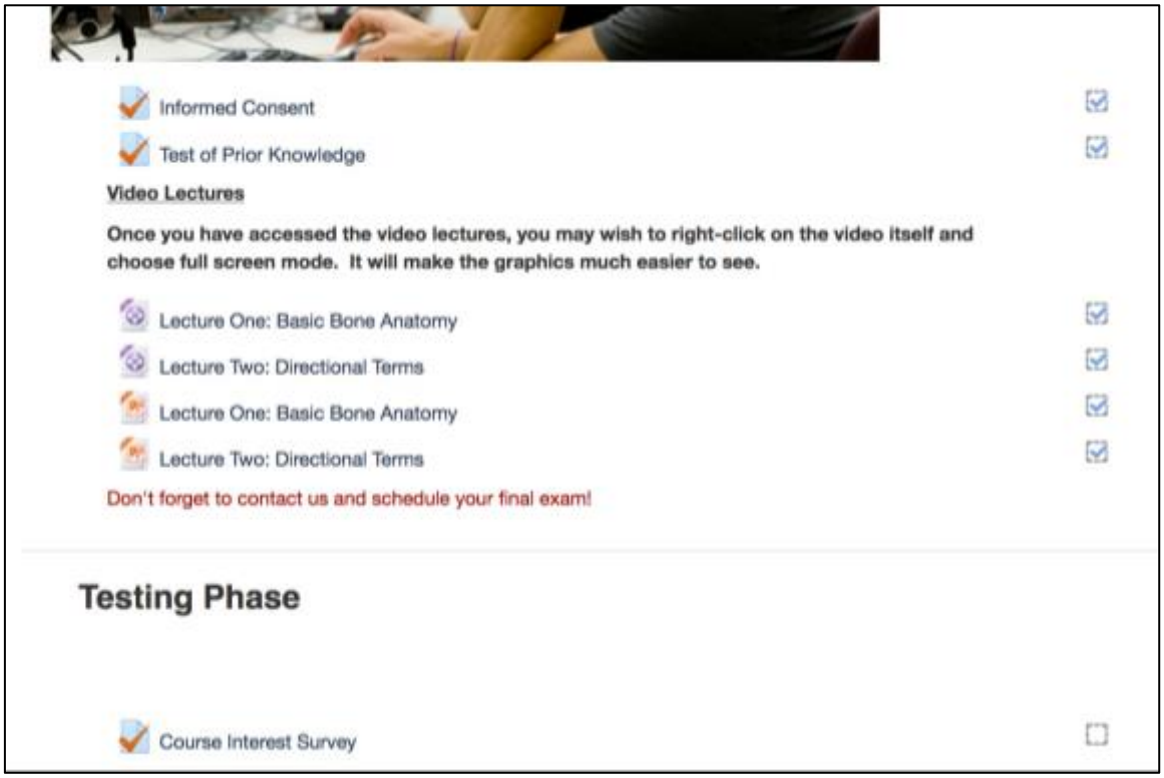

Figure 1. The Study Moodle page.

This 3D, manipulable-type of file is most commonly accessed by the free application Adobe Acrobat, though a variety of other applications exist for this purpose. Once the file is downloaded and opened through the Adobe Acrobat Reader application, the student is able to manipulate the three-dimensional image of the bone, spinning or rotating the bone to view it from any angle. The participant even has the ability to zoom in for a close look at the surface structure of the bone. The file consists of a three-dimensional digital framework, over which high-resolution images of the physical bone are placed. Finally, the file comes with a drop-down menu allowing the student to choose from the six standard anatomical views of the bone: superior, inferior, anterior, posterior, medial, and lateral. When the participant chooses one of these views, the image of the bone quickly shifts, moving into the chosen view. As the image rotates into position, the names of all the anatomical features associated with that bone appear around the bone with arrows and lines, indicating the specific location of each feature from that specific perspective. Figure 2 displays a screen shot of the 3D pdf used for the study with labeled features visible.

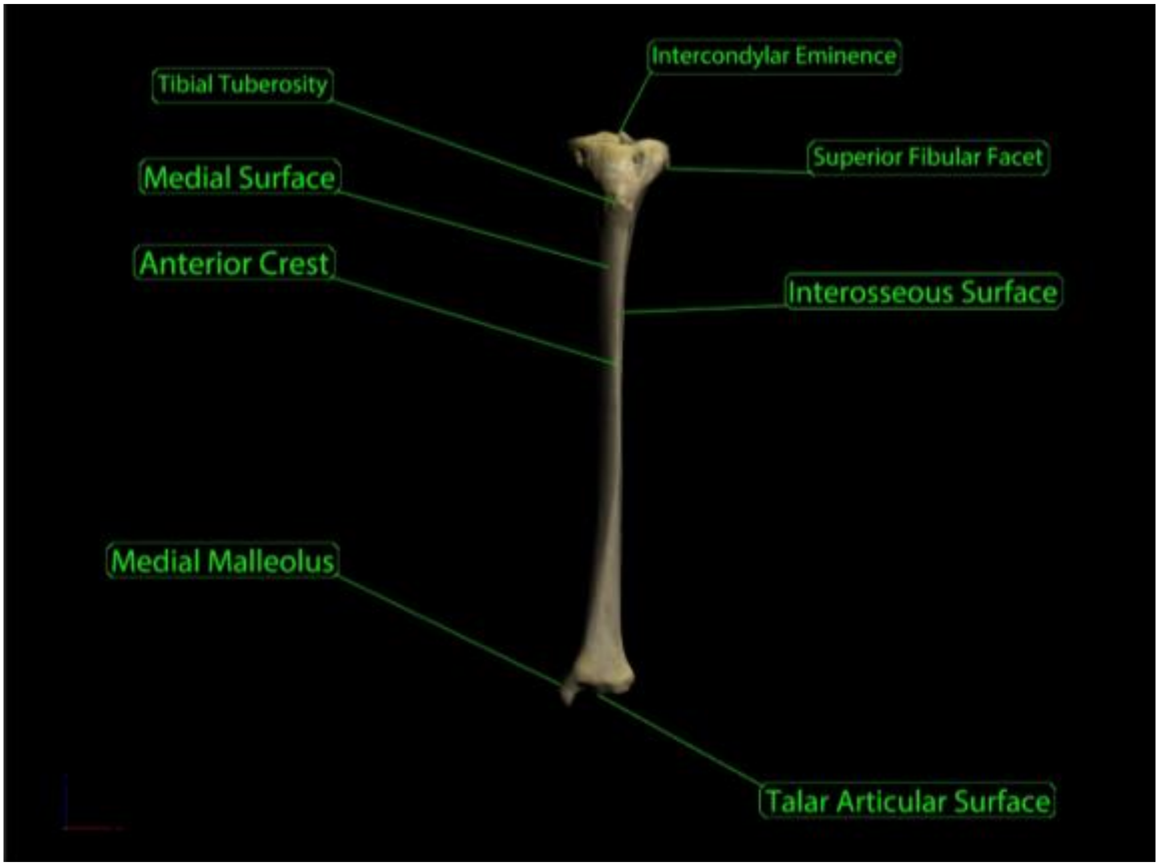

Figure 2. 3D pdf, tibia, anterior view with feature labels.

Instrumentation

Three instruments were used to assess student performance and attitudes in order to answer the research questions. These include a ToPK, the posttest, and the Course Interest Survey (Keller, 2006). In addition, students were asked two open-ended questions concerning their learning experience at the bottom of the practical lab quiz answer sheet.

Test of Prior Knowledge (ToPK). This test was administered to identify any preexisting skeletal knowledge among the participants, as preexisting knowledge of the skeleton could influence post-test results. Further, Clark and Mayer (2001) suggest that media such as animation or three-dimensional images have a significantly greater impact on novice learners as compared to learners with previously existing knowledge on the subject of the instructional material (Clark & Mayer 2011). However, in order to avoid any possible threats to internal validity, the ToPK did not resemble the posttest in either format or the portion of the skeleton being covered. By quizzing students on a different, but similar, portion of skeletal anatomy, general prior knowledge of skeletal anatomy can be measured.

The test was delivered through the study's Moodle page as a quiz. When the participants accessed the ToPK, they were asked twenty questions dealing with the basics of skeletal anatomy as well as specific features of the radius, one of the bones found in the lower arm. The questions dealing with the specific features of the radius were paired with static 2D graphics with labels to indicate the features to be named (see Figure 3). The ToPK asked the participant to identify the side of the body from which the radius they are observing originates. These questions are aligned with the objectives of the instructional modules of the experiment, although applied to the lower arm instead of the lower leg. The ToPK is shown in its entirety in Appendix B.

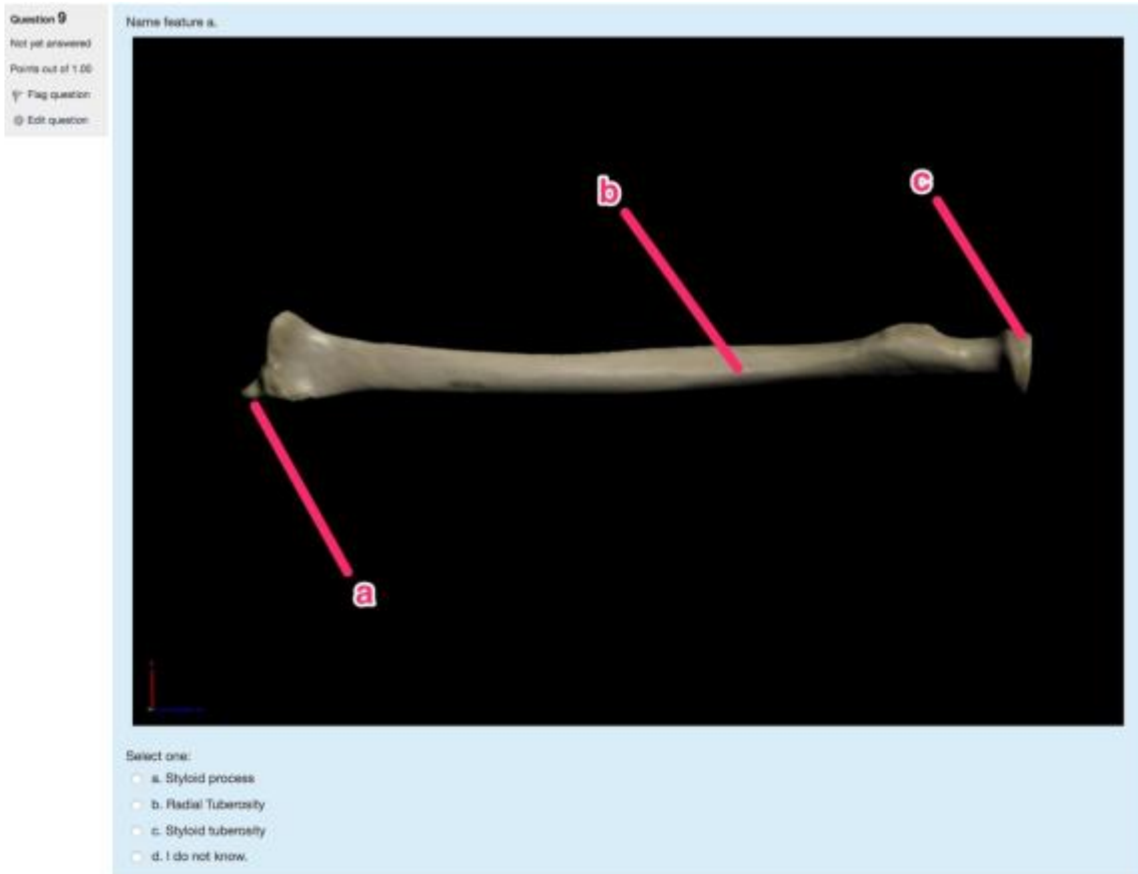

Figure 3. Question 9, ToPK. A screen grab of question nine of the Test of Prior Knowledge.

Posttest. The posttest consisted of a practical lab-based assessment delivered at the end of the one-week study, and is the posttest currently used in the ANTH4432: Human Osteology course, specific to the tibia. The participants were asked to come to the Human Osteology Laboratory in the Department of Anthropology in order to complete a practical exam consisting of 30 questions dealing with the tibia (Appendix C). Ten of the questions dealt with basic tibia anatomy, associated soft tissue, and directional terms. The next twenty questions were grouped into five, four part questions. For each group of questions, participants were directed to a single tibia or tibia fragment. The grouped questions covered specific features, the soft tissue structures associated with the feature, or the side of the body (left or right) from which the bone originated. The features specified for each question was designated by a small, brightly colored dot. See Figure 4 for details.

Figure 4. Posttest questions 4 a-d and 5 a-d. A photograph of the bones associated with Posttest section two, questions four and five.

Course Interest Survey (CIS): The last item on the Moodle page was the Course Interest Survey. When the participants contacted the research assistants to schedule their posttest, the assistants asked that the CIS be completed before participants arrived for the posttest. The completion of the CIS was checked before the participant was allowed to take the posttest. The CIS was chosen for a number of reasons. (1) The CIS is a measure of student motivation specific to a learning condition, in this case, online education and three-dimensional files. (2) Further, the CIS can be tailored very specifically due to the wording of many of the questions. (3) Finally, the CIS is backed by the ARCS model (Keller 2006). Thus, the model has been well tested and the survey itself has been verified.

Open-ended questions. On the last page of the posttest, the participants were asked to answer two open ended questions. 1) What did you find helpful or unhelpful about the instructional material used to teach this topic? 2) What else should I know about your learning experience with this material? These questions were designed to gather qualitative information on the participants experience during the study.

Procedures

Appendix E outlines the experience of the participant during the study. Two weeks prior to the beginning of the study, the students enrolled in the various sections of ANTH1100: General Anthropology were contacted via email. The email included the deadline for joining the study, the dates of study, the tasks required in order to fully participate, the amount of time the study would require, and indication of the extra credit points available. The email also included the email address of the two graduate students assisting with the study as a point of contact.

The students who answered the email or otherwise contacted one of the research assistants were given access to a Moodle page created for this study. However, none of educational materials housed on the study Moodle page were visible to the participants initially. Those materials did not become visible to the participants until 6:00am on the Monday of the week of the study. The ToPK and the informed consent form were visible to all who had access to the study Moodle page from the moment they gained access.

Student received instructions when they were added to the Moodle page, directing them to complete the Informed Consent quiz and the ToPK.

The deadline for participating in the study was set for the Monday of the week the instructional materials become available. Once the participation deadline had passed, the participants received an email of introduction, including information on the sequence of events involved in the study, and orienting the participants to the study Moodle page. The participants were also reminded, again, that the Informed Consent and the ToPK needed to be complete before any other materials became visible.

On the Monday of the week the study took place, the first two lectures and associated study materials become available. The first two lectures covered basic bone anatomy and directional terms. Part of the orientation instructions the participants received were instructions to contact a research assistant as soon as they had complete the second lecture so that the rest of the materials could be made available to them. This is the point where they were added to either the treatment or control groups, though the participant were not notified of this assignment. Further, they were reminded at that time that they had until the following Friday to complete the learning modules, at which time access to all teaching materials would be closed.

At this point, the participants had access to the video lectures covering the tibia specifically. The students were asked to learn to recognize a set of anatomical features on the tibia as well as the soft tissue structures associated with the various features. As the tibia is a paired bone, the participants were also taught to recognize the differences between a right and left tibia. In the control group, the instructional material was composed of text coupled with static two-dimensional images of the bone.

Participants in the treatment group received access to a video lecture created using the 3D graphics. During the lecture, the 3D graphics are manipulated while the narrator discusses individual features and how they relate in three-dimensions. Further, the 3D graphic was available under the study materials for participants in the treatment group to download and use for study. It is important to note that even though the 3D PDF files were housed on the study Moodle page, the control group did not have access to them. Students only have access to materials allowed by the course administrator. Midway through the week, participants in both groups received emails reminding them to contact the research assistants in order to schedule a time during the next week to take the posttest.

Upon arriving for the posttest, each participant was given a brief orientation to the exam format and the paper exam document. During the practical exam in the Physical Anthropology lab, each participant was presented with real human tibia. As described above, the participants first answered ten questions dealing with general skeletal knowledge. Then the participants were asked five four-part questions. Three of the five questions dealt with a whole bone, two dealt with a fragmentary tibia. Each bone or bone fragment had two to four brightly colored, 5mm adhesive dots placed next to one of the features identified in the learning module the participant completed for the study.   Each colored dot corresponded with one of the four sub-questions (for more details see appendix c). The participant where be asked to identify the anatomical feature or soft tissue structure associated with the indicated location on the bone or fragment, according to the question prompts on the exam document. It addition, the participants were asked to indicate whether the bone was from the left or right side of the body, or to identify the function of a specific feature. The participants were given 40 minutes to complete the posttest. The exams were collected and the results were cored and recorded by the research assistants.

Data Collection

The ToPK was delivered as a quiz through the study Moodle page, collecting data on the participants' preexisting knowledge of the human skeleton. Moodle graded the quiz and each question on the ToPK was worth ½ point, so each participant received a score out of ten points. The scores were saved in Moodle, but the participant did not see a grade.

The participants also took the Course Interest Survey at the end of the instructional material. The CIS was also delivered as a quiz through the study Moodle page. The 57-question quiz was set up as a Likert scale. Each question was worth 5 points. The participant was awarded a score out of 285 and the scores were saved in Moodle, again without the participant seeing a grade. Both the quizzes were then be exported as Microsoft Access files which will import into SPSS for analysis.

The Posttest was delivered in person and was graded by hand by the research assistants. Each participant received a score out of 30 points. The results of the posttest were then entered into the SPSS database created for the study.

Data Analysis

After the data were collected, they were analyzed in order to answer the three research questions. First, the demographic information from the previous six semesters was compared with the demographic information from the summer semester of 2016 from which the sample was pulled, as previously mentioned. This is done in order to ensure that the fall semester classes do not differ significantly from previous semester on relevant demographic factors.

Though it did not explicitly answer one of the research question, the results from the ToPK were compared to make sure that there was no difference in preexisting knowledge between the treatment and control groups. The scores of the ToPK were compared using an Independent sample t-Test.

Next, the results from the posttest were compared with an Independent sample t-Test in order to identify a possible significant difference between the control and treatment groups (Research Question 1). Then, a One Way ANCOVA was performed to see if the preexisting knowledge, as measured by the ToPK acted as a covariate in the comparison of the posttest scores (Research Question 2).

The scores of the CIS were compared using an Independent sample t-Test in order to see whether there was a significant difference between the motivation of the treatment and control groups. (Research Question 3).

Finally, the two open-ended questions from the posttest were analyzed using qualitative analysis methods. The analysis was performed to investigate the possibility of a significant difference in participant attitude toward learning human skeletal anatomy online between the treatment and control groups. The participant comments were analyzed and specific themes were identified.

Chapter IV

Results

The purpose of this study was to explore the efficacy of the use of 3D images as surrogates for physical bones in an online laboratory course setting. Specifically, the study explored the possibility that 3D, manipulable images could simulate an authentic learning experience when coupled with text-based information and static 2D images and thus positively impact participant performance and motivation.

Description of the participants

The sample for this study was students at a mid-size western university registered in twelve different sections of the ANTH1100: General Anthropology course, during the fall semester of 2016 and the spring semester of 2017. Table 3 provides a simple demographic breakdown of the study sample.

While the breakdown of the participants by class standing does not seem to deviate from the average for the university, there are two differences worth noting (see Table 4). Two thirds of the participants in the study were female. This exceeds the relative frequency of females in the university where women are just under 45% of the population. In addition, a relatively large percentage of the participants speak English as a second language, when compared to the university population. So, the study sample does seem to differ from the university population in two ways.

During the fall semester of 2016, seven sections of the ANTH1100 class were involved with 27 students volunteering to take part in the study. Of those 27 volunteers, 14 failed to complete the study materials and take the posttest, leaving 13 participants from the fall semester. During the spring semester of 2017, five sections of the ANTH1100 course were involved, with a total of 44 volunteers. Of those 47 volunteers, 13 failed to complete the study materials and take the posttest, leaving 34 participants from the spring semester, resulting is a total of 47 participants.

Table 3.

Demographic information for the sample of 47 students included in the data analysis.

Category	Number	Percentage
Male	16	34%
Female	31	66%
Freshman	20	42.6%
Sophomore	16	34%
Junior	5	10.6%
Senior	6	12.8%
Native English Speakers	27	57%
English as a Second Language	20	43%

Unfortunately, this means that the sample did not meet the requirement of the power calculation. This problem introduces a serious threat to the internal validity of the study. Because of the low number of participants, the study is likely to find only the largest of differences between the treatment and control groups. A subtle difference would not be detected.

Table 4.

Demographic comparison between study sample and the students enrolled in ANTH1100 for the last six years.

Category	**Study Sample**	**University Population**
Male	34%	54.3
Female	66%	45.7%
Freshman	42.6%	39.9%
Sophomore	34%	33.1%
Junior	10.6%	13.9%
Senior	12.8%	12.2%
Native English Speakers	57%	81.3%
English as a Second Language	43%	18.7%

Assessment Results

Four different assessment methods were included in this study. A ToPK was administered before the instructional materials became available to the participants. This assessment was designed to determine if a participant had significant preexisting knowledge of the human skeleton. A posttest was given, at the end of the study period, in order to assess the performance of the learner on the objectives of the 2D and 3D instructional materials. The Course Interest Survey (Keller, 2006) was administered to assess student motivation specific to the instructional materials, to look for differences between the treatment and control groups. Finally, two open-ended questions were answered by the participants in order to look for qualitative differences in the participants' attitudes toward the teaching material.

Test of Prior Knowledge. An Independent Samples t-Test was used to investigate the possibility that a significant difference existed in the results of the ToPK between the treatment and control groups. The results are presented in Figure 5. The control group had an *n* of 23 participants with a mean score of 3.76 points out of a possible of 10 points (SD = 2.38). The treatment group had an *n* of 24 participants with a mean score of 3.41 points out of a possible of 10 points (SD = 2.42). There was no significant difference between the scores of the treatment and control groups, $t = .49$, $p = .62$. Thus, the two groups were statistically equivalent in prior knowledge as measured by the TOPK.

Group Statistics

	group	N	Mean	Std. Deviation	Std. Error Mean
Quiz:Test of Prior Knowledge (Real)	a	23	3.761	2.3878	.4979
	b	24	3.417	2.4212	.4942

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Quiz:Test of Prior Knowledge (Real)	Equal variances assumed	.058	.811	.490	45	.626	.3442	.7018	-1.0692	1.7576
	Equal variances not assumed			.491	44.961	.626	.3442	.7015	-1.0688	1.7572

Figure 5. Independent Samples t-test results, showing that there is no significant difference in the ToPK scores between the control (a) and treatment (b) groups.

Course Interest Survey. The Course Interest Survey (CIS) was administered online through the study Moodle page after the participants completed the instructional modules, but before they scheduled their practical lab quiz. The CIS consists of 57 Likert scale questions based on the ARC model put forth by Keller (2006). The results are presented in Figure 6. The control group had an *n* of 23 participants with a mean score of 186.05 points out of a possible of 285 points (SD = 49.78). The treatment group had an *n* of 24 participants with a mean score of 211.87 points out of a possible of 285 points (SD = 27.43). There was a significant difference between the scores of the treatment and control groups, $t = -2.19$, $p = .035$, meaning the treatment groups had a higher level of motivation as measured by the CIS.

Group Statistics

	group	N	Mean	Std. Deviation	Std. Error Mean
CIS	a	23	186.0435	49.78086	10.38003
	b	24	211.8750	27.43262	5.59966

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CIS	Equal variances assumed	1.412	.241	-2.216	45	.032	-25.83152	11.65786	-49.31165	-2.35139
	Equal variances not assumed			-2.190	33.920	.035	-25.83152	11.79412	-49.80212	-1.86092

Figure 6. Independent Samples t-test results, showing that there is a significant difference in the Course Interest Survey scores between the control (a) and treatment (b) groups.

Posttest. The posttest was a practical assessment delivered at the end of the second week of the study. The results are presented in Figure 7. The control group had an *n* of 23 participants with a mean score of 8.13 points out of a possible of 30 points (SD = 6.18). The treatment group had an *n* of 24 participants with a mean score of 7.58 points out of a possible of 30 points (SD = 6.89). There was no significant difference between the scores of the treatment and control groups, $t = .286$, $p = .776$.

Group Statistics

	group	N	Mean	Std. Deviation	Std. Error Mean
exam score	a	23	8.13	6.189	1.290
	b	24	7.58	6.896	1.408

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
exam score	Equal variances assumed	.396	.532	.286	45	.776	.547	1.914	-3.308	4.402
	Equal variances not assumed			.286	44.813	.776	.547	1.910	-3.300	4.394

Figure 7. Results of the Independent Samples t-test results, showing that there is no significant difference in the Posttest scores between the control (a) and treatment (b) groups.

Open-Ended Questions. On the last page of the practical exam (the posttest), the participants were asked to answer two open-ended questions. The questions are as follows: *1) What did you find helpful or unhelpful about the instructional material used to teach this topic? 2) What else should I know about your learning experience with this material?* The participants were told that part of the study was an exploration of their experience. Further, the participants were instructed to provide as little or as much information as they were willing to give and that the questions were to guide their answers but that the questions were not the limit of what they should share if they had something to tell the investigator. A qualitative analysis was then performed on the participants' comments.

A total of 172 sentences was gleaned from the participant comments, 79 from the control groups and 93 from the treatment group. The sentences were then reduced to 223 specific data bits, 103 coming from the control group and 120 from the treatment group.

These data bits were clustered into categories, which were further reduced and synthesized into seven different themes, which will be discussed later in this chapter.

Research Question 1

Is there a significant difference in student knowledge of skeletal anatomy as measured by an in-person practical examination, between students who receive 3D digital bone images in addition to the regular online 2D instruction, and those students who receive the regular online 2D instruction only?

In order to answer the first research question, an Independent Samples t-Test was used to determine whether or not the treatment had a statistically significant impact on the outcome of the posttest of the treatment group. As can be seen on Figure 7, the treatment did not have a significant impact on the posttest scores. This does not support the hypothesis that the inclusion of 3D images had a significant impact on learner outcomes. Thus, the hypothesis was rejected.

Research Question 2

If there is a significant difference in the posttest results of the treatment and control groups, can the difference be attributed to the preexisting skeletal knowledge of the participants?

The second research question relied on a significant outcome of the first research question. A One-way ANCOVA was conducted to determine a statistically significant difference between the posttest scores of the treatment and control groups controlling for preexisting skeletal knowledge as determined by the participants' score on the ToPK. The results of the ANCOVA are presented in Figure 8.

Between-Subjects Factors

		N
group	a	23
	b	24

Tests of Between-Subjects Effects

Dependent Variable: exam score

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	20.447[a]	2	10.224	.234	.792
Intercept	680.858	1	680.858	15.607	.000
QuizTestofPriorKnowledgeReal	16.932	1	16.932	.388	.537
group	2.465	1	2.465	.056	.813
Error	1919.510	44	43.625		
Total	4837.000	47			
Corrected Total	1939.957	46			

a. R Squared = .011 (Adjusted R Squared = −.034)

Figure 8. ANCOVA results, showing that the preexisting skeletal knowledge, as measured by the ToPK, did not have a significant impact on the results of the posttest

The group significance is .813. As there is no significant difference between the posttest scores of the two groups, the possibility of the difference between the scores of the two groups being caused by preexisting knowledge is meaningless as differences do not exist.

Research Question 3

Is there a significant difference in student attitude toward learning skeletal anatomy as measured by the Course Interest Survey, between students who receive 3D digital bone images in addition to the regular online 2D instruction, and those students who receive the regular online 2D instruction only?

As can be seen in Figure 6, the difference between the treatment and control groups are significant ($p = .035$). Further, the mean score of the control group is 186.05, while the mean score of the treatment group is significantly higher at 211.87. Thus, the results support the hypothesis that the introduction of 3D digital images did have a positive impact on the learners' motivation in an online learning environment.

Research Question 4

While the results of the CIS survey indicate that the treatment group had a significantly more positive response to the instruction than the control group, Research Question 4 asked whether there was a qualitative difference in student attitude between the two groups as indicated by participant responses to two open-ended questions. While there were minor differences between the treatment and control groups, the experiences of the two groups were far more similar than they were different.

While the differences between the treatment and control groups were minor, there was a great deal of variation from participant to participant in how much information was provided and the concepts each participant found important. The comments of the participants were transcribed into a word document and then the participants' comments were reduced to separate sentences and those sentences were further reduced to specific concepts or data bits. While many participants wrote little more than a single sentence for each of the two questions, several participants provided a great deal of information on their experience during the study. A number of sentences and data bits were subsumed or eliminated from the analysis for various reasons. For instance, many of the participants made repetitive comments, which were subsumed. For example, a first sentence was identical to a second in subject matter, with the second sentence providing specific information, allowing the first to be subsumed by the second. Examples of eliminated comments include those made by a participant who spent several sentences describing their spouse's opinion of the teaching materials, and other participants who, made small quips about their experience before retracting those quips ("just kidding", for instance) and then presenting their perspectives, which were included as data. If the sentence or data bit of a specific participant was similar to that of another and did not add more information it was subsumed by the representative comment. Because of this, 16 sentences, containing a total of 22 data bits were subsumed, leaving 63 sentences and 81 data bits. For the treatment group, 31 sentences, containing a total of 41 data points were subsumed, leaving a total of 62 sentences and 79 data bits. The data bits were then grouped together into categories and synthesized to emerge as five themes. The themes are presented below.

Theme One: Helpful material/design. The comments from both the treatment and control groups are very similar for this theme. Members of both groups felt that the lectures clearly and concisely presented information to the learner. The participants also liked the linear nature of the progression though the study material. Finally, members of both groups mentioned the helpfulness of the individual slides at the end of the instructional sequence, provided as study materials. Overall, little or no difference was detectable for this theme.

> "The slides were easy to understand and navigate through." *Participant 10, control group*

"The explanation of the basic anatomical position really helped me orient myself somewhat, when dealing with the bones. The availability of the ppt. slides w/the pictures was also very helpful." *Participant 42, control group*

"The 3D formation was very helpful. It explain as if you are learning in the lab practically." *Participant 21, treatment group*

"The 3D notes were a great help. I could see how useful it would be to an online class. The power points and lectures were simple and straight to the point, yet filled with all the information that you need to know." *Participant 39, treatment group*

Theme Two: Learning material was enjoyable and engaging. As with the previous theme, there was little difference between the treatment and control groups on this theme. Members of both groups commented that they found the subject material interesting and the process of learning the material enjoyable.

"I got to learn more about skeletal system practically. Doing this survey I enjoyed learning." *Participant 3, control group*

"I found the material engaging, interesting, and applicable." *Participant 33, control group*

"I thought that overall the study informative was good and I would like to learn more." *Participant 46, treatment group*

"It was fun and I would not mind doing it again." *Participant 7, treatment group*

Theme Three: Posttest expected to mirror pretest. Another common comment subject was the participant expectations specific to the posttest. In general, the participants felt that since the ToPK was multiple choice, the posttest would be as well.

> "I personally would have benefited more on this exam if I had a list of choices to choose from." *Participant 24, control group*

> "…I think I was more mentally prepared for multiple choice than anything." *Participant 34, control group*

> "The lectures were easy, however I didn't though that we should memorize the names. I thought that it is a multiple choice and that is why it was difficult for me." *Participant 1, treatment group*

> "I would take caution when looking at my exam because along with studying the notes, I was also focused on the fact that my professor usually has multiple choice quizzes or exams." *Participant 39, treatment group*

Theme Four: Speaker/Material repetitive and unengaging. While many students commented on how useful and engaging they found the instructional material, a number of students also found the materials and the lectures repetitive or simply boring.

> "The material used to teach the topic was easy to understand but got boring and repetitive at times." *Participant 19, control group*

> "I think if you were hoping for good result you should have been more engaging in the lectures. It seemed like you were reading a script." *Participant 28, treatment group*

Theme Five: Desire for hands-on/interactive material. The final shared theme was the only one directly applicable to the research questions. A number of students discussed their difficulty with the online environment, several mentioning that online courses were especially difficult for them. Further, the transition from the graphics presented in the instructional materials to the actual bones of the posttest proved difficult and stressful. The solution suggested by participants in both groups would be to provide some hands-on activity as part of the instructional process. Finally, one student in the control group, actually mentioned the desire for 3D, interactive graphics.

> "The 2D photos were incredibly beneficial in your lectures up until they were replaced with the Final Exam's 3D objects this was very challenging…" *Participant 33, control group*

> "I do believe that with hands on activities I would have been able to memorize and recognize the features of the bones more easily." *Participant 7, treatment group*

> "I wish the pictures were interactive or something. I feel that would have helped my learning, to rotate the pictures and see the bone in 360 degrees." *Participant 42, control group*

Summary of Results

This experiment examined the impact of the addition of 3D digital images in an online learning environment on student posttest scores and student motivation and attitudes as measured by a Course Interest Survey as well as a pair of open ended questions. The results of the study indicate that the addition of the 3D images to the instructional materials did not significantly affect performance on the posttest, even when prior knowledge of skeletal anatomy was considered. Although the CIS survey indicated significantly higher motivation in the treatment group, participant responses to open-ended questions did not support a more positive perception of the teaching materials in one group over the other. Responses from both groups were similar in their critique of the instructional materials.

Chapter V

Interpretation and Conclusions

This study explored the impact of the addition of three-dimensional digital files on both educational effectiveness and learner attitudes toward an online laboratory course. Three-dimensional digital graphics have become common in online courses, particularly laboratory courses but, as discussed in Chapter II, there is little research to support the effectiveness of such 3D graphics in the learning process. In order to address this gap in research literature, a set of video lectures and study materials were created, covering gross skeletal anatomy, directional terms, and the specific features of the human tibia. One set of video lectures and study materials was designed and created using two-dimensional digital images of the human skeleton in general and the tibia in specific. Another set of video lectures and study materials was designed and created using three-dimensional digital images. Students were recruited over two semesters from the fourteen sections of the ANTH1100: General Anthropology course esters; these classes included students from a broad cross-section of the university population. The participants in the sample were divided into a control group which had access to the two-dimensional materials, and a treatment group which has access to the same materials plus the three-dimensional PDF files.

This chapter will summarize the results of the study and will offer a discussion based on those results. This chapter will also offer a discussion of the strengths and weaknesses of the research design as well as recommendations for practice and suggestions for further research.

Interpretation of the Results

Impact of the addition of 3D images on educational effectiveness. The first research question asked whether the introduction of 3D graphics would lead to an increase in participant achievement of a posttest. The results presented in Chapter IV clearly show that there was no significant difference between academic performance on the posttest between the control and treatment groups. It is possible that because the number of participants was lower than required to meet the sample size called for by the power calculation, a small but significant effect was missed; however, that is simply supposition at this point.

Increase in motivation based on treatment. The third research question asked whether there was significant difference in student motivation toward learning skeletal anatomy as a result of the addition of the 3D graphics in the instructional materials available to the treatment group. The results suggest that the participants who received the treatment were more motivated than those participants in the control group. Thus, the introduction of the 3D materials as well as the way in which the 3D materials were integrated into the rest of the learning materials provided a learning environment that positively impacted the motivation of the treatment group. However, the posttest scores and the results of the open-ended questions do not show a significant difference between the treatment and control groups. One possible explanation for this is was discussed in Chapter I as a threat to external validity. New experiences have a disruptive impact on human behavior (Bracht & Glass, 1968). It is conceivable that the novel nature of the video lecture wherein the 3D graphics were manipulated while the narrator discussed the features combined with the use of the 3D pdf helped to create the difference seen on the

CIS. Put more simply, the novel and engaging nature of the 3D, interactive graphic might have helped to engage the participants, thus impacting the way they scored the CIS, without having an appreciable impact on their posttest scores or the comments made immediately after taking the posttest.

Do 3D graphics add value to the learning process? The original assumption envisioned during the development of this study was that the 3D materials simulated an authentic learning experience, simulating a physical skeletal anatomy laboratory class. The 3D images would create an authentic context in which to develop a set of skills, in this case the ability to recognize the features of the human tibia. Further, given the layering of video, interactive graphics and text, the learning environment was designed to provide a rich and engaging learning experience. However, based on the comments to the open-ended questions, the results were mixed. As seen from the second theme gleaned from the open-ended questions, many participants found the learning environment fun and engaging. The materials stimulated the participants' interest in the subject and multiple participants expressed a desire to learn more. Others found the environment repetitive and unengaging. Further, these sentiments were expressed by both the treatment and control groups. Both groups expressed a desire for more interactive learning materials to study: the 2D group for 3D materials, and the 3D group for "real bones."

The purpose of this study was to explore the effect of the addition of three-dimensional digital files on both learner performance and learner attitudes toward an online laboratory course, the 3D added-value in creating a learning environment perceived as equivalent to a face-to-face environment. For the reasons articulated in

Chapter I, this 3D environment can save time, money, and instructor resources. However, based on the posttest scores and comments specific to the amount of material versus available time, if the environment is not carefully constructed with ample time allowed for the learners to engage with and master the information, the introduction of any graphics, 3D or otherwise, would be of limited value.

Confounding Factors

A number of unforeseen aspects of the study design and the sample of convenience led to the introduction of a number of confounding factors that had a significant impact on the study. While these factors may have had an impact on the internal and external validity of the study, each is very instructive as to the nature of educational research and each lends itself to improving this study design in order to carry out further research on the subject.

Low participant numbers. The participants were to be drawn from a set of classes that historically have contained large numbers of students. The ANTH1100: General Anthropology course has averaged around 60 students per section over the last six years and each semester at least seven sections are taught, with an average of over three hundred students enrolled in the course each semester. If one in five students volunteered to participate in the study, the number required by the power calculation would be met. However, obtaining participants proved to be problematic. One of the first problems was an unexpected, university wide, loss of a large portion of the students who had previously taken the General Anthropology course. The semester the study began saw average class sizes drop from over 60 students per class to less than 40 students per class. Thus, in order to achieve the required sample size, a much higher proportion of each class would need to participate. Unfortunately, student participation was much lower than expected. While there were still more than two hundred students enrolled in the various sections of General Anthropology during the fall semester, only 27 students volunteered for the project. During the spring semester, the study was run twice, timed to take place immediately after the first and second exams of the semester to maximize student interest in the extra credit. Between the second and third run of the project, 44 more participants volunteered, bringing the total up to 71 participants who started the study. While this number was greater than the 60 required by the power calculation, it did not leave much room for mortality.

Mortality. Chapter I describes various potential threats to internal validity; it was recognized that experimental mortality could be a possible threat. However, there were a number of features of the study and the sample population that were thought to minimize this threat to the study. First, as mentioned above, the participants were to be drawn from a set of classes that historically have contained large numbers of students. Second, the short duration of the study was considered to work in favor of the study. Two weeks was considered to be short enough that the participants were unlikely to lose interest in the study, forget that they were part of the study, or have some external issue arise that would compromise their participation in the study. Third, the fact that the majority of the materials and activities for the study would be delivered through a Moodle page meant that the materials could be accessed at the convenience of the participants and that reminders could be delivered through email to help keep the participant on track. Finally, completion of the study would mean an award of extra credit which was thought to be an adequate reward for the work required to complete the study.

Unfortunately, many of these assumptions were demonstrated to be unsupported once the study had begun. Of the 27 participants that enrolled in the study the first semester, 13 completed the study. Of the 44 participants that enrolled during the course of the second semester, 34 completed the study. The mortality rate was expected to be minimal. Instead, the study saw a mortality rate of over 33%. This mortality rate brought the total number of participants who completed the study down to 47. This low sample number could account for a lack of significant findings as only a very large effect would be recognized from this sample.

Extra credit. One of the possible causes of low student interest in volunteering and the high rate of participant mortality could be the reward for participation being insufficient to provide ample motivation for a participant to complete the study. It is important to mention that at this point we are not discussing motivation specific to the work of John Keller.

From the work of Porter and Lawler (1868) and later Gagne and Deci (2005), research suggests that the learner is motivated both internally and externally, often referred to as intrinsic and extrinsic motivation. Intrinsic motivation is derived from the learner’s interest in the subject matter and the satisfaction obtained by interacting with the instructional material due to that interest. Extrinsic motivation is derived from an external consequence such as a reward for successful completion of the materials or a negative consequence for the failure to successfully complete the material.

It is reasonable to assume that for many, if not the majority, of the participants in this study, the instructional material was not interesting and thus was not material that would involve their intrinsic motivation. While many participants did state that they enjoyed learning about the material, the majority did not. Further a number of participants also mentioned finding the material and the video lectures boring and repetitive. Thus, their successful completion of the materials would have to come from extrinsic motivation.

Further, in order to gain the extra credit reward, the students had to complete the materials on the Moodle page and then complete the in-person practical exam. The Moodle page was designed in such a way so that a participant gained access to the materials sequentially. Giving informed consent opened the ToPK. Completing the ToPK opened the lecture on Basic Bone Anatomy, which led to the lecture on Directional Terms which then led into the lectures specific to the treatment and control groups. Finally, completion of the last lecture opened the study materials, which in turn opened the Course Interest Survey. However, with the exception of the quizzes, simple access was all that was required to open the next item in the chain. No mechanism to ensure that the participant had actually watched the lecture was included in the study or even considered during project design. Simply by clicking on one link after the other, a participant could progress rapidly through the instructional materials and gain access to the Course Interest Survey within a few minutes. Then the participant could simply schedule the in-person exam and by finishing the exam, gain access to the extra credit reward, without ever watching a lecture or studying a 2D or 3D graphic. There are certainly alternate explanations, but this could account for the low posttest scores.

As stated above, extrinsic motivation is derived from an external consequence. In this case, the reward of extra credit. Again, based on the low completion rates of the participants (47 out of 71 participants completed the study), it is clear that the extra credit reward was not a sufficient extrinsic motivator. In fact, the extrinsic motivator was further diluted due to the requirements of the Institutional Research Board. As the study was voluntary, an alternate source of extra credit was provided for those who did not wish to participate in the study. In effect, if a participant found the materials of the study unappetizing or too difficult, there was an available alternative.

Overall poor results. While there were a few notable exceptions, the majority of the participants did very poorly on the posttest. As the t-test did not find a significant difference between groups, the posttest scores were treated as a single group for the purposes of this discussion.

A point that is particularly interesting is that even the participants who scored well on the ToPK did not score higher than a 30% on the posttest. Further, nearly 75% of the participants scored less than a 50% on the posttest. So, while the poor performance on the posttest by itself does not account for a lack of significance between the two groups it is symptomatic of a larger set of issues with the participant sample in specific and the study in general.

Expectations. Further, given the responses to the open-ended questions it is likely that this was caused in part by the participants' expectations of a selected response posttest, similar to the format of the ToPK. Participant expectations about the format of the posttest may have also affected performance. The ToPK delivered at the beginning of the study was a multiple-choice quiz delivered through the study Moodle page. Even though the posttest was described as a practical exam and the format was described to the participants in the initial email instructions and at the time the appointment to take the exam was made, several students commented that they expected a multiple-choice posttest and that part of the reason they did so poorly on the posttest was that they had not prepared for a fill-in-the-blank practical exam. It is quite possible that this misunderstanding led to lowered scores for a number of participants.

Learned capabilities. Finally, there was also a difference between the way the material was presented to the participant and the way the posttest sought to illicit the information. Drawing on Gagne's Five Learned Capabilities (Gagne and Medsker, 1996), we would characterize the video lectures as transmitting verbal information. The participants were presented with labels and facts on the form of specific anatomical structures. However, when the participants encountered the practical exam, the participants were asked to discriminate between various features and to use complex sets of rules to decide what tissues connected where. While this expectation was mentioned in the video lectures, the participants were not given the opportunity to practice this cognitive transition prior to the posttest.

Duration of the study. Participants also indicated that the short duration of the study may have affected their performance. A concern voiced in the open-ended responses was that there was not enough time to properly learn the material required for the posttest. During the design of the study, it was decided that the subject material should focus on a single bone as anything beyond that would require multiple weeks and that a single bone would provide all of the material required to look for differences between the control and the treatment groups. During the development of the study, it became obvious that a simple introduction to the skeleton as a whole, including subjects such as directional terms, basic bone anatomy, and a basis discussion of joints would be necessary to give the lecture on the tibia proper context. In effect, a basic schema needed to be created in order for the participant to understand and to be able to remember the material on the tibia. The two instructional videos that covered the skeletal and directional fundamentals added, at least, another half hour to participants' time and increased the amount of material for students to learn. Given that most of the participants would need to cover the material more than once, the additional material added a significant time burden to the study. When you factor in the hours' worth of lecture on the tibia and the study materials and the Course Interest Survey and the ToPK, the time required to learn the material to the extent necessary to succeed on the practical exam became greater than the participants were willing to dedicate for the reward of extra credit.

Self-efficacy. Finally, it is reasonable to assume that the sample for the study may have contained a larger number of students without sufficient self-efficacy to properly complete the materials and perform on the posttest. Bandura describes self-efficacy as a learner's belief that they can successfully complete a task (Bandura 1997). Learners with a high degree of self-efficacy are more likely to start a task, start it earlier than students with low self-efficacy, and therefore are more likely to successfully complete the task. Further, learners with high self-efficacy are more likely to succeed in a class and are thus less likely to need extra credit.

Using the 3D images. An issue related to the short duration of the study is the difficulty participants may have encountered in handling the 3D PDF files. During the design of the study, it was assumed that most of the computers used by the participants of the study to access the instructional materials would already have a version of Adobe Reader installed, as Adobe reader is a common feature of all of the computers available to students at the university at which the study was completed. However, three participants did contact the research assistants or the primary investigator during the course of the study for help in opening the PDF files.

Further, once the file was opened, the participant had to click on the image and then wait for a moment before attempting to manipulate the image. Further, the images required clicking and dragging to reposition, and opening the list of features required finding and then accessing a drop-down menu. While instructions on how to accomplish this were presented on the Moodle page, it is probable that even if the participant could successfully manipulate the image, the process is not necessarily easy and this may have interfered with the learning process. Given enough time and practice, the file manipulation could have become much easier, but time was limited.

Implications for Practice

Because of the lack of significant differences between the posttest scores of the treatment and control groups, the recommendations for practice are limited to one point. The relationship between the addition of three-dimensional materials and an increase in learner performance is not clear cut. Even before the results of this study are examined, it is worth noting that any media used in the educational process must be properly integrated into the instructional material and that the integration of such media must be done deliberately and with an eye toward the relevant educational theory and research.

The results of this study suggest that integrating three-dimensional images into instructional material will have no greater impact on learner outcomes than the previously existing two dimensional materials. Thus, in an educational environment with limited resources, the existing two-dimensional graphics are equally effective and less costly. If three-dimensional graphics are added to instructional materials it should be recognized that an increase in learner achievement is not guaranteed.

Researcher Reflections

During the design and development phase of this study, as I began the task of assessing the internal and external threats to the validity of the study, I felt that I had a firm grasp of what could go wrong. Having been a college instructor for nearly twenty years, I felt that I understood the student, what they were willing to do and how much they could handle. Unfortunately, dealing with students in a classroom and participants in a study are two very different situations.

One of the areas that caused the most trouble in the final analysis was the fact that the primary investigator was both a subject matter expert and conformable with technology. The subject matter expert for this project helped make a number of significant decisions and offered their opinion on what freshmen level student would be able to handle within the time frame of the study. The SME also helped to design the instructional material and then ran through the material to look for errors. The instructional materials were then tested by several classes made up of freshmen and sophomores, who were all majors in the department of anthropology, but had not yet been exposed to the human skeleton. While these students seemed like perfect surrogates for the participants who would be using the website, these were majors in the department, who were being asked to cover material they would need to master in a few weeks anyway. Further, they were being asked to cover the material by instructors who were members of their department, people who were mentoring them and whom they would be interacting with regularly in class after class. It is obvious now, that they were willing to put far more effort into mastering the material than students enrolled in the only anthropology course they would ever need to take.

This all seemed so thorough at the time. However, in retrospect, the fact that the primary investigator teaches upper division and graduate level courses in the human skeleton, led to the development of a study that does require the participant to cover more material than is reasonable within a week's time, with only extra credit as a reward, on top of a normal class load.

While too much experience led to difficulties in judging the proper amount of effort to expect from the sample population, a lack of experience led to another major issue. A volunteer rate of one in ten seemed easily achievable and the design of the study seemed so secure that even though the threat of experimental mortality was covered in Chapter I, the actual possibility that the study would suffer a significant rate of participant withdrawal seemed highly unlikely. Further, when it became apparent that participant withdrawal would be an issue, given the ease with which instructors in the Anthropology Department gave their cooperation, it seemed reasonable that instructors in English and Philosophy would also be willing to allow access to their students. However, this was not the case.

Suggestions for Further Research

Refine and continue this project. While there are flaws in the research design, these flaws can be fixed and the study would yield useful data. The simplest fix would be to find another reward for participation besides extra credit, perhaps a grant to allow monetary compensation. Better tracking of the completion of tasks would need to be included, along with the addition of self-checks at the end of each lecture, requiring a certain score before the next lecture became available. A more detailed analysis of the CIS could also be included, along with a more comprehensive set of open ended questions.

Investigate current software packages that include 3D graphics. Of even more importance is the exploration of the efficacy of the software packages containing 3D graphics already in use in online laboratories. This would include large format 3D tables such as those sold by Sectra or Automage. These large format touch screens can cost upward of $60,000 dollars, so the analysis of the benefits of the use of this technology is of obvious importance.

Conclusions

The results of this study suggest that the introduction of 3D, manipulable graphics to online learning environments does not have a significant impact on learner achievement of educational assessments or the learner's perception of the value of the instructional material. Participant posttest scores as well as the participant comments on the open-ended questions showed no significant difference between treatment and control groups. However, the small sample size, the poor performance on the posttest, and the reports of insufficient time available to properly handle the material could have created a set of confounding variables that masked an actual difference or did not create an environment where a difference in learning could occur.

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Appendix A

Course Interest Survey Questions

Course Interest Survey

John M. Keller

Florida State University

1 (or A) = Not true, 2 (or B) = Slightly true, 3 (or C) = Moderately true,

4 (or D) = Mostly true, 5 (or E) = Very true

1. The instructor knows how to make us feel enthusiastic about the subject matter of this course.
2. The things I am learning in this course will be useful to me.
3. I feel confident that I will do well in this course.
4. This class has very little in it that captures my attention.
5. The instructor makes the subject matter of this course seem important.
6. You have to be lucky to get good grades in this course.
7. I have to work too hard to succeed in this course.
8. I do NOT see how the content of this course relates to anything I already know.
9. Whether or not I succeed in this course is up to me.
10. The instructor creates suspense when building up to a point.
11. The subject matter of this course is just too difficult for me.
12. I feel that this course gives me a lot of satisfaction.
13. In this class, I try to set and achieve high standards of excellence.
14. I feel that the grades or other recognition I receive are fair compared to other students.
15. The students in this class seem curious about the subject matter.
16. I enjoy working for this course.
17. It is difficult to predict what grade the instructor will give my assignments.

18. I am pleased with the instructor's evaluations of my work compared to how well I think I have done.

19. I feel satisfied with what I am getting from this course.

20. The content of this course relates to my expectations and goals.

21. The instructor does unusual or surprising things that are interesting.

22. The students actively participate in this class.

23. To accomplish my goals, it is important that I do well in this course.

24. The instructor uses an interesting variety of teaching techniques.

25. I do NOT think I will benefit much from this course.

26. I often daydream while in this class.

27. As I am taking this class, I believe that I can succeed if I try hard enough.

28. The personal benefits of this course are clear to me.

29. My curiosity is often stimulated by the questions asked or the problems given on the subject matter in this class.

30. I find the challenge level in this course to be about right: neither too easy not too hard.

31. I feel rather disappointed with this course.

32. I feel that I get enough recognition of my work in this course by means of grades, comments, or other feedback.

33. The amount of work I have to do is appropriate for this type of course.

34. I get enough feedback to know how well I am doing.

1. When I first looked at this lesson, I had the impression that it would be easy for me.
2. There was something interesting at the beginning of this lesson that got my attention.
3. This material was more difficult to understand than I would like for it to be.

4. After reading the introductory information, I felt confident that I knew what I was supposed to learn from this lesson.
5. Completing the exercises in this lesson gave me a satisfying feeling of accomplishment.
6. It is clear to me how the content of this material is related to things I already know.
7. Many of the pages had so much information that it was hard to pick out and remember the important points.
8. These materials are eye-catching.
9. There were stories, pictures, or examples that showed me how this material could be important to some people.
10. Completing this lesson successfully was important to me.
11. The quality of the writing helped to hold my attention.
12. This lesson is so abstract that it was hard to keep my attention on it.
13. As I worked on this lesson, I was confident that I could learn the content.
14. I enjoyed this lesson so much that I would like to know more about this topic.
15. The pages of this lesson look dry and unappealing.
16. The content of this material is relevant to my interests.
17. The way the information is arranged on the pages helped keep my attention.
18. There are explanations or examples of how people use the knowledge in this lesson.
19. The exercises in this lesson were too difficult.
20. This lesson has things that stimulated my curiosity.
21. I really enjoyed studying this lesson.
22. The amount of repetition in this lesson caused me to get bored sometimes.
23. The content and style of writing in this lesson convey the impression that its content is worth knowing.
24. I learned some things that were surprising or unexpected.
25. After working on this lesson for awhile, I was confident that I would be able to pass a test on it.

26. This lesson was not relevant to my needs because I already knew most of it.

27. The wording of feedback after the exercises, or of other comments in this lesson, helped me feel rewarded for my effort.

28. The variety of reading passages, exercises, illustrations, etc., helped keep my attention on the lesson.

29. The style of writing is boring.

30. I could relate the content of this lesson to things I have seen, done, or thought about in my own life.

31. There are so many words on each page that it is irritating.

32. It felt good to successfully complete this lesson.

33. The content of this lesson will be useful to me.

34. I could not really understand quite a bit of the material in this lesson.

35. The good organization of the content helped me be confident that I would learn this material.

36. It was a pleasure to work on such a well-designed lesson.

Appendix B

The Test of Prior Knowledge

Question One

a. What type of joint is the articulation between the radius and the humerus?

Synovial

b. What is the name of the tissue that covers the entire outer surface of the bone, except for the articular surfaces?

Periosteum

c. What is the name of the feature through which the blood vessel passes as it enters the bone?

Nutrient foramen

d. What is the name of the general bone cell?

Osteocyte

Question Two

Using the proper directional terms, answer the following questions.

a. The radius is _____________ in relation to the ulna.

Lateral

b. The radius is __________ in relation to the carpals.

Proximal

c. The radius is ______________ in relation to the Humerus.

Distal

d. The dorsal or Lister's tubercle is on which aspect of the radius?

Posterior

Question Three

a. Name this feature.

Styloid process

b. Name this feature.

Oblique line

c. Name this feature.

Radial head or Circumferential articulation

d. What bone articulates with this feature?

Humerus or ulna

Question Four

a. Name this feature.

Ulnar notch

b. What specific feature articulates with a?

The radial/circumferential articulation

c. Name this feature.

Interosseous crest

d. What tissue attaches to c?

Interosseous ligaments

Question Five

a. Name this feature.

Radial/bicipital tuberosity

b. What muscle inserts at a?

Biceps brachii

c. Name this feature.

Radial head/articular fovea

d. what specific feature articulates with a.

The Capitulum of the Humerus.

Appendix C

The Posttest

Name: ___________________________________

This exam is divided into four separate sections. Section three is the only section where the skeletal material will be necessary. Please complete section three first. Then you can move up to the lobby to complete the first, second and fourth sections.

Section One: General information

1) Have you ever attended a class dealing with human anatomy including the human skeleton?
Circle one: Yes / No

2) Demographic Information
a. Gender: __________
b. Class standing: __________
c. Is English your native language? Circle one: Yes / No
d. Major of study: __________

Section Two: Basic skeletal knowledge

1) Which bone articulates with the tibia superiorly? Femur

2) What is the name of the large cavity located in the bone shaft? Medullary/Marrow cavity

3) The proximal and distal ends of any long bone are known as __________? Epiphyses

4) The standard position of the human body during any anatomical discussion is known as the ________________. (Standard) Anatomical Position

5) The basic bone cell is known as a ____________________. Osteocyte

6) What is the name of the joint class known for its movement? ____________________ synovial joint

7) The fluid at the held in the joint capsule of any movable joint in the human body is known as ____________________. Synovium

8) The tough, fibrous tissue covering the external surface of bones is known as _______________. Periosteum

9) What is the name of the smooth material that covers the articular surface of bone? ____________________ hyaline cartilage

10) To what general bone type, does the tibia belong? _____________________
long bone

Section Three: The practical exam

Question One:
A) Which feature is this? _____________________ lateral intercondylar tubercle

B) What basic class of soft tissue inserts at A? _____________________ cruciate ligaments

C) Which feature is this? _____________________ superior fibular facet

D) Which side is this bone? _____________________ right

Question Two:
A) Which feature is this? _____________________ medial malleolus

B) Which side is this bone? _____________________ left

C) Which feature is this? _____________________ inferior fibular articular surface

D) Which bone articulates at C? _____________________ the fibula

Question Three:
A) Which feature is this? _____________________ tibial tuberosity

B) What muscle attaches here? _____________________ quadriseps femoris

C) Which feature is this? _____________________ anterior crest

D) Which feature is this? _____________________ nutrient foramen

Question Four:
A) What tissue would cover B & C in life? _____________________ hyaline cartilage

B) Which feature is this? _____________________ medial condyle

C) Which feature is this? _____________________ lateral condyle

D) Taken together, B & C are part of a larger feature known as the _____________________.
tibial plateau

Question Five:
A) Which feature is this? ____________________ interosseous surface

B) Which feature is this? ____________________ interosseous crest

C) What soft tissue structure attaches at B? interosseous ligament

D) Which bone does the tissue form B connect to the tibia?
____________________ fibula

Section Four: Open ended questions

Please use the remaining space on this page and the next to answer the following questions.

1) What did you find helpful or unhelpful about the instructional material used to teach this topic?

2) What else should I know about your learning experience with this material?

Appendix D

Demographic Comparison

Demographic information on the ANTH1100: General Anthropology course has been obtained for the past six years. The database is available upon request.

Appendix E

The procedural sequence of the study.

Phase	Tasks	Timing
Participant Selection	Participant email is sent out. Interested students apply. Participants are enrolled in the study Moodle page.	Two weeks prior to the start of the study.
Study Begins	Students receive information orienting them to the study Moodle page. Students complete the informed consent form and the Test of Prior Knowledge. Students who have completed informed consent and Test of Prior Knowledge are randomly assigned to treatment/ control.	The deadline to enroll in the study passes on Thursday of the week prior to the study.
Accessing Materials	Participants gain access to the instructional materials.	Access to the educational material begins the Monday after the enrollment deadline and lasts for seven days.

	Students are reminded to schedule their individual posttest. Students are reminded to complete the CIS.	The posttest was administered, in the lab, the week after the instructional material is available.
Posttest	Students complete the posttest. Demographic information is gathered on posttest. Open ended questions are answered.	