5-3-2024

Effects of 3D Visualization Tables on Students' Learning Outcomes in Gross Anatomy

Jorge Eduardo Sarmiento
Walden University

Walden University

College of Education and Human Sciences

This is to certify that the doctoral dissertation by

Jorge Eduardo Sarmiento

has been found to be complete and satisfactory in all respects,
and that any and all revisions required by
the review committee have been made.

Review Committee
Dr. Deanne Otto, Committee Chairperson, Education Faculty
Dr. Richard Hammett, Committee Member, Education Faculty

Chief Academic Officer and Provost
Sue Subocz, Ph.D.

Walden University
2024

Abstract

Effects of 3D Visualization Tables on Students' Learning Outcomes in Gross Anatomy

by

Jorge Eduardo Sarmiento

MS, Findlay University, 2006

MA, University of Phoenix, 2002

BS, University of California San Diego, 1999

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Education – Technology and Design

Walden University

April 2024

Abstract

Higher learning institutions teaching gross anatomy are implementing 3D technology, such as the Anatomage Table, to supplement cadaveric dissection. However, the literature is scant about the effects of introducing 3D technologies on students' learning outcomes in the study of gross anatomy. The purpose of this quantitative study was to determine the difference in written exam scores and laboratory exam scores between Doctor of Physical Therapy (DPT) students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional only instruction at a local university. The study was guided by the adaptable learning theory framework for technology-enhanced learning (AF-TEL) and facilitating student engagement through educational technology. The study used a convenience sample of archival data (N=1334) from a five-campus university in the United States. The data were analyzed using the Mann-Whitney U test and Spearman's rho. Key findings demonstrated a significant difference for students using the Anatomage Table on laboratory exam scores, while written exam scores were not significantly different. Correlational analysis revealed a moderate, significant relationship between the Anatomage Table utilization and laboratory exam performance and a significant but small relationship between Anatomage Table utilization and written exam scores. Many students could be helped to select a learning environment that uses various modalities to learn anatomy. Institutions could make curricular designs to introduce tested technologies to enhance student comprehension and performance, thus advancing social change in the educational field.

Effects of 3D Visualization Tables on Students' Learning Outcomes in Gross Anatomy

by

Jorge Eduardo Sarmiento

MS, Findlay University, 2006

MA, University of Phoenix, 2002

BS, University of California San Diego, 1999

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Education – Technology and Design

Walden University

April 2024

Dedication

This dissertation is dedicated to all who could benefit from its findings and those who patiently endured the long hours of my absence from their lives. As a follower of the Lord Buddha, I dedicate this work to the Dhamma teachers and the Sangha of monks who inspired me to become a better human being. As a son, I dedicate this dissertation to my mom, who has supported me in all my endeavors. As a husband, I dedicate this work to my beloved Farouk, who encouraged me, endured my frustrations, and supported me in challenging times. And as a brother, I dedicate this work to my sisters Rutty, Magda, Claudia, and my brother Harold, and to my siblings who departed this earth too early. And last but not least, to my Chair, Dr. Otto, for her timely guidance, skillful feedback, and moral support when life threw a wrench on my path when I lost my dear sister Elizabeth. Much Metta (good will/loving kindness) to you all!

Acknowledgments

I am grateful to all the faculty who, through their knowledge and expertise, provided me with an excellent background to understand how education and technology can be used to improve learning. I am especially grateful to my Chair, Dr. Otto, for her patience, support, and guidance throughout the dissertation process. With her guidance, I accomplished a steep milestone in my professional and academic life. I would also like to thank my co-chair, Dr. Hammett, for his feedback and support. Lastly, I am grateful to my husband, mom, siblings and co-workers for enduring my questions and taking their precious time with my feedback requests.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction to the Study

Current research shows that 3D technologies such as visualizing and dissection tables or the Anatomage Table enhance anatomy learning and complement other learning modalities used in gross anatomy studies, like 3D models, cadaveric dissection, and prosections (Afsharpour et al., 2018; Barillas, 2019; Iwanaga et al., 2021; Narnaware & Neumeier, 2021; Tenaw, 2020; Triepels et al., 2020). Many students could be helped to select a learning environment that uses various modalities like the Anatomage Table, cadaveric dissection, and plastic models to learn anatomy. Institutions could make curricular designs to introduce tested technologies to enhance student comprehension and performance, thus advancing social change in the educational field. Moreover, finding out whether introducing 3D technologies produces improved learning outcomes in gross anatomy studies could open the doors to broader implementation of these technologies in institutions involved in teaching anatomical sciences (Fleagle et al., 2018; Jamil et al., 2019; Sotgiu et al., 2020 ; Triepels et al., 2020). For instance, nursing, dental, medical, physical, occupational, and chiropractic students could benefit from knowing which schools use 3D visual technologies in their classrooms to complement gross anatomy studies. Although several researchers have found that the introduction of 3D technologies like visualization and dissection tables such as the Anatomage Table yielded positive and significant effects on learning outcomes, most of the studies did not evaluate learning outcomes based on summative assessments like written and laboratory exams and instead used subjective Likert scale surveys to assess students' perceptions on the use of the 3D technology (Abdulrahman et al., 2021; Downer et al., 2020; Stecco et al., 2020).

Background

Students in the medical field require good knowledge of gross anatomy to understand the functions of body systems and how those systems relate to each other. Furthermore, students must become proficient in anatomical knowledge to apply to upper-level courses drawing from it. Students must also demonstrate what they learned in the classroom and the anatomy laboratory via laboratory examinations and written quizzes and exams. Medical students relied on human cadavers to study human anatomy for many centuries. For instance, the earliest recorded anatomical atlas, the Chinese *Mawangdui* medical atlas, dates to 168 B.C.E. (Shaw et al., 2022), while European anatomical texts, like *De Humani Corporis Fabrica* (On the Fabric of the Human Body) by Vesalius, was first made public in 1543 (Varner et al., 2021). However, technological innovation began introducing 3D electronic devices like the Anatomage Table as early as 2014 (Anatomage, n.d.). This advanced system uses computerized tomography (CT) to recreate, using 3D technology, human tissues and body systems with high accuracy, anatomical detail, and high-resolution visualization and dissection capabilities. With this technology, students can visualize, manipulate, and dissect the human body without the limitations of actual human bodies (Anatomage, n.d.). In fact, according to Ben Awadh et al. (2022), Darras et al. (2019), Fulmali et al. (2021), and O'Rourke et al. (2020), the use of this 3D technology by medical students has produced positive effects on learning outcomes.

Although the bulk of the literature regarding the learning effects of introducing 3D technologies like the Anatomage Table and similar visualization and dissection tables to study gross anatomy is based on medical students, other authors have researched students' learning outcomes in other medical fields like physical therapy (PT), nursing, occupational therapy, and dental schools with similar results. For example, quantitative and mixed-methods studies measuring learning outcomes based on written and laboratory exams have demonstrated significant improvements in learning outcomes (Afsharpour et al., 2018; Bains & Kaliski, 2020; Baratz et al., 2019; Barillas, 2019; Bartoletti-Stella et al., 2021; Casallas & Quijano, 2018; Ceri, 2021; Deng et al., 2018; Jamil et al., 2019; Narnaware & Neumeier 2021. From a qualitative perspective, researchers like Chakraborty and Cooperstein (2018), Darras et al. (2019), Downer et al. (2020), Dutt et al. (2020), Kažoka and Pilmane (2017), Lin et al. (2020), Tenaw (2020), Whited et al. (2021), and others have used qualitative surveys to assess students' perceptions on the use of 3D visualization and dissection tables. These studies showed that 3D visualization and dissection tables enhanced knowledge, understanding, and application of anatomy.

Current research is scant regarding other medical fields, such as PT, nursing, occupational therapy, and dentistry, but revealed promising results. For instance, PT students demonstrated higher learning outcomes after introducing the visualization and dissection tables (Bains & Kaliski, 2020; Rosario, 2022). Furthermore, nursing students showed significant improvements in learning outcomes (Chakraborty & Cooperstein, 2018; Narnaware & Neumeier, 2021) and improved memorization and comprehension of anatomical structures (Chiliquinga & Perez, 2022). In addition, dental students' performance was significantly higher when using the Anatomage Table versus dissecting cadaver specimens (da Silveira et al., 2021). Finally, Barillas (2019) assessed occupational students when studying anatomical structures, which yielded improved grades, but the results were not statistically significant.

The literature is scant regarding research studies that specifically examined learning outcomes from Doctor of Physical Therapy (DPT) students who took undergraduate anatomy using 3D technology like the Anatomage Table and the effects on graduate gross anatomy outcomes. For example, a singular research study conducted by Shaffer et al. (2018) indicated that prerequisite coursework, such as anatomy, did not significantly impact learning outcomes in subsequent courses that directly drew from the knowledge acquired in those classes. In another study, Peterson and Tucker (2005) found that the gross anatomy final examination scores were strong predictors of passing the USMLE-1, a higher level of understanding of gross anatomy drawing from anatomical knowledge during the formative years in medical school.

A few studies are insufficient to conclude the effects of prerequisite courses like anatomy on more advanced courses like gross anatomy in graduate education. Still, it is essential to note that the literature in this area is limited, and further research is needed for a comprehensive understanding. More literature needs to be written examining the effect of undergraduate anatomy on graduate gross anatomy performance and introducing 3D technology like visualization and dissection tables like the Anatomage Table in the study of anatomical sciences.

The aim of this study was to contribute new knowledge to the literature based on the need for robust research indicating whether 3D technologies such as visualization and dissection tables like the Anatomage Table and other similar 3D technologies affect learning outcomes based on the appraisal of written and laboratory examinations. In addition, the literature is similarly sparse about the effects of anatomical knowledge on subsequent coursework relying upon robust understanding and application of anatomy. Furthermore, the literature should be more explicit regarding the impact of undergraduate anatomy effects on gross anatomy learning outcomes in PT.

Problem Statement

The problem on which this study is based is that there is a lack of understanding about the influence of 3D technologies like the Anatomage Table in the study of gross anatomy. Specifically, not known are the effects that this technology has on learning outcomes in DPT students and the effects of undergraduate anatomy courses on gross anatomy learning outcomes at the graduate level. Previous research primarily focused on qualitative methods that did not measure learning outcomes based on written and laboratory exam grades but only relied on students' perceptions (Clunie et al., 2018; Triepels et al., 2020).

In a quantitative study by Baratz et al. (2019), although the authors had a small sample size of participants, the power analysis demonstrated a 70.3% statistical power based on the $n = 8$ for table users (Group 1) and 7 for non-table users (Group 2), grades were 77.1% for Group 1 and 64.6% for Group 2, with a standard deviation of 7.2 and 9.4, respectively, and $p < .01$. However, the number of participants was deficient in making external validity valid and power, below .80, significant (Baratz et al., 2019).

Measuring and analyzing learner performance using the quantitative methodology for examination grades, final course grades, and performance in prerequisite courses on upper-level education by educational institutions is essential. Those are necessary metrics to obtain funding, continue medical training, and report graduation rates and overall performance. For instance, medical school students must pass the United States Medical Licensing Examination Step 1 (USMLE-1) to continue their medical training. Research by Peterson and Tucker (2005) found that the gross anatomy final examination scores were strong predictors of passing the USMLE-1.

Furthermore, there are a limited number of quantitative studies (Triepels et al., 2020) looking at the difference between undergoing traditional learning (plastic models and cadaveric dissection) and using 3D technologies like the Anatomage Table as an adjunct tool to learning gross anatomy (Clunie et al., 2018). Additionally, maintaining carry-over knowledge of gross anatomy is essential because medical and allied medical sciences students in nursing, PT, dental, chiropractic, and physician's assistant programs heavily rely on anatomical knowledge to evaluate, diagnose, and establish a plan of care to treat patients (Narnaware & Neumeier, 2021). In addition, a recent study by Iwanaga et al. (2021) showed that 3D technology improves learning outcomes, thus impacting the carry-over knowledge needed for medical practitioners. Lastly, the effects of introductory courses on students' performance in upper-level courses are poorly understood, including whether they learned the required skills to succeed in upper or parallel classes (Shaffer et al., 2018).

Purpose of the Study

The purpose of this quantitative study was to determine the difference in written exam scores and laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university, while controlling for effects of undergraduate anatomy scores. Data from the 2018 school year from three cohorts from the Residential DPT program were analyzed.

This study contains one independent variable, two dependent variables, and one covariate. The independent variable includes students who used and did not use (yes/no) the Anatomage Table technology to study gross anatomy. In this case, this 3D technology was introduced to the gross anatomy curriculum in the second term of 2018. The Anatomage Table technology was unavailable at the university in the first term of 2018. The second aspect of this independent variable incorporates students who did not use Anatomage Table technology to study gross anatomy. The dependent variables in this study include first written exam scores after using the Anatomage Table technology. This refers to the scores obtained by male and female students on written examinations involving anatomical knowledge of the human body after using Anatomage Table technology. Second, Laboratory Exam Scores after using Anatomage Table technology: This pertains to the scores achieved by male and female students on laboratory examinations after using Anatomage Table technology. Laboratory exams include identifying human anatomical structures in cadaver specimens and plastic models. The specific laboratory exams considered in this study include GA1 (related to the gross anatomy of the upper extremity) and GA2 (associated with the gross anatomy of the lower extremity). These two types of exams, written and laboratory, test different areas of knowledge. Thus, they were treated as separate dependent variables. Lastly, this study includes one covariate, undergraduate anatomy scores.

Research Questions

The research questions and corresponding hypotheses for this study were as follows:

- RQ 1: What is the difference in written exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university while controlling undergraduate anatomy scores?

  $H_0$1: There is no significant difference in written exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction.

  $H_1$1: There is a significant difference in written exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction.

- RQ 2: What is the difference in laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university while controlling for undergraduate anatomy scores?

$H_0 2$: There is no significant difference in laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction.

$H_1 2$: There is a significant difference in laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction.

Theoretical Framework

The theoretical foundation of this study focuses on two theories: the Adaptable Learning Theory Framework for Technology-Enhanced Learning (AF-TEL) proposed by Havard et al. (2016) and Facilitating Student Engagement Through Educational Technology by Bond and Bedenlier (2019). The former emerged from an abundance of technological teaching tools and educational theories in constant influx, needing a theoretical framework to help guide and bring together learning approaches, theories, and instructional characteristics. Havard et al. (2016) expressed the need for an integrative approach incorporating cognitive, social, and teaching presence to help elucidate how learning outcomes are achieved using effective and efficient strategies. This flexibility enables this framework to be used to accommodate and analyze 3D technologies while emphasizing who is learning, what is being learned, and how individuals learn. The latter examines student engagement and the use of technology. Bond and Bedenlier's assessment includes a bioecological framework, technology microsystems, curriculum, and teacher interventions, as well as how these factors promote student engagement. According to the authors, the engagement concept is sometimes confused with motivation. Thus, they developed a definition that aided their proposed framework and included how students use their energy and effort to participate in learning. Bond and Bedenlier (2019) used cognitive and behavioral characteristics that communicated with internal and external influences and the environment and were related to activities to promote education. These external influences and backgrounds, a new technology introduced into learning the gross anatomy process, could be better understood using the authors' framework.

Use of the AF-TEL in Earlier Studies

Havard et al. (2016) used the AF-TEL to propose e-learning theories to address issues that students face with e-learning technologies (Ochukut & Oboko, 2019). Those problems are relevant to how learners acquire knowledge based on the tools they use for knowledge acquisition. For instance, when learners use 3D technologies, they could be expected to manipulate the tool to extract information that requires simple and complex analysis (Ochukut & Oboko, 2019). Students perform this analysis using the device known as an Anatomage Table because they can access basic anatomical structures with the tool. Adaptive learning systems include content, learner, and adaptive (pedagogical) models. The content model provides a tool that challenges students at different skill levels. The novice student is tasked with lower-level activities, while senior students are assigned more challenging exercises. Instructors could provide these activities to identical learners during a particular course at different times. For instance, learners need to build moderate to intricate anatomical maps to correlate basic anatomical structures and how these structures interact with the rest of the body, thus improving their understanding of the subject matter. Therefore, the expectation is that higher-knowledge learners correctly explain and discuss the material written or laboratory exams. The data used in my study are retrospective and include several summative and formative assessments for gross anatomy and subsequent courses drawing anatomical knowledge. Therefore, the adaptive model enabled me to link the various evaluations used in the anatomical sciences with the performance for these assessments and use correlation statistics to see whether the lower-level courses in anatomy positively affect the upper-level classes.

Furthermore, Havar et al. (2016) described how learning outcomes are a focus in AF-TEL and how the acquisition of skills should align with the required skills needed in upcoming generations of students used to technological advances in school. This emphasis ensures that students acquire enough knowledge and skills to improve their learning outcomes and use their skills in the future. This process requires active learning, the ability of students to extract the information gained from the tool on their own by actively engaging with their environment, as is the case when using 3D technologies such as dissection tables, like the Anatomage Table. Therefore, for this study, I used the adaptable learning theory framework by Havard et al. (2016) to understand the ramifications of 3D technologies like the Anatomage Table, dissection tables, or visualization tables. The adaptable learning theory framework informed my study by allowing me to draw from its two central concepts, namely “who” and “what,” and integrate these concepts into the focus of this dissertation.

First, *who* refers to the instructor, the educator having the experience and ability to guide the student to manipulate the 3D interactive tool, like the Anatomage Table, so that the student is guided to learn to use it and extract information from the 3D device the required knowledge and later apply it practically. The 3D tool and the content are described in the adaptable learning theory framework (Havar et al., 2016). Furthermore, written and laboratory examinations are the standards used to measure students’ knowledge and comprehension before knowledge application is given to assess learning outcomes. In this study, I examined the ramifications of 3D technology, such as the Anatomage Table, in gross anatomy by reviewing previous studies that adopted the adaptable learning theory on the same topic.

Nature of the Study

The rationale for the quantitative design evaluating learning outcomes is that in the absence or scarcity of robust quantitative studies, quantitative designs offer the opportunity to fill the gap in the literature, provide a more comprehensive understanding of the topic (i.e., the effects of introducing the Anatomage Table in learning outcomes of anatomy students), and contribute to evidence-based practices. In addition, many studies have lacked enough participants to make their results significant and limited the generalizability of the study findings to the larger population. This study aims to fill the gap by providing comprehensive quantitative data on the influence of introducing 3D technology like the Anatomage Table on student learning outcomes. I also examined the effect of introducing the 3D Anatomage Table on student learning outcomes for students (males vs. females) measured by theoretical and laboratory exam scores using archival data. This study assessed two dependent variables: written exam scores and laboratory exam scores. A quantitative approach was utilized to examine the relationship between the selected variables, aiming to address the need for comprehensive quantitative literature on student learning outcomes in gross anatomy using a 3D technology like the Anatomage Table. This study also seeks to analyze the performance of male and female students before and after the introduction of the Anatomage Table.

For this study, I used archival data from the 2018 school year involving graduate male and female students enrolled in a DPT program across four campuses in three states. Data collection included written and laboratory examination scores for upper and lower extremity anatomy over three terms (15 weeks each) before and after implementing the Anatomage Table technology.

I used analysis of covariance (ANCOVA) to compare the performance in written and laboratory exam scores of the two groups of PT students while accounting for the potential confounding effect of undergraduate anatomy scores (Khammar, Yarahmadi, and Madadizadeh (2018). Participants' identifiers were not included in the data, and permission from the Walden University Institutional Review Board (IRB) was obtained before data collection.

Definitions

This study contains three independent and three dependent variables. The first independent variable includes students who did not use Anatomage Table technology to study gross anatomy. In this case, Anatomage Table technology was not introduced to the gross anatomy curriculum; thus, students learned gross anatomy without using Anatomage Table technology. The second independent variable incorporates students who used Anatomage Table technology to study gross anatomy after the Anatomage Table technology was introduced in the anatomy curriculum. Finally, the third independent variable includes students who used Anatomage Table technology to study anatomy and participated in upper-level courses drawing knowledge from anatomy.

The dependent variables in this study encompass two distinct components:

- Written Exam Scores: This refers to the scores obtained by male and female students on written examinations involving anatomical knowledge of the human body.
- Laboratory Exam Scores: This pertains to the scores achieved by male and female students on laboratory examinations. Laboratory exams include identifying human anatomical structures in cadaver specimens and plastic models. The specific laboratory exams considered in this study include GA1 (related to the gross anatomy of the upper extremity) and GA2 (associated with the gross anatomy of the lower extremity. These scores reflect the participants' performance in applying their practical knowledge and skills in these areas.

The terms used in this study having multiple meanings include the following:

- *Anatomage Table technology*: A 3D device with high-fidelity depictions of cadaver anatomy based on CT scans and visualization and dissection capabilities (Anatomage, n.d.).
- *Spectra Terminal*: A 3D device with high-fidelity similar to the Anatomage Table (Spectra, n.d.).
- *Visualization tables*: Anatomage Table, Sectra Terminal visualization table.
- *Dissection tables*: Anatomage Table, Sectra Terminal visualization table.
- *Term*: 15-week instruction.
- *Gross anatomy*: The study of human anatomy using cadaveric dissection, plastic models, and 3D technologies like the Anatomage Table by various branches of medicine, including medical students, PT students, occupational therapy students, chiropractic students, and several others.
- *Learning outcomes*: Learning outcomes refer to the measurable changes or achievements in knowledge, skills, or attitudes resulting from educational interventions like introducing the Anatomage Table to study gross anatomy.
- *Plastinated models*: Plastinated models refer to human cadavers dissected and treated with a unique technique to make them durable and easy for students to manipulate.

Assumptions

The assumptions in this study include the following: First, after requesting archival data, it was assumed that the data provided by the registrar would consist of the

2018 school year. Second, it was assumed that the requested data would include only students in the DPT program and not the Occupational Therapy program because both programs include the study of gross anatomy. Third, it was assumed that the instructors in the Residential DPT program and the Flexible DPT program grade students similarly. Lastly, it was assumed that the content in all the courses examined in this study, namely Gross Anatomy, is the same across all campuses and programs.

Scope and Delimitations

This study examined the measurable outcomes of male and female gross anatomy students enrolled in a DPT program based on written and laboratory exam scores after introducing the high-fidelity visualization Anatomage Table for studying gross anatomy at a local university. The specific elements of the research problem chosen include the lack of understanding of the effects of 3D technologies in the study of gross anatomy due to limited quantitative literature (Triepels et al., 2020). Even though quantitative research has been done on the subject, most studies have used qualitative methodology to examine students' perceptions about the 3D technology and not learning outcomes based on exam scores (Abdulrahman et al., 2021; Alasmari, 2021; Bartoletti-Stella et al., 2021; Clunie et al., 2018; da Silveira, 2021; Darras et al., 2019; Downer et al., 2020; Fu et al., 2022; Miamoto et al., 2021; Sotgiu et al., 2020; Stecco et al., 2020). Addressing these gaps in the literature is crucial for advancing the understanding of the impact of 3D technologies on student learning outcomes in gross anatomy education. Furthermore, the literature was meager regarding studies on the effects of 3D technologies like the Anatomage Table on PT students' learning outcomes.

The boundaries of this study encompass the participants, male and female students in the DPT program in the Flexible and Residential programs on four campuses of a higher learning institution. This study did not include nursing, language pathology, medical doctors, chiropractic, occupational, nursing, or physician assistant students.

In the broader context, the results of this study could have implications for various medical fields, as the study of gross anatomy is fundamental for comprehending human body function and the interconnections between different anatomical regions. The study of gross anatomy includes all the major body systems in the human body, which is emphasized in medical fields such as PT, occupational therapy, medicine, chiropractic, and nursing schools. The findings in this study could provide valuable insights into the potential impact of 3D technologies like the Anatomage Table on student learning outcomes in gross anatomy education, addressing significant gaps in the existing literature. However, it is essential to note that this study focuses exclusively on male and female students enrolled in the DPT program in a local higher learning institution.

Limitations

This study design and methodology are limited to a specific program and institution in the United States, which may limit the generalizability of the findings to other settings. In addition, this study focuses on quantitative data collected from written and laboratory exam scores. It does not include qualitative data informing on students' perceptions based on focus groups or interviews about the use and experience using the Anatomage Table or similar 3D technologies. Lastly, the study does not address potential confounding variables that could impact the results, such as instruction quality or student engagement with the Anatomage Table technology.

Potential biases in this study include sample bias: The sample may not represent the broader population, potentially limiting the generalizability of the study findings. However, excluding participants' identifiers may mitigate some biases, but there could still be inherent biases within the selected sample. In addition, measurement bias may be included in this study since the study relies on written and laboratory examination scores as the primary outcome measures for learning outcomes. This could introduce measurement biases, such as subjective grading or variations in the difficulty level of different exams or terms. These biases may affect the reliability and validity of the results. Lastly, because this study was aimed at analyzing the performance of male and female students before and after the introduction of the Anatomage Table, this focus on examining the effects of the technology on learning outcomes could introduce confirmation bias, potentially leading to a tendency to emphasize and interpret findings that support the expected positive impact of the 3D technology.

Significance

This study contributes new knowledge to the literature on the effects of introducing a 3D technology like visualization and dissection tables such as the Anatomage Table to study gross anatomy, emphasizing measuring PT students' written and laboratory performance. In addition, this study addressed the lack of research in these areas while providing more robust research on the effects of 3D technologies on learning outcomes in PT, nursing, occupational therapy, dentistry, and other medical fields in which gross anatomy is a foundational course.

This study includes several implications for positive social change. First, if the study results demonstrate positive effects in learning outcomes with the use of 3D technologies like visualization and dissection tables for the study of gross anatomy, it could lead to increased demand for this technology in higher learning institutions and improved access to this technology for students in medical professions requiring the study of anatomical sciences. In addition, this study could influence teaching practices and curriculum development by providing insights into using 3D technologies in teaching gross anatomy. Educators and institutions of higher learning in medical fields could make informed decisions about integrating 3D technologies like the Anatomage Table into their teaching methodologies, potentially leading to more effective and engaging educational experiences for students.

Summary

The purpose of this quantitative study was to determine the difference in written exam scores and laboratory exam scores between PT students who participated in the 3D technology for one semester and PT students who participated in traditional instruction at a local university while controlling for undergraduate anatomy scores effects. In addition, this study addressed the lack of research in these areas while adding to the literature robust research on the effects of 3D technologies on learning outcomes in PT, nursing, occupational therapy, dentistry, and other medical fields in which gross anatomy is a foundational course. Finally, this study may help educators and institutions of higher learning make informed decisions about using 3D technologies in teaching gross anatomy. Introducing these technologies can improve student comprehension and performance and could open doors for broader implementation in institutions teaching anatomical sciences. Although many studies have found positive effects on learning outcomes using 3D technologies, most have not evaluated these outcomes through summative assessments like exams. In the following chapter, I will provide a comprehensive review of the current literature regarding the use of 3D technology like the Anatomage Table in several medical fields for the study of gross anatomy, providing insight into the effects of this technology on learning outcomes.

Chapter 2: Literature Review

The problem on which this study was based is that there is a lack of understanding about the influence of 3D technologies like the Anatomage Table in the study of gross anatomy. Specifically, not known are the effects that this technology has on learning outcomes in DPT students and the effects of undergraduate anatomy courses on gross anatomy learning outcomes at the graduate level. In addition, the purpose of this quantitative study was to determine the difference in written exam scores and laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university while controlling for undergraduate anatomy score effects. The relevant constructs selected for this study include 3D visualization technologies, including visualization tables, 3D applications, 3D dissection tables, and the Anatomage Table. All the terms above refer to the same technology used in studying gross anatomy. These technologies use high-definition CT scans from human cadavers combined with complex software applications to give the user a streamlined 3D view of the whole human body, anatomical structures, and body systems for a deep study of human anatomy. The Anatomage Table is a 3D tool that enables the user to dissect cadaveric images, rotate and manipulate anatomical structures and body systems, view human pathologies and imaging, allowing the users to engage in deeper anatomical studies. These technologies serve as adjuncts to cadaveric dissection in medical schools, occupational schools, and nursing and chiropractic schools. Although most past studies have been qualitative, this review includes research using qualitative, quantitative, and mixed-methods methodologies. It is important to note that many studies on the relevant subject have had few participants.

Strategies Used for Literature Research

This literature review includes sources from several research engines and scholarly resources, including peer-reviewed articles, books, statistical reports, educational technology publications, empirical research articles, and seminal works. The relevant literature materials included in this study focused on documents from the past 5 years. Key words and terms used included three-dimensional technologies, 3D technologies, visualization technologies, three-dimensional visualization technologies, dissection tables, three-dimensional dissection tables, Anatomage, Anatomage Table, learning outcomes, and technological learning outcomes. In addition, the following databases were accessed: Cochrane Database of Systematic Reviews, ERIC, Google Scholar, MEDLINE with full text, ProQuest Health, and Education Source (EBSCO).

Theoretical Foundation

The theoretical foundation of this study focuses on two theories: the AF-TEL proposed by Havard et al. (2016) and Facilitating Student Engagement Through Educational Technology by Bond and Bedenlier (2019). The former emerged from an abundance of technological teaching tools and educational theories in constant influx, needing a theoretical framework to help guide and bring together learning approaches, theories, and instructional characteristics. Havard et al. (2016) expressed the need for an integrative approach incorporating cognitive, social, and teaching presence to help elucidate how learning outcomes are achieved using effective and efficient strategies.

This flexibility enabled this framework to accommodate and analyze 3D technologies while emphasizing who is learning, what is being learned, and how individuals learn. The latter examines student engagement and the use of technology. Bond and Bedenlier's assessment includes a bioecological framework, technology microsystems, curriculum, and teacher interventions and how these factors promote student engagement. According to the authors, the concept of engagement is sometimes confused with motivation. Thus, they brought up a definition that aided their proposed framework and included how students use their energy and effort to participate in learning. The authors used cognitive and behavioral characteristics that communicated with internal and external influences and the environment and were related to activities to promote education. These external influences and backgrounds, a new technology introduced into learning the gross anatomy process, could be better understood using the authors' framework.

Use of the AF-TEL in Earlier Studies

Havard et al. (2016) used the AF-TEL to propose e-learning theories to address issues that students face with e-learning technologies (Ochukut & Oboko, 2019). Those problems are relevant to how learners acquire knowledge based on the tools they use for knowledge acquisition. For instance, when learners use 3D technologies, they could be expected to manipulate the tool to extract information that requires simple and complex analysis (Ochukut & Oboko, 2019). Students perform this analysis using the device known as an Anatomage Table because they can access basic anatomical structures with the tool. Adaptive learning systems include content, learner, and adaptive (pedagogical) models. The content model provides a tool that challenges students at different skill levels. The novice student is tasked with lower-level activities, while senior students are assigned more challenging exercises. These activities can also be provided to identical learners during a particular course at different times. For instance, learners need to build moderate to intricate anatomical maps to correlate basic anatomical structures and how these structures interact with the rest of the body, thus improving their understanding of the subject matter. Therefore, the expectation is that higher-knowledge learners correctly explain and discuss the material written or laboratory exams. The data used in my study are retrospective and include several summative and formative assessments for gross anatomy and subsequent courses drawing anatomical knowledge. Therefore, the adaptive model enabled me to link the various evaluations used in the anatomical sciences with the performance for these assessments and use correlation statistics to see if the lower-level courses in anatomy positively affect the upper-level classes.

Furthermore, Havar et al. (2016) described how learning outcomes are a focus in AF-TEL and how the acquisition of skills should align with the skills needed in upcoming generations of students who are used to technological advances in school. This emphasis ensures that students acquire enough knowledge and skills to improve their learning outcomes and use their skills in the future. This process requires active learning, the ability of students to extract the information gained from the tool on their own by actively engaging with their environment, as is the case when using 3D technologies such as dissection tables, like the Anatomage Table. Therefore, in this study I used the adaptable learning theory framework by Havard et al. (2016) to understand the ramifications of 3D technologies like the Anatomage Table, dissection tables, or visualization tables. The adaptable learning theory framework informed my study by allowing me to draw from its two central concepts, namely "who" and "what," and integrate these concepts into the focus of this dissertation.

First, *who* refers to the instructor, the educator having the experience and ability to guide the student to manipulate the 3D interactive tool, like the Anatomage Table. Therefore, the instructor guides the student in learning to use it, extracting the required knowledge from the 3D device and later applying it practically. The 3D tool and the content are described in the adaptable learning theory framework (Havar et al., 2016). Furthermore, instructors assign written and laboratory examinations—the standards used to measure students' knowledge and comprehension before knowledge application—to assess learning outcomes. The ramifications of 3D technology, such as the Anatomage Table, in gross anatomy were examined by reviewing previous studies that have adopted the adaptable learning theory on the same topic.

Use of the Conceptual Framework in Facilitating Student Engagement Through Educational Technology in Earlier Studies

Bond and Bedenlier (2019) used their student engagement framework to explore diverse areas of educational technology through four systems. The authors considered four systems encompassing robust student learning characteristics: macrosystem, exosystem, mesosystem, and microsystem. The emphasis is on the microsystem and the macrosystem because my study focuses on learning outcomes after introducing 3D technology like the Anatomage Table in learning gross anatomy. The microsystem is the fundamental system that students first encounter (the classroom) when learning to use the

3D technology and where they first interact with peers and teachers. Conversely, the macrosystem is the broader technology umbrella encompassing educational institutions and regulatory policies. 3D technologies like the Anatomage Table, dissections tables, and visualization tables are becoming ubiquitous in academic institutions, making it essential to address this area of the adaptable learning theory related to my study. With the advent of technological advances in high-resolution 3D tools in the study of gross anatomy in medical schools, PT schools, occupational therapy schools, and many other allied medical sciences schools, a window of opportunity opened up to allow students to interact with these 3D tools to explore the effects that these technologies have in learning outcomes.

Compared to Bond and Bedenlier (2019), Aldridge and McChesney (2018) had, in an earlier study, established that the microsystem represents other models geared to how technology plays a vital role in engagement and students' success. Both studies indicate that introducing a 3D technology tool to study gross anatomy could positively impact student performance.

Three-Dimensional Visualization Technologies

With the advent of 3D visualization tables like the Anatomage Table for the study of gross anatomy in 2015 (Narnaware & Neumeier, 2021), universities teaching medical sciences grappled with the technology to replace cadavers because the technology is expensive, was not fully developed, and its application not fully understood. However, this 3D technology is gradually entering medical schools, nursing schools, PT, and other medical sciences schools, aiming to adopt the technology required to complement anatomical learning while maintaining or improving students' learning performance. This quasi-experimental research by Narnaware and Neumeier (2021) aimed to determine if the Anatomage Table to study anatomy produced positive learning outcomes in nursing students. The authors enrolled students from two semesters in 2015 (n = 132) who learned anatomy without the Anatomage Table and a comparison group from two consecutive years, 2016 and 2017 (n = 503), instructed in gross anatomy using the Anatomage Table. Additionally, the authors administered a 5-point Likert scale survey with close-ended questions to the students using the Anatomage Table, ranging from outstanding to unsatisfactory, with closed-ended questions to provide information about the effectiveness of the Anatomage Table for learning anatomical structures. Furthermore, midterm and final examinations were given to the students to assess learning outcomes.

The results of the midterm and final exams were statistically compared using 2-sample t tests and repeated ANOVA. Narnaware and Neumeier (2021) set the statistical significance at $p < .05$ for midterm and final exams. The midterm and final examination differences were analyzed using Cohen's "d" and produced values between .10 and .30, respectively. These values represent a small effect size. In the final analysis, the authors found that students using the Anatomage Table significantly improved their scores in all three midterm exams and the final exam and GPA for the course compared to those not using the Anatomage Table. The significance for the first midterm was $p < .05$; for the second and third midterms, $p < .02$; and for the final exam, $p < .05$. The p-value for the GPA was .05. The relevance of this research is that the authors of this study selected students who were not introduced to the Anatomage Table and students who were later introduced to the Anatomage Table. This scheme is similar to the data I used for my study.

Whereas Narnaware and Neumeier (2021) focused on the learning acquisition of nursing students, Bains and Kaliski (2020) aimed to discover the learning effect of introducing various learning strategies, including a visualization and dissection table for studying gross anatomy in PT students. The authors used an anatomy workshop for first-year PT students before the start of the entire semester. The study included 41 students who received anatomy instruction during the workshop and 59 who served as control. Students were assigned anatomical models, plastinated anatomical structures, a visualization and dissection table, and Acland's anatomical structures videos. In addition, students learned several upper and lower extremities structures. Students took a pretest before starting the learning activities and a posttest after they finished them. The researchers compared pretest and posttest results and showed statistically significant ($p < .001$) improvements in the posttests for both the upper and lower extremities tests.

Bains and Kaliski (2020) used multivariate regression analysis to assess significant relationships between the scores obtained during the workshop and gross anatomy laboratory testing scores. The results indicated higher scores with a $p < .001$ for students who participated in the workshops for upper and lower extremity quizzes and the perceived preparation for anatomical studies with a $p < .001$. Their study demonstrated a significant ($p < .01$) confidence between anatomy laboratory scores and participation in the workshop. The authors concluded that the workshop effectively prepared students for further anatomical knowledge using various learning tools, including the visualization table. Furthermore, Bains and Kaliski (2020) indicated that the results demonstrate learning and retention. However, their retention assessment is arguable because the authors did not test the students in this study after they started their first semester.

Although most studies focus on using visualization tables in medical schools, other allied science schools gradually incorporate this technology into their curriculum (Afsharpour et al., 2018). In addition, literature over the past 5 years has shown the positive effects of these technologies in improving knowledge acquisition of anatomical structures (Gloy et al., 2021), as demonstrated by significantly higher test scores of students who used 3D tools versus students who did not use them. Afsharpour et al. (2018) conducted a study to compare student learning performance using a virtual dissection table to study gross anatomy in a Doctor of Chiropractic program. The authors examined the progress and performance during three consecutive academic years. Their analysis demonstrated improvement in scores from cohort to cohort when performing cadaveric dissection tests with a $p < .001$, while no significant differences were found between cohorts for written examinations. As a result of this study, Afsharpour et al. suggested a need for further evaluation of long-term retention of anatomical concepts in subsequent courses requiring knowledge of anatomy, which is one of the areas my study focused on.

Although a strong background in anatomical sciences is required for students to further their education, using 3D visualization technologies is crucial to improve students' decision-making process in medical diagnoses and physical and occupational therapeutic interventions like rehabilitation of musculoskeletal injuries and neurovascular disorders by enhancing student thinking and analytical skills. Barillas (2019) examined the effects of introducing 3D human anatomy software in the study of gross anatomy. The study included 35 students enrolled in the master's level occupational therapy program. Students were assigned to a control and a research group comprising 18 and 17 participants. The investigators did not introduce a control group to the 3D anatomy software. The author used independent sample *t* tests to compare the written and laboratory performance of the two groups. Furthermore, Barillas used nonparametric tests to wage grade performance based on age and learning. The author concluded that the final course grades were higher for the intervention group but not statistically significant (p = .364) when comparing themes with the control group. Furthermore, although the grades for written and laboratory exams were higher for the intervention group, they were not statistically significant (p = .891 and .507, respectively). Lastly, 82% of the subjects indicated that the software helped them understand course materials. This research is significant for my study because the introduction of the 3D software helped students improve their performance on three levels: final grades, written exam grades, and laboratory exam grades, although not statistically significant. Nevertheless, students and faculty alike look for performance improvements, and the 3D tool could be beneficial to achieve that aim.

Building on Barillas's (2019) findings, Rosario (2022) investigated the effects of introducing the Anatomage Table to supplement the al formal study of human anatomy. The author enrolled 216 first-year PT students who attended the fall semester from 2016 to 2019 academic years and placed students into two cohorts. The first cohort of 108 students (male = 29; female = 79) did not use the Anatomage Table. The second cohort of 108 students (male = 23; female = 85) also used the Anatomage Table to study gross anatomy. The students were required to study four units of human anatomy. The first unit included the back and upper extremities. The second unit comprised the lower extremities, the third was the thoracoabdominal and pelvic regions, and the fourth was the head. The researchers used a one-way ANOVA to compare both groups and a *p*-value of .05. The results demonstrated an increase in grades but were insignificant ($p = .35$) (Rosario, 2022).

Equally important is the study by Fleagle et al. (2018). They investigated the preferences and learning outcomes of 242 students from 2011 to 2013 before a flipped model of instruction was implemented (pre-flipped model) and 241 students from 214 to 2016 (flip model implementation) regarding the use of 3D technology anatomical atlas figures and dissection videos. A flipped class model focuses on students' preparation before class and laboratory time. Preparation before class includes studying the anatomical structures to be dissected during laboratory time, taking a short, graded quiz, and reviewing the anatomical structures assigned for the class using 3D videos and anatomical atlas figures. Students prepared before lab activities for an average of 27 minutes. The subjects graded the 3D tool and the critical anatomical atlas structures as the most assisted students. Elaborating on Fleagle et al.'s (2018) findings, Baratz et al. (2019) compared the effectiveness of the Anatomage Table, a visualization and dissection technology for studying anatomical structures. The authors used a crossover design including 16 medical students randomly assigned to either the Anatomage Table or to perform cadaveric dissections of the pelvis and perineum (PP) or the musculoskeletal system (MSK). After learning from their assigned dissection group, students would cross over to the other modality (the MSK group to the PP group and vice versa). For statistical analysis, the authors used several statistical tests to analyze the results. The authors used the Shapiro-Wilks tests to assess the normality of the results and *t*-tests on results for the pre-and post-written tests and, pre- and post-lab exams, and quizzes that did not show a normal distribution. Further, the investigators used Mann-Whitney U tests to analyze the resulting data (Baratz et al., 2019).

Furthermore, students answered a two 3-point Likert scale survey before and after the laboratory activities. The pre-lab survey assessed the degree of comfort with the material covered during the intervention, the enthusiasm for conducting the dissection, and how prepared they felt for it. The students were evaluated via a post-lab survey to assess how much they thought they learned, the degree of ease/difficulty of the dissections, and the degree of excitement about returning to the subsequent dissection (Baratz et al., 2019). In addition, the authors found that students who took the (PP) lab exam using the Anatomage Table performed statistically better (p-value = .01). However, when the students took the MSK lab exam using the Anatomage Table, the results were higher but not statistically significant, with a p-value = .39. Thus far, both studies suggest that using a 3D visualization tool like the Anatomage Table helps improve student performance among anatomy class students.

In addition, Narnaware and Neumeier (2021) examined the effect of Anatomage, a 3D dissection table, on nursing schools' student performance. Their methodology approach was quasi-experimental. The cohort included 635 nursing students divided into two groups—an experimental group with more than 500 individuals and a control group of 134 subjects. Their statistical analysis indicated a significant increase ($p < .05$) in grade scores for all the examinations and the final GPA for the subjects in the experimental group when compared with the control group (Narnaware & Neumeier, 2021). The quasi-experimental nature of this research informs my study since the authors used a group of students who were not taught anatomy using the Anatomage Table and compared their performance with another group of students who were instructed in anatomy using the Anatomage Table. Tenaw (2020) explored the usefulness and functionality of the Anatomage Table for learning gross anatomy in an earlier study to understand better the impact of 3D technologies on learning gross anatomy at a medical school. Although the study included 89 second-year medical students, 51 males and 38 females, the author did not differentiate the outcomes from each gender. Ultimately, the results indicated that students were satisfied with the new technology in many areas, including visualization of anatomical structures, understanding relationships between different anatomical regions, and improved knowledge of gross anatomy using the dissecting tool, among other features (Tenaw, 2020).

Moreover, in the study by Deng et al. (2018) at a medical school, the authors examined the effects of a digital virtual simulation (DVS) application to teach gross anatomy to 120 medical students in four classes. The control group received traditional teaching using cadaveric dissection, while the two classes used the digital virtual simulation application. Deng et al. (2018) concluded that laboratory testing and written examination scores were significantly higher in the researched group than in the control group, with $p < .01$ and $p < .001$, respectively. Agreeing with Deng et al. (2018), Ben Awadh et al. (2022) enrolled 329 new medical students to investigate their perceptions using a mix-method methodology comparing the 3D technology intervention, the Sectra Terminal visualization table, with cross-sectional views of thoracic anatomy from a two-dimensional control using cross-sectional views of the same thoracic anatomy. The authors used a 7-point Likert scale to determine the extent of the learning challenge between the two interventions. They found that the anatomical cross-sectional images in the visualization table challenged students more than anatomic dissection due to the complexity of cross-sectional images, which show partial views of a series of organs. In addition, cross-sectional anatomy posttests scores were significantly ($p < .001$) superior for students using the visualization table compared to those using two-dimensional images.

Although several studies about the effects that visualization tables in the anatomy curriculum have on students' performance are subjective, Awadh et al. (2021) used a comprehensive approach to explain the impact of a multimodal 3D visualization table in first-year medical students learning gross anatomy. The results indicated that the visualization table challenged students more than anatomic dissection. Triepels et al. (2020) reported similar results. Their systematic review (Triepels et al.,

2020) examined whether 3D technology improves the understanding of anatomical structures among medical students compared to standard instruction methods using cadavers and anatomical models. The authors selected 1148 articles, from which 21 were found relevant for the systematic review.

In summary, the articles indicate that using a multi-modal method of instruction, such as cadaveric dissection and 3D tools like the Anatomage Table, could improve the ability of students to identify cross-sectional anatomical images, thus improving learning outcomes. Of the 21 articles, 15 included research on 3D tools like visualization tables, dissection tables, and the Anatomage Table or a similar 3D tool. Furthermore, most articles (47.6%) used a mix-methods methodology that included Likert scale surveys and written tests. Nearly 29% of the papers used only written tests and quiz scores to measure learning outcomes; the remaining used subjective Likert scale surveys to determine students' perceptions about the benefits of 3D technologies in studying gross anatomy.

Furthermore, nearly 52% of the articles demonstrated that the 3D tool was significantly better than traditional methods of studying gross anatomy, while 23.8% indicated that 3D tools were not considerably better. Only two studies (.095%) showed that conventional methods were significantly better than using a 3D tool to study gross anatomy. Therefore, the authors concluded that 3D technology outperformed traditional study methods. Further research is necessary because only some relevant studies investigate 3D technologies' impact on learning outcomes, which is one of my study's areas.

In addition to the previous studies, such as Deng et al. (2018), Jamil et al. (2019) examined the effects of three 3D visualizations on laboratory and written test performance. The study included 67 medical students divided into two unequal groups. The experimental group comprised 25 students, 11 males and 14 females, while the control group included 22 males and 20 females. The experimental group participated in studying mental rotation ability tests (spatial fluency) and a 3D tool to learn anatomical structures. The control group was not trained in 3D spatial fluency during anatomical studies and did not use the 3D tool to study anatomy.

Spatial fluency is the ability to rotate 3D objects in space, a skill required to study gross anatomy. The authors used a *p*-value calculated by paired student's *t*-test to calculate the difference between pre-test and post-test performance within each group (Jamil et al., 2019). The mental rotation ability test scores demonstrated a significant improvement ($p < .017$) after the training, and male participants recorded higher scores than females ($p < .016$). Written and lab anatomy test scores were compared and showed significance in favor of trained students. The results were calculated by paired student *t* tests, indicating the difference between pre-tests and post-test performance within each group. The trained group demonstrated significance with a $p < .002$, while the untrained group showed a $p < .005$. Ultimately, the authors acknowledged that expanding research on this subject in all areas of medical training before and after internships will be beneficial to gathering evidence of the role of spatial fluency in the study of anatomy and medical training.

While students using 3D visualization tools to learn anatomical structures face new challenges, the tools are promising in learning performance. Mitrousias et al. (2018) examined the effectiveness of 3D software in studying the anatomy of the upper limbs. Seventy-two first-year medical school students were enrolled in the study. Forty students learned gross anatomy using cadaveric prosections, and the remaining 32 used the BioDigital Human (BDH) software, an interactive 3D platform to study human anatomy and pathology. The results indicated that students using the BDG 3D software performed better than those using prosections (dissected sections of cadaveric specimens, such as an entire arm and shoulder, etc.) with a $p = .05$. Cohen's $d = .5$. They demonstrated a medium-sized effect when the two means of students' scores.

Furthermore, the authors used *t*-tests to compare the results of students' exam testing performance (Mitrousias et al., 2018).

Other Applications of 3D Technologies in the Medical Field

Although 3D visualization technologies are used in the medical field to study gross anatomy, this technology has other applications. For instance, the study by Stecco et al. (2020) enrolled eight participants divided into four groups. Group 1 consisted of two medical radiology students; Group 2 included two junior medical radiology residents; two senior residents formed Group 3. Group 4 consisted of two staff radiologists. Researchers showed CT scans of Le Fort fractures, followed by a review of the 3D-generated models using the Anatomage Table. The study assessed if the participants could accurately identify fracture grades if they were confident in their diagnosis and intra-reader agreement. Cohen's test was used to evaluate the intra-reader reliability. The authors used a Likert scale questionnaire to measure qualitative results. Stecco et al. (2020) concluded that the Anatomage 3D table provided medical students, junior and senior residents, and staff radiologists with the appropriate knowledge to accurately diagnose and classify complex injuries of the face and maxilla. In addition, the users were more accurate in diagnosing the three types of maxillofacial fractures compared to CT scans alone. The authors used four other parameters, including Cohen's grading system, to assess the intra-reader agreement on the maxillofacial fractures, confidence in diagnosis, anatomical resolution, and handling of 3D models (Stecco et al. 2020). In addition, the intra-reader agreement reached 90%. The authors used a Likert scale for qualitative analysis, showing that seven out of eight participants were nearly perfect in their assessment of maxillofacial fractures and substantial agreement in 1 out of 8 participants.

Furthermore, according to the survey, Stecco et al. (2020) concluded that the participants preferred the 3D Anatomage Table over the CT scans. Building upon the previous study by Stecco et al. (2020), Lin et al. (2020) also examined the effects of 3D visualization technology and CT scans for surgery in the pancreas by gastrointestinal surgery students. The authors enrolled eighty-eight surgical residents (77 males and 11 females) randomly assigned to two groups of 44 students each. One group used the CT scan station, and the other used the 3D dissection table station. The activities on the stations consisted first of receiving instruction on resecting a tumor in the pancreas. After that, one group studied the case scenarios using either the 3D dissection tool, the other using the 3D dissection tool, and another using the 2D CT scans. At the end of the instruction and active learning activities, both groups took the same test, which showed images of the pancreas in a case study format. They also answered a 14-item questionnaire using a 5-point Likert scale. The authors concluded that the anatomy and diagnostic knowledge scores were not statistically significant. However, the mean scores from the questionnaire referring to stages of the pancreatic tumor, planning of surgical approach, and benefits of using the 3D technology were significantly higher in the group using the 3D dissection table.

The systematic analysis by Sotgiu et al. (2020) examined multiple studies using various tools to study neuroanatomy. The authors used 3D visualization, 3D models, flip classrooms, and other devices in their analysis. Their systematic study included 276 citations, from which only 18 studies were selected. The authors used primary and secondary outcomes to identify the benefits found in their research. The authors defined primary outcomes as "an improvement in recognition of anatomical structures and the understanding of organ relationships, while secondary outcomes were defined as "improvements in long-term retention of knowledge and the levels of student satisfaction." (Sotgiu et. al., 2020, p. 6). Five of these 18 studies used 3D technology to achieve primary outcomes, meaning that students improved their ability to recognize anatomical parts and were able to understand the relationships between organ systems better. One study demonstrated significant ($p < .01$) improvements in understanding intricate neuroanatomy and how the multiple areas of the brain and nervous tissues relate to each other. Only three studies achieved secondary outcomes. In brief, the authors concluded that 3D technologies enabled students to achieve better outcomes than the other tools examined. The technology was also influential in experiential domains such as student satisfaction and the likeability of 3D technology.

Dental schools also use 3D technologies to study gross anatomy instead of cadaveric specimens or in conjunction with them. In this regard, da Silveira et al. (2021) performed a cross-sectional study examining the effects of using a 3D technology visualization system in studying a dental school's temporomandibular joint (TMJ). The authors used two teaching strategies. One uses traditional cadaveric dissection and theoretical instruction; the other uses the Anatomage Table and academic education. The study included 41 dental school students assessed after participating in the teaching strategy in which they were included before and after class, after practicums on donor bodies, and after using a digital anatomy table. The statistical results, which compared the results between the two strategies, were analyzed using the Kruskal-Wallis test. The test indicated that the median test scores showed a significantly higher ($p = .002$) performance when using the Anatomage Table versus cadaveric dissection (da Silveira et al., 2021). Furthermore, the authors established that students' perceptions were favorable toward the new technology and could be used in anatomy curricula. Finally, the authors recommended further research on the efficacy and best practices of implementing a 3D tool like the Anatomage Table (da Silveira et al., 2021).

Previously, it examined the use of 3D technology for surgical training by medical doctors and the study of TMJ anatomy by dental school students. However, it is essential to consider the impact of 3D visualization tools in other disciplines, especially if they require PT and hand-approach interventions. For instance, besides being required to learn gross anatomy for apparent reasons, midwives need hands-on training. Nevertheless, this proves difficult due to the lack of experience before going into clinical internships. Thus, 3D technology enables them to train and evaluate their performance. Downer et al. (2020) study used 3D software for midwifery education and assessed its efficacy in training midwives. The authors recruited 14 students and tested them in the knowledge of human physiology and the anatomy of the placenta using a five-point, eight-question Likert scale to assess the perceptions of the subjects about the experience, knowledge gained, and discomfort experienced with the tool (Downer et al., 2020). The authors found that most of the responses were optimistic regarding the use of the technology and its positive effect on knowledge acquisition. Furthermore, 64% of the students strongly agreed that the 3D technology enabled them to achieve learning outcomes. Summing up, the authors suggested, for further inquiry, a randomized study with a more significant number of subjects to determine if the 3D technology could improve learning outcomes and knowledge retention.

Likewise, medical schools and undergraduate programs use 3D visualization tools like Visible Body or Complete Anatomy. In this regard, Chakraborty and Cooperstein (2018) examined an anatomy application loaded onto an iPad at an undergraduate program teaching Anatomy and Physiology. The authors included more than 300 nursing, exercise science, physical education, and biology students. They examined the effect on student performance based on test grades and a Likert-scale survey to gather students' perspectives on using the application. The results indicated student grades improved (Chakraborty & Cooperstein, 2018). Equally, Houser and Kondrashov (2018) examined the effect of using various tools to teach gross anatomy in a medical school. One hundred seventy-two students answered a Likert scale survey, which included four modalities: cadaveric dissection, virtual multimedia dissector, a Virtual Human (VH) dissector, and ultrasonography. Of the four modalities, cadaveric dissection and the virtual multimedia dissector scored significantly higher ($p < .05$) than the VH and ultrasonography technologies (Houser & Kondrashov, 2018). Even though the authors did not measure the effect on learning outcomes, they concluded that using multiple modalities to teach anatomy in medical schools benefits student learning.

Although single studies help examine this dissertation's subject, systematic reviews aid in evaluating relevant literature by identifying, analyzing, and synthesizing the research conducted in individual studies while making the evidence readily accessible to other researchers. The Bogomolova et al. (2021) meta-analysis examined 3,934 articles, selecting 13 randomized control studies for the analysis. The studies included 3D stereoscopic anatomical models, 3D monoscopic models, and 2D images of anatomical structures. Six out of 13 studies compared student learning outcomes when using interactive stereoscopic 3D technology (using 3D goggles) with interactive monoscopic 3D technology, similar to the Anatomage Table. The authors found a significant difference between the two technologies in favor of the 3D stereoscopic technology ($p < .0001$). Furthermore, seven of 13 studies compared student learning outcomes using non-interactive stereoscopic 3D tools and 2D images of anatomical structures. The authors did not find a significant difference between the two modes of assessment (Bogomolova et al., 2021).

In summary, Bogomolova et al. (2021) found that stereoscopic 3D technology is valuable in studying anatomy because it improves understanding of anatomical structures. Furthermore, the authors acknowledged several limitations, including the difference in stereoscopic quality in different studies that could affect learning outcomes.

Analogous to the research by Bogomolova et al. (2021), the systematic review by Santos et al. (2022) about the technological tools used for teaching and learning gross anatomy in medicine shed light on the effect of these tools on student performance. The authors identified 102 relevant studies out of the 875 in their initial search and categorized them into four main areas: 3D printing, Extended Reality, Digital tools, and other digital technologies. Their analysis found that the technologies examined provided a positive or a neutral benefit in studying anatomy. Two studies demonstrated a positive effect on learning outcomes when the Anatomage Table, a 3D dissecting tool, was used. The authors used no statistical analysis of essential differences. In conclusion, the authors expressed that the technologies that seemed more practical for implementation included internet-based technology and 3D printing of anatomical models.

Although the impact and effect of introducing a technological tool to learn gross anatomy have been scantly examined from a quantitative perspective, the result of this preliminary research points out the positive influence on student performance (Deng et al.; Jamil et al., Mitrousias et al., and Narnaware et al.) First, however, it is necessary to include how these promising results on knowledge acquisition and student performance in gross anatomy influence student performance after using a 3D visualization table in upper-level courses requiring mastery of foundational gross anatomy courses. In this regard, Shaffer et al. (2018) examined the ramifications of physiology prerequisites in upper-level anatomy and physiology courses, including human physiology laboratory, human anatomy, and molecular pharmacology. The study used data from two terms during the 2015 and 2016 school years comprising 377 students. The authors examined student performance in Biological Sciences Physiology, Molecular Pharmacology, and Human Anatomy and how their respective prerequisites (BioScience Human Physiology and Pharmacology Science Human Physiology) affect their performance.

The study results were mixed, concluding that substantial improvements in follow-up and prerequisite courses might not affect learning outcomes in upper-level related courses (Shaffer et al., 2018). However, the authors mentioned that there could be reasons for the lack of significant differences in knowledge retention performance, such as students experiencing difficulty applying prior knowledge in a course with different and perhaps unrelated material because of the relationship of the information they learned in the prerequisite course was not explicit, thus difficult to apply. Furthermore, the lack of positive results could be because students' knowledge retention fades over time, and instructors did little or no review of prior material.

Shaffer et al. (2018) suggested curricular mapping to highlight commonalities between prerequisite courses and follow-up coursework to better identify their effects on student performance. Although the results were mixed, it is essential to note that human physiology and molecular pharmacology do not require gross anatomy knowledge. Therefore, selecting follow-up courses that integrate gross anatomy knowledge, like musculoskeletal and movement science, is more appropriate to examine in the context of learning outcomes. This data is relevant because my study focuses on gross anatomy's effect on upper-level courses relying on gross anatomy knowledge.

Similarly, Paech et al. (2016) underlined the significance of adding a visualization table to the anatomy study. Their study focused on the performance of 238 first-year introductory gross anatomy students using a dissection visualization table. The authors divided the students into three groups. Group 1 received anatomy training using cadaveric images obtained by CT scans on the visualization table and an instruction-based seminar on reading and interpreting radiological images. Group 2 only attended the seminar, and Group 3 received traditional anatomy training. Statistical analysis included a 5-point Likert scale with questions on vascular anatomy, and nonparametric Friedman tests to determine significant differences between groups and pairwise comparisons using the Student-Newman-Keuls (SNK) to obtain mean differences. The authors set the level of significance to $p < .05$.

The test results indicated a significant ($p < .001$) improvement in grade outcomes performance in the major anatomical systems, including the upper extremities, abdomen and thorax, osteology, head and neck anatomy, and vascular structures for students exposed to CT scans on the visualization table versus students not exposed to the technology (Paech et al., 2016). In conclusion, the authors stated that 3D dissection tables to study gross anatomy significantly improved students' learning performance. Furthermore, CT scans were an ideal complement to cadaveric dissection but should not be considered a substitute (Paech et al., 2016).

In another study by Paech et al. (2018), the authors enrolled 138 medical students in two groups. A control group of 78 students did not use CT scan 3D technology, and an intervention group of 58 students used CT scan 3D technology. All students were instructed on the anatomy of the head, neck, thorax, abdomen, and extremities. They were examined via four multiple-choice tests of 15 questions each after being introduced to the anatomical structures via conventional teaching (non-CT scan 3D technology) and using the technology. The intervention group achieved significantly higher scores with a $p < .01$ in the head and neck anatomy. However, no significant differences were found between the intervention and the control group regarding the anatomy of the thorax, abdomen, and extremities. The author concluded that using CT scan 3D technology significantly improved learning outcomes in the study of head and neck anatomy.

Accordingly, the cross-sectional descriptive study by Alasmari (2021) enrolled 78 medical students to examine via a questionnaire the usefulness, benefits, improvements in learning, improvements in understanding of anatomical relationships, and visualization of body systems through the rotation of 3D images using the Anatomage Table. The results indicated that 81% of the participants preferred the 3D tool in addition to cadaveric dissection. About 73% of the students stated that the Anatomage Table benefited their studies and improved their engagement with the anatomical structures and with their peers. Furthermore, most indicated that dissecting in different planes improved their understanding of anatomical structures, their relationship with other structures, and the location of other internal organs. In addition, 90% of the students noticed that using the rotational capabilities of the Anatomage Table improved the visualization of the various body systems. The authors encouraged further studies to investigate the effectiveness of 3D dissection tables as an addition to cadaveric dissection for gross anatomy instruction and learning. In addition, those studies could explore the difference in learning performance between students using the 3D dissecting tool and cadavers for dissection.

Likewise, the comprehensive review by Bartoletti-Stella et al. (2021) examined the impact of the Anatomage dissection table, a 3D visualization technology, on studying anatomy. The study included 70 articles published within the last 15 years, with data divided into three main areas: student learning impact, clinical practice, and usefulness during the COVID-19 pandemic. The authors found that several studies demonstrated positive learning outcomes in the area of student learning impact. The authors found comparable learning outcomes in the pelvis and musculoskeletal anatomy knowledge in clinical practice when using 3D technology and cadaveric dissection. They also found the 3D device a good resource for learning gross anatomy in medical schools (Bartoletti-Stella et al., 2021). Although the study acknowledged the limitations of the 3D visualization tool, the results were positive and significant. In synthesis, the authors concluded that the Anatomage Table is expensive and lacks children's cadaveric images and nerve tissue details. However, the Anatomage Table can potentially improve learning outcomes due to the realistic nature of the images, the application in radiology and surgery, and the structures to study pathological structures.

Moreover, the cross-sectional study by Abdulrahman et al. (2021) examined first-year medical students' perceptions and attitudes after being introduced to their learning experience of three different tools to learn anatomy. The tools included plastinated human anatomical structures and the Anatomage Table. Two hundred eleven students attended two lectures, followed by a laboratory session. After the lectures and laboratory session, the authors assigned the students to three similar groups, A, B, and C. Group A used the Anatomage Table, Group B used the plastinated models, and Group C used the Anatomage Table and the plastinated models. The three groups learned the same information. All the participants took a laboratory exam of 10 questions, and only 15 students took 15 closed-ended questions using a Likert questionnaire. The data were analyzed using a one-way analysis of variance to compare the mean values. The means demonstrated a significant difference between using the Anatomage Table and the plastinated models versus the Anatomage Table alone or the plastinated models alone. In sum, even though using both modalities yielded higher results, including either of the technologies improved knowledge acquisition.

In line with Abdulrahman et al. (2021), Darras et al. (2019) examined the educational value of using a virtual dissection table in medical sciences. The authors enrolled 105 first-year medical students in the study to identify their perceptions about the effectiveness of the technology. The authors used a Linkert scale questionnaire asking three main questions: 1. Did virtual dissection improve your understanding of clinical relevance in anatomy? 2. Did the knowledge of radiological anatomy improve? 3. Did the virtual dissection help understand the visuospatial relationships of anatomical structures? For the first question, the participants strongly agreed, with 77% for the second question, 75.9%, and for the third question, 64.4% strongly agreed. Additionally, 88.5% of the students “agreed” or “strongly agreed” that using the virtual dissection tool enhanced their understanding of pathological causes of human disease. Although the results are not quantitative, they point to improving learning outcomes, first because there was a strong agreement on the first and third questions regarding understanding, which is primordial to improving outcomes.

In a related study involving medical students, Fu et al. (2022) performed an analysis focused on introducing multiple instructional tools for studying human anatomy, including visualization technology tables. This investigation included 141 participants from a medical school for two consecutive years divided into four groups. First, two received multi-tool instruction, including a cooperative activity between the students using the jigsaw model. Next, a group of students learned a specific anatomical area, and another group learned a different one. After that, they exchanged the corresponding knowledge cooperatively. The other mode of instruction included using a visualization table called the Chinese Digital Human Anatomy System (CDHAS). Finally, the control group received the standard method of teaching.

The results were significant for knowledge acquisition, with a *p*-value of $< .001$ for the scores obtained in laboratory testing compared with the control group. However, the results from the written exam testing were insignificant for the two groups. Furthermore, 100% of the students believed the multi-faceted learning style was better than the traditional study method. In conclusion, the authors encouraged a long-term evaluation of the instructional tools since the study was not comprehensive enough due to limitations during the COVID-19 pandemic.

In a similar study by Wang et al. (2020), the authors examined the effects of studying anatomy when using three learning strategies, including 3D visualization, Mixed Reality, and text-only. Fifty-two medical students (34 males and 18 females) participated in this randomized study to measure theoretical knowledge. The authors randomly assigned the participants to three groups: Group 1 ($n = 18$) used textbooks only, group 2 ($n = 15$) used a 3D tool for the study of anatomical structures, and Group 3 ($n = 19$) used Mixed Reality (MR) to study anatomical structures. The researchers administered two tests to the students, one after the intervention with the tools and a second test 30 days later and psychometric tests to explore the subjects' memory, reasoning ability, and focus. The results did not include the difference in performance between males and females.

Statistical analysis included Analysis of Variance (ANOVA) with Bonferroni post-hoc analysis to determine if the treatment groups' results differed in performance on the test's three sections evaluating nominal, spatial, and mixed sections of the first anatomy exam. The one-way ANOVA revealed a significant difference ($p < .001$) for nominal questions for the first anatomy test when comparing learning groups. Furthermore, there was no statistical difference in learning performance when comparing spatial-type questions in the learning groups. The authors indicated that the Mixed Reality group performed better regarding theoretical retention at thirty days but did not perform well in theoretical knowledge. However, long-term retention indicated significant differences when anatomy scores improved over time ($p = .006$). In addition, students in the 3D and Mixed Reality groups showed superior engagement. In summary, the authors concluded that their study suggests that 3D visualization technologies could improve knowledge acquisition and carry-over knowledge in studying anatomical structures.

Likewise, Boscolo-Berto et al. (2020) used different learning tools and examined the performance of 30 second-year medical school students, 12 females, and 18 males. The authors randomly divided the participants into two equal groups of 15 students. The experimental group used the Anatomage Table, a 3D dissection tool, and the control group studied with books with anatomical pictures and descriptions. After the initial intervention, using books with anatomical structures and the 3D tool, both groups engaged in cadaveric dissection. After that, all the participants took a test on bones, muscles, blood vessels, nerve tissue, and the proximal and distal areas of the forearm.

The post-test scores showed superior performance with a low power significance of $p = .62$. Furthermore, > 70% of the students agreed that the Anatomage Table made studying anatomy more engaging and beneficial to their learning than textbooks and anatomical atlases (Boscolo-Berto et al., 2020). Although the results did not reach a high level of significance, perhaps due to the small number of participants, the results are nevertheless positive and should be considered.

In contrast to the study of the multi-instructional tools by Fu et al. (2022), O'Rourke et al. (2020) examined a visualization technology using CT scans similar to technologies such as the Anatomage Table and Visible Body. The study included first and second-year medical students. The group from the first year ($n = 79$) and the second year (n = 59) engaged in self-directed activities in gross anatomy. One hundred thirty-eight participants were enrolled and completed a testing series before and after the introduction of laboratory sessions. Students focused on the anatomy of the paranasal sinuses in two different settings (traditional vs. 3D). The totality of the participants took a pre- and a post-test. Based on regression analysis, the authors concluded that students without 3D experience were less likely to perform well in tests of anatomical knowledge ($p < .05$). However, for students with experience using the 3D technology, the model interfered with students in this group who needed more anatomy knowledge of the anatomy studied in this experiment ($p < .001$).

Fu et al. (2022) used regression analysis to elaborate on post-learning results. The 3D visualization technology was more difficult for those students who needed to gain experience using the technology. However, the authors indicated that 3D technology encourages learners to use the standard tools typically used in anatomy labs. They also concluded that students should learn to use the technologies before starting regular curriculum work to maximize the benefits of the 3D devices introduced to learn anatomy.

In the same way, Fulmali et al. (2021) examined the performance of medical students using cadaveric dissection and virtual dissection using a 3D dissecting table. Their comparative cross-sectional study comprised 200 medical students evenly divided into two groups of 100. Group A, the intervention group, and Group B, the control group, received equal didactic instruction on the triangle of the neck followed by dissection of the same area of the body. However, Group A used 3D dissection before cadaveric dissection, and Group B did not use the 3D dissection tool before cadaveric dissection. After the dissections, both groups took a multiple-choice question to assess their understanding of the topic and the effectiveness of the Anatomage Table (3D dissecting tool).

Fulmali et al. (2021) used paired *t*-tests to compare the pre-and post-tests of groups A and B. The results indicated that students exposed to the Anatomage Table before cadaveric dissection performed significantly higher $p < .001$ than those who did not use the Anatomage Table before cadaveric dissection. In addition, the difference between the pre-test and post-test means was significant ($p < .001$) for both groups. However, the unpaired *t*-tests showed a lower significance level between group A.

Casallas and Quijano (2018) also investigated the impact of 3D technology on gross anatomy instruction in a medical school. Eighty medical students participated in the study, divided into two equal groups of 40 individuals. Group A used the 3D technology tool to examine heart anatomy, and Group B utilized textbooks and other standard printed anatomical materials (Casallas & Quijano, 2018). Both groups received didactic lectures with the same content and took a didactic and a laboratory test after the instruction. The results indicated a superior performance from Group A in all areas.

The results showed that the average grade for Group A was 4.3, 14% higher than for Group B, 3.6. In addition, 97.5% of students in Group A passed the exam, while only 75% in Group B passed, a 25% difference. Furthermore, the number of individuals obtaining the highest score was in Group A, with approximately 22.5% (Casallas & Quijano). In conclusion, the authors stated that students found the 3D dissection a valuable tool for learning the heart's anatomy while improving academic performance.

These findings are similar to other studies where 3D technology was used to enhance learning outcomes.

Expanding on Casallas and Quijano (2018), Kažoka and Pilmane (2017) examined the impact of the Anatomage Table on teaching and learning anatomy at a medical institution. Two hundred students participated in the study. The authors divided into groups of 100 students each (100 medical students and 100 dental students. The participants used dissection tools to perform incisions in different areas of the body, remove body tissues like muscles and bones, and then return them to their anatomical position. After the dissections, students answered questions, including the advantages and disadvantages of virtual dissection in the Anatomage Table. The questionnaire used questionnaires with free answers to collect data.

Although the study was qualitative and the authors mentioned positive learning outcomes, it did not offer a Likert scale for question analysis. In conclusion, Kažoka and Pilmane (2017) stated that students could recognize, dissect, and remove anatomical structures and establish relationships. In addition, students could examine different body parts from different vantage views, which are often difficult to assess in cadaveric dissections where the body part is exposed but not entirely removed from the body (Kažoka & Pilmane, 2017). In summary, the participants reported that the anatomical structures were more easily visualized, thus contributing to their learning and comprehension of the subject.

In a similar study by Darras et al. (2019), the authors examined the general attitude of first-year medical students toward implementing 3D technology through a virtual dissection table (VDT) into the medical curriculum. The study included 292 medical students. In addition, the study included six gross anatomy laboratories with VDT technology. Students answered a 5-point Likert scale with three questions. The results showed that most students (78.7%) believe the VDT improved their understanding of gross anatomy.

Similarly, 78.7% agreed that the VDT positively influences its clinical application in the future. Furthermore, 73.8% of the subjects stated that the VDT was helpful in the anatomy laboratory. According to the survey results, the authors concluded that the VDT was a valuable tool to use in conjunction with cadaveric dissection. They also suggested further research to determine if combining a VDT and cadaveric dissection could significantly affect learning outcomes.

Previously, Darras et al. (2019) used a 5-point Likert scale to examine students' general attitudes toward implementing 3D technology in the study of gross anatomy. Alternatively, Ben Awadh et al. (2022) used a multi-modal approach to study the effect of a 3D visualization table to analyze anatomical structures. They compared it with 3D printed models and a 2D standard method used as a control group. The mixed-method experimental approach focused on the challenge that 3D visualization virtual technology and a 3D printed anatomical model presented while learning gross anatomy compared to a standard two-dimensional mode of learning anatomy. The analysis required a seven-point Likert scale survey answered by 319 medical students.

The results indicated a $p < .001$ regarding the difficulty of identifying clinical images compared to surface and gross anatomy. Pre-testing and post-test analysis also demonstrated a $p < .001$ regarding significant improvements in performance in the study of cross-sectional anatomy. Furthermore, pre-testing and post-testing calculated from test scores were significant ($p < .001$) for participants using 3D visualization and 3D models compared to students using the 2D activities. In brief, the authors established that a multi-modal approach to learning cross-sectional anatomy improved students' performance and understanding of anatomical features and suggested further study, exploring similar strategies for learning cross-sectional anatomy Ben Awadh et al. (2022).

The preceding study examined the performance of medical students using a multi-modal approach when learning cross-sectional anatomy. In contrast, Whited et al. (2021) examined whether learning gross anatomy using a 3D anatomy table by Nurse Practitioners (NP) and Doctor of Nursing Practice students improves their understanding of anatomical structures during patients' health assessments. Seventeen students participated in the study to assess anatomy knowledge of children's heads, eyes, ears, and noses and to understand anatomical systems. After learning the anatomical structures, students took a pre- and a post-test. The authors analyzed the data using a Mann-Whitney *U* test with independent samples. The results demonstrated significant improvement in overall test scores.

Furthermore, the results indicated that 3D technology enhanced DNP and NP students' assertiveness of children's anatomy and organ systems. In synthesis, the authors found that 3D dissection technology significantly improved the subject's ability to understand pediatric anatomy. In addition, they proposed a large cohort study to examine the effect of this technology further when learning pediatric anatomy.

In a related study by Ceri (2021) on the effect of a 3D dissection table, human dissection atlas, and plastic models of human anatomy, the author enrolled 120 medical students (62 males and 58 females) who voluntarily participated. The students received a practical and theoretical lesson on neuroanatomy, cardiovascular, and digestive systems, followed by a final 10-minute examination of the learned anatomical structures. The authors randomly assigned 40 participants into three groups of 40 students. The author assigned 40 students to the human anatomy atlas group, 40 to the human anatomy models group, and 40 to the 3D human anatomy app group. The mean of the final examination was higher in the group assigned to the 3D tool than in the two other groups for each anatomical region studied.

The results based on the One-way ANOVA for practice groups according to the anatomical areas showed a significant difference ($p < .004$) when comparing the 3D tool users vs. those not exposed to the technology. The author concluded that the students in the 3D human anatomy app group performed better than the other two groups. Although the authors did not offer any suggestions for further study, it will be essential to follow up with quantitative research clearly defining the learning outcomes based on the performance on written and laboratory examinations. In closing, the authors determined that 3D apps for the study of anatomy should be made more accessible because this technology has the potential to improve learning performance.

Although the results of the study by Ceri (2021) were significant, many other authors have found effective results regarding the positive effect on student learning outcomes during the anatomy study. In this regard, the randomized controlled study by

Rosa et al. (2020) explored the impact of students' learning the anatomy of the liver and its biliary ducts using a 3D dissection table and cadaveric dissection. The authors enrolled 20 students (7 males and 13 females) from 4th-year medical school randomly assigned to two groups (10 – 3D dissection table and 10 – Real liver). The students took three tests, one before the intervention and two post-tests, about the anatomy of the liver and its ducts. In addition, the authors also evaluated the participants' perceptions regarding their experience with both tools.

The results indicated a significant knowledge improvement ($p < .001$) for the first post-test and $p < .01$ for the second. However, the longitudinal comparison between the pre-test and the second post-test showed a significant performance improvement ($p < .002$) for students using the actual liver. In contrast, the group assigned to the 3D dissection table demonstrated a significant performance improvement ($p < .04$) between the pre-test and the third post-test. The authors concluded that the 3D dissection table yielded higher knowledge acquisition of hepatobiliary anatomy than the real liver when compared to their previous knowledge. Furthermore, more than 80% of the students were satisfied with the tools used for the study duration. In addition, a large cohort was recommended for further research to examine the liver and other anatomical structures (Rosa et al., 2020).

In contrast with the study by Rosa et al. (2020), Silén et al. (2022) examined students' perceptions of the use of a 3D visualization table based on two research questions regarding the benefits of using 3D technology in learning anatomical structures and the view of the tutor in supporting and interacting with medical students learning anatomy. The cohort of participants included 24 medical, nursing, and physiotherapy students. The participants were allowed to interact individually with the 3D images, interact with each other, and study in pairs. The tutor acted as a facilitator and guide during the intervention. At the end of the intervention, the authors interviewed the students using video and recorded their perceptions. In general, this study found that students believed that learning from the 3D visualization table improved their understanding of human anatomy, and self-learning was an effective strategy for enhancing knowledge. In summary, the authors concluded that combining different techniques along with the use of 3D technologies projecting realistic anatomical images enables students to learn the subject meaningfully while allowing them to learn on their own and with the guidance of a tutor. In addition, the intricacy of the 3D images encourages students to immerse in the subject, thus allowing them to engage with the structures more deeply.

In another study using the Anatomage Table, a 3D dissection table, and other technology tools in a simulation laboratory, Dutt et al. (2020) examined the effect of a multi-prong approach to teaching and learning cardiovascular anatomy and physiology. The authors enrolled 145 1st year medical students (65 males and 80 females) who worked in four stations. The first station contained the Anatomage Table, a 3D dissection tool; the second included an ultrasound simulator, and the third had a High-Fidelity Human Patient Simulator (HPS). The fourth station used a METIman (Medical Education Technologies Inc), a high-fidelity patient simulator. All the students answered a Likert-type questionnaire to report their experience with the four stations. The results indicated that the 3D dissection tool rated the highest (84.3%) and enhanced their learning activities, followed by the HPS simulation with 68.3%. Furthermore, this study included a gender-wise comparison indicating that females significantly preferred hands-on activities using the HPS and the 3D images of the heart versus males (Dutt et al., 2020). This is the first study in this literature review using gender-wise comparison learning outcomes. In closing, the authors expressed that simulation activities benefit teaching and learning anatomy and physiology. They would like to see these technologies implemented in medical and other fields of study.

Similarly, Tenaw (2020) study examined the Anatomage Table, a 3D technology for studying gross anatomy. The survey comprised eighty-nine 2nd-year (51 males and 38 females) medical students who attended an anatomy session. After the session, the participants answered ten questions on a 5-point Likert-type scale (the authors did not clearly state that it was a Likert scale) using Strongly Agree (SA) to Strongly Disagree (SDA). The questions tried to determine the overall satisfaction with the 3D tool to understand how anatomical structures and systems are related and to observe the actual anatomical size of various organs and the normal position inside the body (Tenaw, 2020). The results indicated that male students strongly agreed with two of the ten questions, while three female students strongly agreed.

In contrast, "agree" was higher for males with eight out of ten responses, while for females, this result was seven out of ten questions. Furthermore, the authors found that the more time spent using the 3D tool, the better the positive perception of the 3D tool as an excellent learning device due to the ability of the 3D table to provide the user with a better view of the relationship between different anatomical structures. (Tenaw, 2020). In summary, most participants strongly agreed or agreed with the satisfaction with the 3D technology as an aid to learning gross anatomy. There was no significant difference between genders. It is important to note that the author did not produce any other relevant statistical analysis.

Although most studies in this literature review include research on the effects of 3D visualization and dissection technology, meta-analysis, and systematic reviews, it is essential to include in this chapter, to add knowledge to the reader, several of the features that attract users of this technology. For this purpose, the study by Elanjeran et al. (2021) reviews the features of 3D technology (Anatomage Table) in the context of using it as a learning aid for medical students in the field of regional anesthesiology. The authors highlighted the importance of accurately knowing the intricacies of regional anatomy in general and the brachial plexus in particular for regional anesthesia intervention. The brachial plexus is a bundle of nerves arising from the cervical spine (neck) that branches to the fingers. Interventional radiologists and medical students must create a visual memory of the structures. The 3D technology enabled the participants to fully recognize the features of the plexus and its relationship with other areas of the upper extremity. This was possible by using several of the features of the Anatomage Table, including the ability to display anatomical structures, anatomical variances, regional and surface, and deep landmarks, as well as the correlation between bony structures, vascular, neurological, and muscular structures, axial sections, and neurovascular complications that may arise when performing a nerve block. In the end, the authors summarized the benefits of this 3D technology as being an advanced tool for studying regional, local, and systemic anatomy, its ability to provide numerous clinical case studies, and its application in the clinical setting for consultation and medical diagnosis.

Although most of the studies into visualization tables, Anatomage Table, dissections tables, etc., are aimed at medical schools and ancillary medical fields, the study by Smith et al. (2019) provided a glimpse into the benefits of the 3D technology for Certified Registered Nurse Anesthesia (CRNA) students and elementary school children. According to the author, CRNA students could identify the anatomical structures needed to perform anesthetic procedures and match them correctly during an actual procedure. During the Physiology Understanding Week outreach, the authors gave elementary school children a pre-test and a post-test of anatomical structures. The results indicated higher performance for those students using the Anatomage Table than those not exposed to the 3D technology. Although the study did not provide statistical analysis, this unique research showed that dissection tables started to reach beyond medical students and other allied medical professionals.

Even though allied medical students are exposed to 3D technologies like dissection tables and visualization tables such as the Anatomage Table and other similar technologies, the bulk of the corpus researching learning outcomes or perceptions on using these technologies falls into medical students. Although my study investigates learning outcomes, knowing if students' perceptions could be aligned with learning outcomes is vital. In this regard, Alasmari (2021) used retrospective data from 78 medical students during the second and third year of medical school who answered a six-question questionnaire to investigate students' perceptions regarding the effectiveness of the Anatomage Table as an adjunct resource to cadaveric dissection to learn anatomy. The questionnaire included questions to determine if the Anatomage Table was a valuable tool in addition to the dissection of human cadavers, the benefits of using the electronic dissection tool, whether or not the 3D tools improve active learning, and enhance understanding of the relationship between anatomical structures. The results indicated that 86% of students perceived 3D technology enhanced their ability to locate anatomical structures within the body. The study did not differentiate results between genders.

Although Alasmari (2021) noted that integrating the 3D technology with cadaveric dissection was highly approved by the participants because the Anatomage Table uses CT scans similar to what they will be using in a realistic environment (Alasmari, 2021), there was no statistical analysis to corroborate those findings. In contrast, 90% indicated that by using the rotational capabilities of the Anatomage Table, they could better understand anatomical structures visualized from different angles. In conclusion, the author encouraged using control groups in further studies to compare the 3D technology and hands-on anatomical dissection on human cadavers and whether incorporating the Anatomage Table into anatomical dissection could improve long-term knowledge retention.

In line with Fulmali et al. (2021), the randomized cross-sectional study by Anand and Singel (2017) examined the learning outcomes measured by pre-test and post-test scores and students' perceptions of using the 3D technology termed Anatomage Table. The study included 122 first-year medical students randomly distributed into two (A and

B) equal groups of 61 students. Both groups received three one-hour didactical instructions followed by a one-hour laboratory session in which they studied and dissected the same anatomical structures, namely the basal ganglia and the spinal cord. Group A used the Anatomage Table to dissect the internal capsule, the basal ganglion, and the spinal cord; Group B worked the same structures as Group A but on a cadaveric specimen.

Fulmali et al. (2021) evaluated students' perceptions using a 10-point Likert scale questionnaire. The data demonstrated that the *p*-value between groups A and B's pre-test scores was $p = .3150$, while the post-test scores showed a $p = .079$. The results of the mean scores pre- and post-test within each group were $p < .0001$ for both groups. In synthesis, both groups showed statistically significant improvement in knowledge. Thus, both learning modalities helped with the acquisition of learning anatomical structures. However, the authors found similar academic performance between groups A and B regarding using the 3D tool vs. dissecting cadaveric specimens.

Although descriptive studies help understand students' perceptions, it is essential to include quantitative data based on learning outcomes to provide a better picture of the usefulness of 3D technologies for learning anatomy. In a quantitative, non-experimental, descriptive study on nursing students' perceptions of using the interactive 3D Table, Anatomage by Chiliquinga and Perez (2022), 49 nursing school students participated using a validated questionnaire. A 5-point Likert scale ranging from totally disagree, disagree, no agree nor disagree, agree, and agree. Most respondents agreed that the 3D technology enabled them to memorize, identify, and comprehend anatomical structures well; 82% agreed. Furthermore, in a second 5-point Liker scale, comprehension and learning ability showed an 80% agreement, and sound visualization, rotation, and dissection of anatomical structures ranged between 68% and 76%; nearly 74% stated that more time with the Anatomage Table could be more beneficial to their learning.

Similarly, Bianchi et al. (2020) examined the effectiveness of digital tools in nursing schools using questionnaires and exam scores. Out of 133 nursing students, 24 volunteered to be part of the study using the 3D dissection tool. The authors used a 4-point Likert-type questionnaire ranging from not satisfying, few satisfying, satisfying, and very satisfying to obtain students' perceptions of using the 3D dissection table. The survey results partially demonstrated that 100% of students were satisfied or very satisfied regarding the contents, completeness, and quality of the dissection table and its usefulness in nursing education.

Regarding test performance, students in the dissection table group scored significantly better $p < .05$ than students who did not use the 3D technology (Bianchi et al., 2020). Although the authors did not specify the anatomical content study during their research, the results are encouraging. In conclusion, students were highly satisfied and performed statistically better in the final examination. The authors encouraged further studies on knowledge retention in nursing students at the same level as in the study.

The study by Afsharpour et al. (2018) focused on the learning outcomes of anatomy students after changing teaching approaches in the anatomy laboratory in a chiropractic school. The study aimed to compare learning performance when a virtual dissection table, Anatomage Table, was used to study gross anatomy in a Doctor of

Chiropractic program. The authors examined the progress and performance during three consecutive academic years. The first-year cohort included 352 students, the second year consisted of 350 students, and the third year consisted of 393 students. The participants of the three cohorts were given lectures and laboratory exams during the study. Written examinations had similar content and difficulty, and the laboratory exams consisted of 20 tagged anatomical structures. The data were analyzed using a 1-way analysis of variance, ANOVA, and post hoc t-tests. Their study demonstrated improvement in scores from cohort to cohort in the dissection test with a $p < .001$. However, in a closer look by the authors using Tukey's honestly significant difference test (Tukey's HSD), the results showed a significant difference between the first and second cohort ($p < .001$), between the first and third cohort ($p < .001$), and between the second and third cohort ($p < .001$).

The authors concluded that the 3D tool helped students' scores increase compared to models or cadavers. However, no significant difference in exam scores during written tests suggests that the virtual table's laboratory dissection activities became more challenging. Still, at the same time, students could perform significantly higher. This study indicates a need for further evaluation of learning outcomes. After all, healthcare practitioners should be able to apply their knowledge when examining patient records and to record their findings after evaluating a patient.

Summary

The purpose of this quantitative study is to determine the difference in written exam scores and laboratory exam scores between Physical Therapy (PT) students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university while controlling for undergraduate anatomy scores effects. Although gross anatomy is foundational in all medical sciences, recent technological advances have tried to complement the longstanding tradition of dissecting human cadavers. The use of 3D technologies, namely dissection tables, visualization tables, the Anatomage Table, and other similar technologies, has opened a new path to learning gross anatomy in medical schools, nursing schools, PT schools, occupational therapy schools, and other allied medical sciences. New specialized tools have been created over the last ten years to facilitate, improve, and complete the learning process in anatomy studies. Still, the literature, new, after all, needs more depth and scope. The exhaustive literature review in this study shows that there needs to be more robust quantitative research to understand these technologies' abilities to improve learning outcomes for students learning anatomy. Unfortunately, a few studies before 2017 are conclusive enough to be included in this review because the 3D technology examined here is relatively recent. In addition, research is mainly focused on students' perceptions of the 3D technology, thus keeping learning outcomes based on factual scores from written and laboratory-based examinations insufficient.

Chapter 3: Research Method

The purpose of this quantitative study was to determine the difference in written exam scores and laboratory exam scores between DPT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and DPT students who participated in gross anatomy with traditional instruction at a local university while controlling for undergraduate anatomy scores effects. In this chapter, I discuss the research design, rationale, methodology, data analysis plan, and threats to validity and ethical procedures.

The research design for this study was quasi-experimental. First, students from two consecutive cohorts, who had all taken anatomy as a prerequisite to enter the DPT program, took written and laboratory exams before Anatomage technology was available. Then, another group of students from two successive cohorts from the subsequent year who had taken anatomy as a prerequisite to enter the DPT program was introduced to Anatomage technology and took the written and laboratory exams. Both groups answered selected exam questions that were standardized across campuses. Students in both groups did not use 3D technologies like the Anatomage Table before enrolling in the DPT program. Before entering the program, all the students were required to have an undergraduate course in anatomy. This study compared the differences in scores between the two groups and evaluated the effect of the Anatomage Table 3D technology on student learning outcomes while controlling for undergraduate anatomy scores.

Research Design and Rationale

A quasi-experimental design was employed to address the research questions. This type of design uses archival (non-experimental data) and non-researcher-induced variations in the independent variable. This approach does not randomly expose participants to an intervention (Gopalan et al., 2020). This study compared the results of written and laboratory exams of PT students who were introduced to 3D Anatomage Table technology in the second term of the 2018 school year to those of PT students who were not introduced to the technology in the first term of the 2018 school year. Three-dimensional technology was added to the current methods of teaching gross anatomy, namely cadaveric dissection and plastic models. The dependent variables were students' written and laboratory exam scores in gross anatomy. The study also involved collecting data as a covariate on the student's previous anatomy performance at the undergraduate level.

Methodology

Population

The population for this study is students enrolled in the DPT program at a local university, including the Residential and Flexible programs. The approximate size of the target population is 2400 students. The study analyzed existing data from the first term of the 2018 school year, for students who did not use the Anatomage Table, and from second-term students who were introduced to the Anatomage Table from the Residential DPT program.

Sampling and Sampling Procedures

The inclusion criteria for the participants in the archival data were the following:

- all students in the Residential and Flexible DPT program who took GA1 and GA2 in the year when the Anatomage Table technology was unavailable
- all students in the Residential and Flexible DPT program who took GA1 and GA2 in the immediate year in which the Anatomage Table technology was introduced to the study of GA1 and GA2
- all students in the Residential and Flexible DPT program who took written and laboratory exams in the year before the introduction of the 3D technology
- all Residential and Flexible DPT program students who took written and laboratory exams in the immediate year after the 3D technology was introduced

In addition, this study included students' undergraduate anatomy scores. Because this study used archival data from the 2018 school year, there was no need for participants' consent.

The exclusion criteria included students enrolled in the Flexible DPT and Nursing and Occupational Therapy programs.

I submitted the Institutional Data Usage Approval (IDUA) form to the institution I work for and received the approval. I started looking into the data as soon as the proposal for this dissertation was approved and I was granted permission to access the data from Walden University's IRB. Then, I submitted the IDUA to the Registrar at the university I work for and to the program directors of each campus to give me access to the courses I used to collect data from GA1 and GA2.

Procedures for Recruitment, Participation, and Data Collection

Data collection came from archival data from the 2018 school year, including written and laboratory exam grades, undergraduate anatomy grades, number of students per term/year, and other demographic data that may or may not be included in the study. The university has a straightforward mechanism that consists of a form to describe the type of data that needs to be accessed by the faculty for research purposes. The procedure for gaining access to the data set includes permission from the Dean of the DPT program, which I obtained.

After receiving Walden University IRB approval, I contacted the program director of the five campuses to provide me access to all the courses in this study, including GA1 and GA2 for the 2017 and 2018 school years. In addition, I obtained the demographic data from the school's registrar, including age, undergraduate anatomy scores, and number of enrolled students per term and school year.

Instrumentation and Operationalization of Constructs

Independent Variable: Participation in 3D Anatomy Technology

Operationalization of the independent variable participation in 3D anatomy technology is a binary (yes/no) categorical variable that was coded 1 for "yes" and 2 for "no." It indicated whether the students had the opportunity to engage with the Anatomage Table 3D anatomy technology during their anatomy courses. To determine the participation status, students are assigned a value of "yes" if they had access to and utilized 3D anatomy technology as part of their learning experience. Conversely, students who did not have access to or did not utilize 3D anatomy technology are assigned a value of "no." By operationalizing this variable in a binary manner, I aimed to investigate the potential impact of 3D Anatomage Table technology on the two dependent variables of (a) written exam scores and (b) laboratory exam scores, while controlling for undergraduate anatomy scores.

Covariate: Undergraduate Anatomy Scores

This study operationalizes the covariate undergraduate anatomy scores as a continuous variable. This variable represents the academic performance in anatomy before enrolling in the DPT program. By operationalizing the covariate undergraduate anatomy scores in this manner, I aimed to explore potential confounding effects on the postgraduate exam scores.

Dependent Variable: Written Exam Scores

In this study, the first dependent variable, written exam scores, is operationalized as a numerical variable measured on a scale ranging from 0 to 100. The scores reflect the student's performance on the written exams conducted as part of all the courses in this study. As illustrated in Table 1, the scores are assigned based on the student's performance on the written exams.

Table 1

Letter Grade Conversion for Written Exam Scores

Letter grade	Numerical value
A	90–100
B+	85–89
B	80–84
C+	75–79
C	70–74
D+	65–69
D	60–64
F	<60

The scale ranges from 0 to 100, with 0 representing the lowest possible score and 100 representing the highest. A 70 (C) or higher threshold determines a passing grade. Students who score 70 or above are considered to have achieved a passing grade, indicating satisfactory performance on the written exams. The study did not use letter grade representations of the written exam scores.

Dependent Variable: Laboratory Exam Scores

The second dependent variable, laboratory exam scores, differs from the written exam scores variable because it is not based on multiple choice questions that use question stems such as “which of the following structures help to bend the elbow” used across campuses. The anatomical structures are based on organ systems, which are standard across anatomy education. This variable is operationalized as a numerical variable measured on a scale of 0 to 100. The scores reflect the student’s performance on the written exams conducted as part of all the courses in this study. Table 2 illustrates how scores are assigned based on the student’s performance on the written exams.

Table 2

Letter Grade Conversion for Laboratory Exam Scores

Letter grade	Numerical value
A	90–100
B+	85–89
B	80–84
C+	75–79
C	70–74
D+	65–69
D	60–64
F	<60

The scale ranges from 0 to 100, with 0 representing the lowest possible score and 100 representing the highest. A 70 (C) or higher threshold determines a passing grade. Students who score 70 or above are considered to have achieved a passing grade, indicating satisfactory performance on the written exams. The study did not use letter-grade representations of the laboratory exam scores.

These scores reflect the student's performance on the laboratory exams assessing their knowledge of anatomical structure. The laboratory exams in this context involve questions that require students to apply their understanding of anatomical structures by directly observing and identifying them in cadavers or plastic models. These exams provide a practical assessment of the student's ability to identify and comprehend anatomical structures in a hands-on setting. The scores assigned to the laboratory exam performance are based on the student's ability to recognize the questions about the anatomical structures. Higher scores indicate a stronger ability to correctly identify anatomical structures and apply their knowledge.

An example of a written examination signature question, along with its answer choices, is as follows:

What is the innervation of the quadriceps femoris, and what movement will be impaired if its innervation is injured?

a. Obturator nerve – decreased plantarflexion

b. Femoral nerve – decreased hip flexion and knee extension

c. Femoral nerve – decreased abduction and knee flexion

d. Obturator nerve – decreased hip flexion and knee extension

The correct answer is “b. Femoral nerve – decreased hip flexion and knee extension.” In this example, the instructor provides students with the correct answer after completing the examination to give the students rationale and feedback.

An example of a laboratory exam item is “Identify this structure – Be specific.” In this case, the instructor pinned the anatomical structure with an arrow sticker or a pin, and the student should identify the name of the structure, for example, the biceps brachii muscle (the most superficial muscle in the upper part of the arm), and the laterality (left or right arm).

Data Analysis Plan

This study used the Statistical Package for the Social Sciences (SPSS; Version 29.0) for statistical analysis and the G*Power software, (G*Power; version 3.1.9.6). The data were cleaned and screened in the following manner: First, grades that only appeared as letter grades were excluded. In addition, grades with “W” for withdrawal or “I” for incomplete at the time of data gathering were excluded. Second, letter grades were replaced by the actual numeric grade value provided by the registrar if such a value exists in the student's record. Third, grades above 100 or negative value grades were excluded. The objective of the data analysis was to answer the following research questions:

- RQ 1: What is the difference in written exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university while controlling for undergraduate anatomy scores?

  $H_0 1$: There is no significant difference in written exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction, controlling for undergraduate anatomy scores.

  $H_1 1$: There is a significant difference in written exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction, controlling for undergraduate anatomy scores.

- RQ 2: What is the difference in laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university while controlling for undergraduate anatomy scores?

$H_0 2$: There is no significant difference in laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction, controlling for undergraduate anatomy scores.

$H_1 2$: There is a significant difference in laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction, controlling for undergraduate anatomy scores.

To examine RQ 1 and RQ 2, I used ANCOVA. This type of analysis is used to determine whether significant differences in the means exist between two normally distributed variables. Furthermore, this test assists with determining the effects of a covariate. Thus, the rationale for using this test was that ANCOVA would enable me to examine whether there is a significant difference in written exam scores between the two types of instruction. In addition, using ANCOVA allow me to find the potential confounding effect of the covariate (undergraduate anatomy scores) on the relationship between the instructional method (using or not the Anatomage Table) and criterion exam scores.

The archival data in this study consisted of 1332 student records from four DPT Program campuses from the 2018 academic year. Additionally, measures to ensure the validity and reliability of the data include using questions in the exams already used throughout the DPT program, controlling for a confounding variable, and using appropriate data analysis techniques.

Threats to Validity

There are various factors, internal and external, that could undermine the validity of this study. According to the seminal work by Campbell and Stanley (1963), internal threats to validity include history, maturation, testing, instrumentation, statistical regression, experimental mortality, or differential loss of respondents from the comparison groups, and selection-maturation interaction. From these eight threats to internal validity, this study may include changes in the DPT curriculum during the two years from which the data was accessed, changes in the standardized questions from written exams, quality of instruction, the experience of the gross anatomy teachers, and age and maturity of students. On the other hand, external threats to the validity of this study may be due to the lack of generalization to other populations such as medical students, occupational therapy students, nursing students, or chiropractic students. Furthermore, the results may be limited to gross anatomy exams in other educational settings and medical programs like the ones mentioned above and other academic disciplines outside medical and allied sciences. Additionally, the results of this study may need to be more generalizable to other technologies used for the study of gross anatomy, like Virtual Reality (VR). Finally, regarding methodology as an external validity threat, the results of this study may be influenced by the research method I will be using or by how the data will be collected, cleaned, and analyzed.

Statistical conclusion validity refers to the accuracy of the relationship between the variables. Thus, threats to statistical conclusion validity may include low statistical power due to a small sample and its influence on detecting the findings' actual effect, leading to a Type II error. This type of error refers to an erroneous acceptance of the null hypothesis (Kim, 2015). In addition, when the data include values outside the norm, outliers could threaten statistical conclusion validity by making results skewed and inaccurate (García-Pérez, 2012). Although multiple testing is another threat to statistical conclusion validity, this study is not expected to use multiple testing to analyze the data.

Ethical Procedures

The ethical procedures and considerations surrounding this research study are aimed at how I will utilize archival data. The focus is on ensuring the confidentiality and anonymity of participants. For the IRB at Walden University Application and data usage, I submitted an IRB application accompanied by all relevant documents to gain approval for the research. The application will encompass detailed information regarding the research objectives for this study, the methodology, and the intended use of data. I utilized archival data, so there will be no direct involvement or interaction with human participants. Consequently, it is unnecessary to elaborate on the treatment of human participants for this study. However, I will provide a comprehensive description of how the archival data will be used to maintain transparency and clarity regarding the research process.

Regarding IRB approval to proceed with this study, I submitted the Research Ethics Form Approval Form A to obtain IRB approval. I was granted permission by the IRB committee to proceed with this study. The IRB approval number for this study is 09-22-23-0979401. Regarding the treatment of data and anonymity measures, since this study involves utilizing archival data, the following stringent standards were implemented to ensure participant anonymity and data security: first, all identifying markers such as name, social security number, date of birth, and prior schools attended, within the archival data will be removed, guaranteeing complete confidentiality. I stored the data in a secure location with password protection, accessible only to me. The data obtained from the archival data will not be disseminated in any form outside the confines of this study, adhering strictly to the principles of anonymity and ethical data handling.

Conflicts of Interest: In this study, I attest to the absence of any conflicts of interest that could compromise the objectivity and validity of the research findings.

Summary

This study examines the impact of the Anatomage Table, a 3D technology for studying gross anatomy, on PT students' exam performance based on scores from standardized written exam questions and laboratory examinations to identify anatomical structures. In addition, evaluate any confounding effects on gross anatomy performance. The research design is quasi-experimental and compares the academic performance of PT students who used the Anatomage Table to study gross anatomy to those who did not while controlling for undergraduate anatomy scores' effects on gross anatomy performance at the graduate level. The rationale is to contribute to the literature on the use of technology in anatomy education and to provide insights for designing effective teaching methods. The research will use historical data, including written and laboratory exam scores, students' undergraduate anatomy scores, and grades from the year before the Anatomage Table was introduced and the year after the Anatomage Table was implemented, and analyze the data using ANCOVA. This test will be utilized to investigate the effects of using or not using the Anatomage Table technology tool in studying GA1 and GA2. The study will include measures to ensure data validity and reliability, such as using standardized questions from the written exams controlling for undergraduate anatomy performance. The archival data includes more than 2400 student records from four DPT Program campuses, including the Flexible and Residential programs. After data gathering and analysis following the procedures in this chapter, I will move forward with the results. The results will be provided in Chapter 4 of this study.

Chapter 4: Results

The purpose of this quantitative study was to determine the difference in written exam scores and laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university while controlling for undergraduate anatomy scores effects. This chapter will present the study results, the time frame for data collection, discrepancies in collecting the data versus the plan presented in Chapter 3, the descriptive and demographic characteristics of the sample, and how representative the sample is to the larger population. This chapter will also provide the basic univariate analysis justifying the inclusion of the covariate.

The research questions and corresponding hypotheses were as follows:

- RQ 1: What is the difference in written exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university while controlling undergraduate anatomy scores?

  $H_0 1$: There is no significant difference in written exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction.

  $H_1 1$: There is a significant difference in written exam scores between PT students who participated in gross anatomy instruction using Anatomage

Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction.

- RQ 2: What is the difference in laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university while controlling for undergraduate anatomy scores?

  $H_0 2$: There is no significant difference in laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction.

  $H_1 2$: There is a significant difference in laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and the written exam scores of PT students who participated in gross anatomy with traditional instruction.

Data Collection

For this study, I obtained archival data from two consecutive semesters during the 2018 school year. The data pertained to students enrolled in the DPT program who had completed gross anatomy courses with and without using the Anatomage Table. Scores from undergraduate anatomy courses were also included in the analysis. Unfortunately, delays in acquiring the above data occurred due to technical problems encountered within the university's learning management system and a lack of staffing resources, resulting in the release of the data later than anticipated. While the delay lengthened the timeline for study completion, it did not impact the overall research plan. There were no discrepancies from the original plan presented in Chapter 3 in the archival data used in this study, which included gross anatomy written and laboratory exam scores from two consecutive semesters and undergraduate anatomy scores.

The sample comprised 665 scores in gross anatomy written exams, 667 in laboratory exams, and 667 in undergraduate anatomy from students before entering the DPT program. The sample represents about 27.8% of the total student population (DPT, OT, Speech Language Pathology, and Nursing) enrolled during the semesters analyzed in this study. Since this study focused on students taking gross anatomy in the DPT program, the sample is relevant to students taking gross anatomy in the general population, including PT, occupation therapy, nursing, medicine, and chiropractic schools, because gross anatomy is one of their foundational courses.

I initially intended to use two dependent variables (written and laboratory exam scores from gross anatomy), one independent variable (YES/NO use of Anatomage Table), and one covariate (undergraduate anatomy scores). However, the selected methodology, ANCOVA, could not be used because the samples did not meet the assumptions of normality and linearity. Therefore, a non-parametric test, the Mann-Whitney U Test (Laerd Statistics, 2015), was used to determine whether there is a difference between two groups on a continuous or ordinal dependent variable. Furthermore, Spearman's rank-order correlation test was used to calculate the r

coefficient (ρ) that measures the strength and direction of the association between two continuous variables (Laerd Statistics, 2015).

Results

A Mann-Whitney U test was calculated to determine whether there were differences in written exam scores between students who took gross anatomy using the Anatomage Table and students who did not use the Anatomage Table. The power calculation for the Mann-Whitney test was .9505. Table 3 shows the descriptive statistics of the test, which demonstrated that the lab gross anatomy exam average score was higher than the average score of the written exam and a high standard deviation (*SD* = 157.00248) indicating a larger dispersion around the mean. In contrast, the written exam demonstrated a low standard deviation (*SD* = 8.24584) and much tighter dispersion around the mean.

Table 3

Descriptive Statistics

Exam type	*N*	*M*	*SD*	Minimum	Maximum
Written	665	82.869	8.24584	56	98.33
Lab	667	86.081	157.00248	58	98

The Mann-Whitney Mean Ranks shown in Table 4 demonstrated a higher mean rank of 356.34 for students not using the Anatomage Table for the written exam and a higher mean rank of 340.89 for those using the Anatomage Table for the laboratory exam.

Table 4

Mann-Whitney Test – Ranks

Exam type	Anatomage	*N*	Mean ranks	Sum of ranks
Written	YES	333	309.73	103140.00
	NO	332	356.34	118305.00
	Total	665		
Laboratory	YES	335	340.89	114198.00
	NO	332	327.05	108580.00
	Total	667		

The test statistics in Table 5 provide information on the rank-sum tests comparing scores between groups (Anatomage versus non-Anatomage participation) for both written and laboratory exams. They demonstrated that written exam scores show a positive difference between the Anatomage and non-Anatomage groups, while the laboratory exam scores do not differ significantly. In addition, the statistics in Table 5 indicate that the mean rank difference for the written exam was significant ($p < .002$), while the mean rank difference for the laboratory exam was not significant ($p = .352$).

Table 5

Test Statistics

Test	Written exam	Lab exam
Mann-Whitney U	47529.000	53302.000
Wilcoxon W	103140.00	108580.00
Z	-3.129	-.931
Asymp. sig. (two-tailed)	.002	.352

Note. Grouping variable: ANATOMAGE versus non-ANATOMAGE participation.

The Spearman's rho (see Table 6) demonstrated a positive moderate correlation between undergraduate and laboratory exam scores with a significance level of $p < .001$.

Table 6

Correlations – Undergraduate vs. Lab Exams Scores

			Undergrad scores	Lab exam
Spearman's rho	Undergrad	Correlation coefficient	1.000	.545**
		Sig. (two-tailed)		< .001
		N	667	667
Spearman's rho	Lab exam	Correlation coefficient	.545**	1.000
		Sig. (two-tailed)	< .001	
		N	667	667

Table 7 indicates that the upper and lower values demonstrated a 95% chance that the correlation between .488 and .598 is certain, with only a 5% chance that the population correlation would fall outside these parameters. Spearman's rho of .545 indicates a moderately significant correlation between undergraduate anatomy scores and laboratory exam scores.

Table 7

Confidence Intervals – Undergraduate vs. Lab Exams Scores

			95% confidence interval (two-tailed) [a, b]	
	Spearman's rho	Significance (two-tailed)	Lower	Upper
Undergrad–lab exam scores	.545	< .001	.488	.598

[a] Estimation is based on Fisher's r-to-z transformation. [b] Estimation of standard error is based on the formula proposed by Fieller, Hartley, and Pearson.

The Spearman's rho shown in Table 8 demonstrated a positive weak correlation of .139 between undergraduate anatomy scores and written exam scores with a significance level $p < .001$ using a two-tailed test. The 95% confidence interval in Table 7 ranges from .061 to .215, suggesting only a 5% chance that the true population coefficient falls outside this range.

Table 8

Correlations – Undergraduate vs. Written Exams Scores

			Undergrad scores	Lab exam
Spearman's rho	Undergrad	Correlation coefficient	1.000	.139**
		Sig. (two-tailed)		< .001
		N	667	665
Spearman's rho	Lab exam	Correlation coefficient	.139**	1.000
		Sig. (two-tailed)	< .001	
		N	667	665

Table 9 shows the confidence interval for this correlation coefficient ranges from .061 to .215, indicating the range within which the true population correlation coefficient is likely to fall with 95% confidence.

Table 9

Confidence Intervals – Undergraduate vs. Written Exams Scores

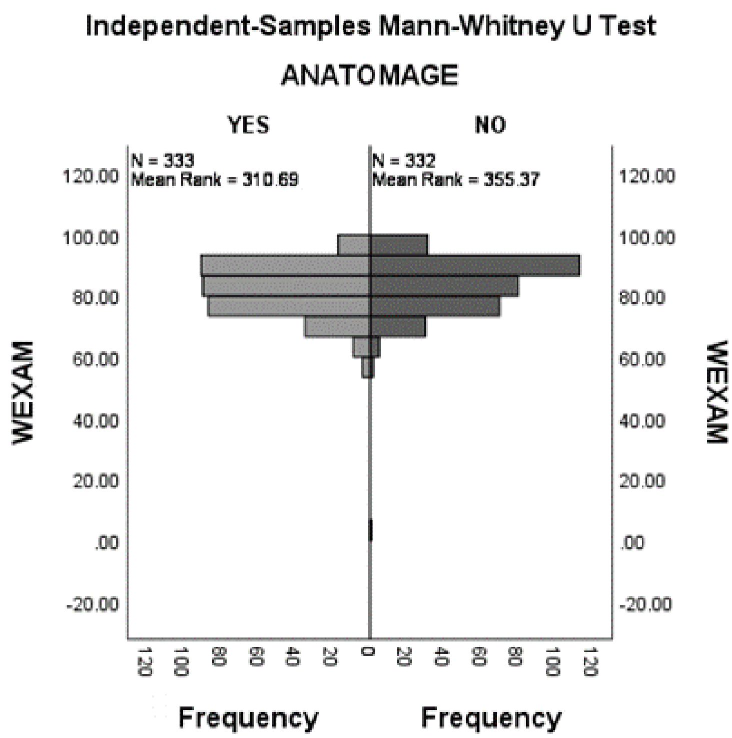
			95% confidence interval (two-tailed) [a, b]	
	Spearman's rho	Significance (two-tailed)	Lower	Upper
Undergrad-written exam scores	.139	< .001	.061	.215

[a] Estimation is based on Fisher's r-to-z transformation. [b] Estimation of standard error is based on the formula proposed by Fieller, Hartley, and Pearson.

Figure 1 demonstrates a similarly shaped distribution between written exam scores of students who used and did not use the Anatomage Table. The similarly shaped distribution enables the calculation to determine whether the median scores differ significantly (Laerd Statistics, 2015).

Figure 1

Pyramid Graph – Anatomage (YES/NO) Written Exam

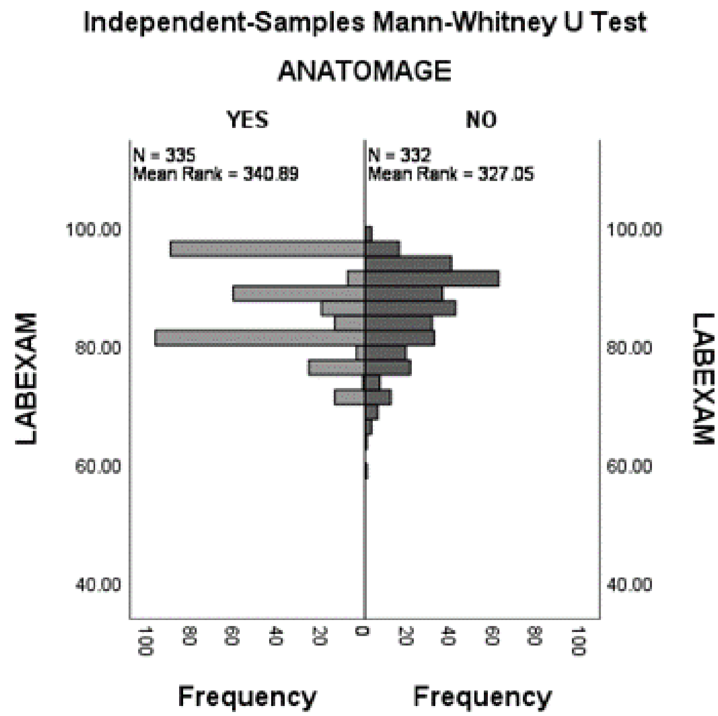


Note. WEXAM = written exam score.

Figure 2 demonstrates a similarly shaped distribution between laboratory exam scores of students who used and did not use the Anatomage Table. The dissimilarly shaped distribution enables the calculation to determine whether the values of one group are statistically significantly lower or higher by comparing the mean ranks (Laerd Statistics, 2015).

Figure 2

Pyramid Graph – Anatomage (YES/NO) Laboratory Exam



Note. LABEXAM = laboratory exam scores.

Evaluation of Statistical Assumptions

There are four assumptions related to the Mann-Whitney U test. These are (a) having a continuous or ordinal dependent variable, (b) the independent variable is categorical with two groups, (c) the observations are independent, and (d) the distribution of the two groups of the independent variable has the same shape (Laerd Statistics, 2015). The data in this study met the four assumptions for the written exam scores variable.

However, the laboratory exam scores data did not satisfy the fourth assumption. This event was resolved using the ranking results from the Mann-Whitney U test and its statistical significance.

I used Spearman's rho to analyze the data regarding the correlations between the undergraduate anatomy scores and the written and laboratory scores. The assumptions for this test include two continuous or ordinal variables with two independent observations and a monotonic relationship between the two variables (Laerd Statistics, 2015). The data in this study met the three assumptions.

Statistical Analysis Findings

The Mann-Whitney U test was performed to analyze the differences between gross anatomy laboratory exam scores based on the use or not of the Anatomage Table. The power calculation was high (.9509) demonstrating that the Mann-Whitney test was well-equipped to notice the differences and effects between groups with good accuracy and reliability. The distributions of written exam scores between the scores of students using or not using the Anatomage Table were similar when visually assessed (see Figure 1), with the median score statistically significantly higher ($p < .002$, $U = 47529$, $z = 53302$). These results enabled us to reject the null hypothesis of RQ 1. However, the distribution of laboratory exams was not similar when visually inspected (see Figure 2), with the median score not statistically significant ($p = .352$, $U = 53302$, $z = .931$). The lack of significance did not allow the null hypothesis for RQ 2 to be rejected.

As mentioned at the outset of this chapter, ANCOVA could not be used to analyze the data because it did not meet the statistical assumptions. Therefore, undergraduate anatomy scores previously intended to be a covariate for ANCOVA were used to determine if they correlated with either dependent variable. To that end, I used Spearman's Rank-order Correlation coefficient rho (ρ), demonstrating a monotonic relationship between undergraduate and laboratory gross anatomy grades. Further analysis revealed a statistically significant, moderate positive correlation between undergraduate anatomy scores and gross anatomy laboratory exam scores, $p < .001$, $r_s = .545$, 95% CI (two-tailed) [.488, .598]. In contrast, the correlation between undergraduate anatomy scores and gross anatomy written exam scores was smaller but significant, $r_s = .139$, $p = .001$, 95% CI (two-tailed) [.061, .215], (see Spearman, 1904).

Summary

During this quantitative study, I encountered unforeseen delays in acquiring archival data due to technical challenges within the university's learning management system. These setbacks extended the timeline for obtaining the data. However, after receiving the archival data, a careful examination revealed no disparities in the data collection process compared to the initially outlined plan in Chapter 3. The sample under investigation was comprehensive, consisting of 665 scores from gross anatomy written exams, 667 from laboratory exams, and an additional 667 from undergraduate anatomy—all derived from students before they entered the DPT program and from two subsequent semesters.

After assessing the sample's representation and external validity, I determined that this group represented approximately 27.8% of the total student population (DPT, OT, Speech Language Pathology, and Nursing) during the semesters examined in this study. Furthermore, the study's focus on students engaged in gross anatomy within the DPT program rendered the sample applicable to a broader context, including PT, occupational therapy, nursing, medicine, and chiropractic schools where gross anatomy is foundational. I initially planned to employ an ANCOVA, considering two dependent variables (written and laboratory exam scores), one independent variable (the use or not of the Anatomage Table), and one covariate (undergraduate anatomy scores). However, due to the inability to meet ANCOVA's assumptions, the methodology was adjusted to incorporate non-parametric tests, namely the Mann-Whitney U test and Spearman's rank-order correlation.

The Mann-Whitney U test was essential in comparing written exam scores between students utilizing the Anatomage Table and those who did not. Significant differences existed with students using the Anatomage Table exhibiting higher median scores. However, a similar comparison for laboratory exam scores did not yield statistically significant differences. Ranking results were utilized to overcome these issues and to address the fact that the shape of distributions for the laboratory exam scores did not meet the assumption. Regarding statistical analysis findings, the Mann-Whitney U test highlighted significant differences in written exam scores based on whether or not the Anatomage Table was used.

In contrast, there was a difference when the laboratory exam scores were examined; however, it was not significant. Additionally, Spearman's rank-order correlation elucidated a statistically significant, moderately positive correlation between undergraduate anatomy scores and gross anatomy laboratory exam scores. The correlation with written exam scores was smaller but was significant.

The above summary illustrates the pathway that I encountered in this study, which included unexpected delays, applying appropriate non-parametric tests when parametric test assumptions were not met, and ultimately revealing insightful findings regarding the influence of the Anatomage Table on written and laboratory exam scores and the correlation between undergraduate anatomy scores and gross anatomy written and laboratory exam performance. In the following chapter, the discussion, conclusions and recommendations will be addressed.

Chapter 5: Discussion, Conclusions, and Recommendations

The purpose of this quantitative study was to determine the difference in written exam scores and laboratory exam scores between PT students who participated in gross anatomy instruction using Anatomage Table technology for one semester and PT students who participated in gross anatomy with traditional instruction at a local university. Furthermore, I examined whether a correlation existed between undergraduate anatomy scores and written and laboratory exam scores.

The nature of the study is quantitative and was conducted to evaluate the learning outcomes regarding introducing the Anatomage Table in anatomy education. The rationale behind the quantitative design was to address the lack or scarcity of robust quantitative studies in the literature, limiting a comprehensive understanding of the effects of incorporating 3D technology like the Anatomage Table on student learning outcomes. The study aims to fill this gap by providing quantitative data on the influence of the Anatomage Table on student learning outcomes, specifically focusing on written and laboratory exam scores in gross anatomy.

The study's key findings demonstrated significant results using the Anatomage Table for students who took written exam scores. In contrast, the laboratory exam scores were not significantly affected. Correlational statistics indicated a moderate and significant correlation between the use of the Anatomage Table and laboratory examinations and also a significant correlation, although minimal, between the use of the Anatomage Table and written exam scores.

Interpretation of the Findings

The statistical data analysis on the effects of using the Anatomage Table on gross anatomy exam scores revealed that students who used the Anatomage Table scored higher on gross anatomy laboratory exams than those who did not. Therefore, the data suggest that the Anatomage Table may be an effective tool for improving learning and understanding of gross anatomy in the laboratory setting. In contrast, there was a negative significant difference in written exam scores between students who used the Anatomage Table and those who did not. The positive results of using the Anatomage Table to prepare students for laboratory exams, indicate that its use by PT students might be more beneficial for practical, hands-on learning experiences rather than theoretical understanding.

Regarding the correlation between undergraduate anatomy scores and gross anatomy performance at the graduate level in DPT school, a moderate positive correlation was found between undergraduate anatomy scores and gross anatomy laboratory exam scores. This finding suggests that students who performed well in undergraduate anatomy courses tended to perform better in gross anatomy laboratory exams. Furthermore, a small but significant correlation existed between undergraduate and gross anatomy written exam scores. Thus, these findings indicate that performance in undergraduate anatomy courses may have some predictive value for success in gross anatomy written exams, although to a lesser extent than for laboratory exams.

In synthesis, the findings suggest that the Anatomage Table can be a valuable tool for improving performance in gross anatomy laboratory exams while highlighting the importance of undergraduate anatomy performance as a predictor of success in gross anatomy exams. It is also helpful to see how the continuity and relationship of anatomical knowledge across educational levels could be seen after looking at the correlation outcomes. These insights may contribute to the ongoing efforts to understand the effects of 3D technologies like the Anatomage Table to enhance anatomy education and improve student learning outcomes.

The findings regarding the effects of the Anatomage Table in improving gross anatomy exam scores are consistent with studies conducted by Darras et al. (2019), Fulmali et al. (2021), and Rosa et al. (2020). These authors also reported significant improvements in student performance when utilizing 3D technologies like the Anatomage Table in anatomy education. Similarly, Ceri (2021) agreed that 3D tools contribute to better learning outcomes in anatomy studies. In contrast, there was a significant difference in written exam scores between students who used the Anatomage Table and those who did not align with the findings of Anand and Singel (2017) and Smith et al. (2019). These studies emphasized the importance of considering several assessment methods when evaluating the effects of 3D technologies on anatomy education.

The correlation findings in this study substantiated those of Alasmari (2021) and Afsharpour et al. (2018) regarding the relationship between undergraduate anatomy scores and gross anatomy performance at the graduate level. Both studies highlighted the predictive value of undergraduate anatomy performance for success in gross anatomy exams in higher education settings. Moreover, the study by Tenaw (2020) provided additional insights into students' positive perceptions regarding 3D technology use, like the Anatomage Table, complementing current research findings.

Therefore, the current findings, along with those of previous studies by Afsharpour et al. (2018), Alasmari (2021), Anand and Singel (2017), Ceri (2021), Darras et al. (2019), Fulmali et al. (2021), Rosa et al. (2020), Smith et al. (2019), and Tenaw (2020), contribute to a deeper understanding of the role of 3D technologies in anatomy education and their impact on student learning outcomes across various assessment methods and educational levels.

The AF-TEL proposed by Havard et al. (2016) provides an integrated tool to analyze the study's findings on the effectiveness of the Anatomage Table in improving learning outcomes in gross anatomy. The framework emphasizes the integration of cognitive, social, and teaching presence to understand how learning outcomes are achieved through instructional strategies that are effective and efficient. Concerning the study's findings, the AF-TEL framework allows the examination of how the Anatomage Table facilitates learning by accommodating different learning approaches and instructional characteristics. The framework's flexibility enables an analysis of who is learning, what is being learned, and how individuals learn when using the Anatomage Table. By considering how cognitive processes enable learning, social interactions, and teaching methods, the framework helps to elucidate the mechanisms by which the Anatomage Table improves student engagement and understanding of gross anatomy concepts.

Furthermore, Bond and Bedenlier's (2019) framework for Facilitating Student Engagement Through Educational Technology helps to understand how technology, such as the Anatomage Table, promotes student engagement in learning. The framework emphasizes the importance of considering various factors, including technology microsystems, curriculum design, and teacher interventions, in promoting student engagement.

Concerning the study's findings, Bond and Bedenlier's framework helps elucidate how the introduction of the Anatomage Table influences student engagement in the learning processes of gross anatomy at the graduate level. Considering the interaction between technology, curriculum, and teacher interventions, this framework provides an integral understanding of how students interact with the Anatomage Table and how it impacts their learning experiences. Additionally, the framework's distinction between engagement and motivation clarifies how students actively participate in learning activities using the Anatomage Table.

Limitations of the Study

Several limitations to generalizability, trustworthiness, validity, and reliability were found. For example, the sample size of 665 scores from gross anatomy written exams, 667 from laboratory exams, and 667 from undergraduate anatomy is significant; however, this sample represents only 27.8% of the total student population (DPT, OT, Speech Language Pathology, and Nursing) during the examined semesters. This limited representation could affect the generalizability of the findings to the entire student population. Furthermore, data collection was challenging, with unforeseen delays in acquiring archival data due to technical difficulties within the university's learning management system. These issues may have introduced biases or errors in the data collection process. Even though the university where I collected the data made substantial efforts to ensure the integrity of the data, such delays could have compromised the trustworthiness and reliability of the study.

Regarding statistical assumptions and methodological adjustments, this study encountered challenges in meeting the statistical assumptions required for data analysis using ANCOVA because the data showed a non-normal distribution. As a result, the methodology had to be adjusted to incorporate the non-parametric Mann-Whitney U test and Spearman's rank-order correlation. While these adjustments were necessary, they may have had implications for the validity and reliability of the study's findings. Furthermore, the study did not include information about the variability of teaching instruction and methods, student levels of engagement, and learning environments.

The external validity and generalizability may be compromised because the study focuses on students engaged in gross anatomy within a DPT program. Thus, the generalizability of the findings to other educational settings, such as occupational therapy, medicine, chiropractic, and nursing schools, may be limited. Even though each of these settings may require gross anatomy as a fundamental course, their unique characteristics and modes of instruction may limit the generalizability of the result from this study.

There are potential biases in the interpretation of findings, such as researcher bias, especially considering the adjustments made to the methodology, the unexpected delays encountered during the study, and the fact that this study was based on data obtained from a higher learning institution where the principal investigator works. However, it is essential to note that I did not use data from courses I taught in this study. This study provided valuable information about the effects that 3D technologies like the Anatomage Table have on students' learning outcomes.

Recommendations

While this study provides valuable information about the effects of the Anatomage Table on written and laboratory exam scores, as well as the levels of correlation between undergraduate anatomy scores and gross anatomy exam performance, the limitations of this study emphasize the need for caution in interpreting and generalizing the findings to other educational settings. Future research should address these limitations and adopt robust and thorough methodologies to maximize the trustworthiness, validity, and reliability of findings in this study area.

Furthermore, the effects of 3D technologies should be addressed in future research, including 3D technologies like the Anatomage Table across diverse educational settings besides DPT programs. Research could focus on the impact of these technologies on learning outcomes in academic settings such as nursing, chiropractic, medicine, and occupational therapy, drawing upon the frameworks proposed by Havard et al. (2016) and Bond and Bedenlier (2019) to understand how different educational environments influence student engagement and learning outcomes.

In addition, conducting comparative analyses between different educational technologies, such as 3D visualization tables, dissection tools, and simulation laboratories, as Gloy et al. (2021) and Baratz et al. (2019) researched, can provide essential information about the effects of these tools in enhancing anatomy education. This type of research can inform educators and institutions about the best or most useful technological interventions for promoting student learning and engagement. Lastly, integrating 3D technologies like the Anatomage Table into anatomy curricula could be addressed in further research, as highlighted by Bains and Kaliski (2020) and Narnaware and Neumeier (2021). Such work can shed light on which instructional strategies and best practices are optimal to maximize the educational benefits of these tools. This type of research should delve into the integration and alignment of 3D technologies like the Anatomage Table with pedagogical principles and learning outcomes to facilitate gradual integration into existing curricula.

Implications

The potential impact for positive social change arising from this study's purpose, analysis, and results spans various areas of interest, starting at the individual level and moving into organizational and societal levels. At the individual level, positive changes include the potential to improve learning outcomes and understanding of various complex anatomical structures needed to better understand and apply in students' medical careers. The integrated dissection tools embedded in 3D technologies like the Anatomage Table provide immersive learning experiences not available with cadaveric dissection. Thus, these technologies could be integrated as additional tools catering to diverse learning styles and preferences, potentially improving student engagement.

At the family level, the impact of these technologies in education may be indirect but substantial because positive social change at the individual level could influence family units from which students arise to pursue medical education in settings such as physical, occupational, chiropractic, nursing, or medical school. It is important to note that family support and encouragement may increase as students are more likely to feel more confident in their academic abilities, thus enabling families to recognize the value of technologies like the Anatomage Table in medical education.

At the organizational level, educational institutions of higher learning, including PT, occupational therapy, medicine, nursing, and chiropractic schools, play a vital role in society and in implementing innovative teaching and learning methodologies that could enhance learning outcomes among their student bodies. This study's findings and recommendations from other research studies can inform institutional policies and curriculum development initiatives to integrate 3D technologies like the Anatomage Table into anatomy education.

Lastly, at the societal and policy levels, the positive impact of the results of this study lies in its potential to influence positive change in healthcare outcomes because the 3D technologies, like dissection tables, provide advanced tools that students and future practitioners in the medical field use to improve their knowledge in essential anatomical structures needed to evaluate further and treat diverse patient populations. Furthermore, policymakers and regulatory agencies in medical institutions may recognize that technological tools, like the Anatomage Table, could be integrated into educational curricula and provide financial incentives to higher educational institutions.

Conclusion

The transformative potential of 3D technologies like the Anatomage Table in anatomy education is not enough to draw rock-solid conclusions. Nevertheless, based on the evidence, theoretical frameworks, methodological considerations, and the literature review used in this study, I can state that this study and many studies cited in this research demonstrated that 3D technologies, such as the Anatomage Table, often contributed significantly and occasionally did not, to enhancing learning outcomes in anatomy education. What was clear, however, was that previous research on the 3D technologies examined in the literature portion of this study did not find that these technologies were detrimental to the study of anatomy. Therefore, this study fills a gap in the literature because previous studies tended to lack robust data, included mainly qualitative analysis, and the majority had small sample sizes. To fill this gap, this study used a relatively large archival sample size of students in the PT field who were introduced to 3D technology like the Anatomage Table and those who were not, thus providing a control group and an intervention group to find out, using quantitative methodologies, the difference between students' learning outcomes based on scores in gross anatomy when using or not using the Anatomage Table and by seeking whether or not there existed a correlation between undergraduate anatomy scores and gross anatomy scores in a PT setting. Even though the results of this study indicated that students using the Anatomage Table performed better in laboratory exams than those who did not, it was clear that this 3D tool may have its limitations because the outcomes showed no improvement with theoretical exams. Nevertheless, the results were promising in that they demonstrated that by using the Anatomage Table, students could improve their learning outcomes in the laboratory setting.

References

Abdulrahman, K. A. B., Jumaa, M. I., Hanafy, S. M., Elkordy, E. A., Arafa, M. A., Ahmad, T., & Rasheed, S. (2021). Students' perceptions and attitudes after exposure to three different instructional strategies in applied anatomy. *Advances in Medical Education and Practice*, *2021*(12), 607–612. https://doi.org/10.2147/AMEP.S310147

Afsharpour, S., Gonsalves, A., Hosek, R., & Partin, E. (2018). Analysis of immediate student outcomes following a change in gross anatomy laboratory teaching methodology. *The Journal of Chiropractic Education*, *32*(2), 98–106. https://doi.org/10.7899/jce-17-7

Alasmari, W. A. (2021). Medical students' feedback on applying the virtual dissection table (Anatomage) In learning anatomy: a cross-sectional descriptive study. *Advances in Medical Education and Practice*, *2021*(12), 1303–1307. https://doi.org/10.2147/AMEP.S324520

Aldridge, J. M., & McChesney, K. (2018). The relationships between school climate and adolescent mental health and wellbeing: A systematic literature review. *International Journal of Educational Research*, *88*, 121–145. https://doi.org/10.1016/j.ijer.2018.01.012

Anand, M. K., & Singel, T. C. (2017). A comparative study of learning with "Anatomage" virtual dissection table versus traditional dissection method in neuroanatomy. *Indian Journal of Clinical Anatomy and Physiology, 4*(2), 177-80. https://doi.org/10.18231/2394-2126.2017.0044

Anatomage. (n.d.). *Anatomage technology*. Retrieved February 4, 2023, from https://anatomage.com/anatomage-technology/

Bains, M., & Kaliski, D. Z. (2020). An anatomy workshop for improving anatomy self-efficacy and competency when transitioning into a problem-based learning, Doctor of Physical Therapy program. *Advances in Physiology Education*, *44*(1), 39–49. https://doi.org/10.1152/advan.00048.2019

Baratz, G., Wilson-Delfosse, A. L., Singelyn, B. M., Allan, K. C., Rieth, G. E., Ratnaparkhi, R., Jenks, B. P., Carlton, C., Freeman, B. K., & Wish-Baratz, S. (2019). Evaluating the Anatomage Table compared to cadaveric dissection as a learning modality for gross anatomy. *Medical Science Educator*, *29*(2), 499–506. https://doi.org/10.1007/s40670-019-00719z

Barillas, R. B. (2019). The effect of 3D human anatomy software on online students' academic performance. *Journal of Occupational Therapy Education*, *3*(2), Article 2. https://doi.org/10.26681/jote.2019.030202

Bartoletti-Stella, A., Gatta, V., Mariani, G. A., Gobbi, P., Falconi, M., Manzoli, L., Faenza, I., & Salucci, S. (2021). Three-dimensional virtual anatomy as a new approach for medical students learning. *International Journal of Environmental Research and Public Health*, *18*(24), Article 13247. https://doi.org/10.3390/ijerph182413247

Ben Awadh, A., Clark, J., Clowry, G., & Keenan, I. D. (2022). Multimodal three-dimensional visualization enhances novice learner interpretation of basic cross-sectional anatomy. *Anatomical Sciences Education, 15*(1), 127–142.

https://doi.org/10.1002/ase.2045

Bianchi, S., Bernardi, S., Perilli, E., Cipollone, C., Di Biasi, J., & Macchiarelli, G. (2020). Evaluation of effectiveness of digital technologies during anatomy learning in nursing school. *Applied Sciences, 10*(7), Article 2357. https://doi.org/10.339/app10072357

Bond, M., & Bedenlier, S. (2019). Facilitating student engagement through educational technology: Towards a conceptual framework. *Journal of Interactive Media in Education, 2019*(1), Article 11. https://doi.org/10.5334/jime.528

Bogomolova, K., Hierck, B. P., Looijen, A. E., Pilon, J. N., Putter, H., Wainman, B., Hovius, K. E., & van der Hage, J. A. (2021). Stereoscopic three-dimensional visualization technology in anatomy learning: A meta-analysis. *Medical Education*, *55*(3), 317–327. https://doi.org/10.1111/medu.14352

Boscolo-Berto, R., Tortorella, C., Porzionato, A., Stecco, C., Picardi, E. E. E., Macchi, V., & De Caro, R. (2020). The additional role of virtual to traditional dissection in teaching anatomy: A randomised controlled trial. *Surgical and Radiologic Anatomy*, *43*(4), 469–479. https://doi.org/10.1007/s00276-020-02551-2

Campbell, D. T., & Stanley, J. C. (1963). Experimental and quasi-experimental designs for research on teaching. In N. L. Gage (Ed.), *Handbook of research on teaching* (pp. 171–246). Rand McNally.

Casallas, A., & Quijano, Y. (2018). 3D rendering as a tool for cardiac anatomy learning in medical students. *Revista de la Facultad de Medicina*, *66*(4), 611–616. https://doi.org/10.15446/revfacmed.v66n4.65573

Ceri, N. G. (2021). Effect of non-cadaveric methods on the anatomy education of medical students. *Meandros Medical and Dental Journal*, *22*(1), 105–116. https://doi.org/10.4274/meandros.galenos.2021.99815

Chakraborty, T. R., & Cooperstein, D. F. (2018). Exploring anatomy and physiology using iPad applications. *Anatomical Sciences Education*, *11*(4), 336–345. https://doi.org/10.1002/ase.1747

Chiliquinga, E. N. C., & Pérez, M. F. Z. (2022). Nursing school students' perceptions about the use of the interactive table (Anatomage). *Enfermería Investiga*, *7*(3), 59–64. https://doi.org/10.31243/ei.uta.v7i3.1684.2022

Clunie, L., Morris, N. P., Joynes, V. C., & Pickering, J. D. (2018). How comprehensive are research studies investigating the efficacy of technology-enhanced learning resources in anatomy education? A systematic review. *Anatomical Sciences Education*, *11*(3), 303–319. https://doi.org/ 10.1002/ase.1762

da Silveira, C. R., Miamoto Días, P. E., Oenning, A. C., de Brito Junior, R. B., Turssi, C. P., & Oliveira, L. B. (2021). Digital anatomy table in teaching-learning process of temporomandibular joint anatomy. *European Journal of Dental Education*, *2022*(26), 131–137. https://doi.org/10.1111/eje.12680

Darras, K. E., Spouge, R., Hatala, R., Nicolaou, S., Hu, J., Worthington, A., Krebs, C., & Forster, B. B. (2019). Integrated virtual and cadaveric dissection laboratories enhance first-year medical students' anatomy experience: a pilot study. *BMC Medical Education*, *19*(1), 1–6. https://doi.org/10.1186/s12909-019-1806-5

Deng, X., Zhou, G., Xiao, B., Zhao, Z., He, Y., & Chen, C. (2018). Effectiveness evaluation of digital virtual simulation application in teaching of gross anatomy. *Annals of Anatomy-Anatomischer Anzeiger*, *218*, 276–282. https://doi.org/10.1016/j.aanat.2018.02.014

Downer, T., Gray, M., & Andersen, P. (2020). Three-dimensional technology: evaluating the use of visualization in midwifery education. *Clinical Simulation in Nursing*, *39*, 27–32. https://doi.org/10.1016/j.ecns.2019.10.008

Dutt, R. A., Jain, R., & Bangera, S. (2020). An integrated simulation-based early clinical exposure module in cardiovascular physiology. *Indian Journal of Physiology and Pharmacology*, *64*(2), 147–154. https://doi.org/10.25259/IJPP-105-2020

Elanjeran, R., Ramkumar, A., & Ganni, S. (2021). The anatomy table - Is it the future learning tool for regional anesthesiologists? *International Journal of Regional Anaesthesia. 2(2),* 111–116. https://doi.org/10.13107/ijra.2021.v02i02.038

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175-191. https://doi.org/10.3758/BF03193146

Fleagle, T. R., Borcherding, N. C., Harris, J., & Hoffmann, D. S. (2018). Application of flipped classroom pedagogy to the human gross anatomy laboratory: Student preferences and learning outcomes. *Anatomical Sciences Education*, *11*(4), 385–396. https://doi.org/10.1002/ase/1755

Fu, X., Wu, X., Liu, D., Zhang, C., Xie, H., Wang, Y., & Xiao, L. (2022). Practice and exploration of the “student-centered” multielement fusion teaching mode in human anatomy. *Surgical and Radiologic Anatomy*, *44*(1), 15–23.

https://doi.org/10.21203/rs.3.rs-1829423/v1

Fulmali, D., Thute, P. P., Keche, H. A., & Chimurkar, V. K. (2021). Effectiveness of exposure to virtual learning before cadaveric dissection to study anatomy for students in health sciences at DMIMSU Wardha, Maharashtra. *Journal of Pharmaceutical Research International*, (33), 81–88. https://doi.org/10.9734/jpri/2021/v33i60A34458

Gloy, K., Weyhe, P., Nerenz, E., Kaluschke, M., Uslar, V., Zachmann, G., & Weyhe, D. (2021). Immersive anatomy atlas: Learning factual medical knowledge in a virtual reality environment. *Anatomical Sciences Education*, *15*(2), 360-368. https://doi.org/10.1002/ase.2095

Gopalan, M., Rosinger, K., & Ahn, J. B. (2020). Use of quasi-experimental research designs in education research: Growth, promise, and challenges. *Review of Research in Education*, *44*(1), 218-243. https://doi.org/10.3102/0091732X20903302

Havard, B., East, M., Prayaga, L. & Whiteside, A. (2016). "Adaptable learning theory framework for technology enhanced learning." *Chapter 30,* In *Handbook of applied learning theory and design in modern education*, edited by E. Railean, G. Walker, L. Jackson, & A. Elci, Hershey, PA: Idea Group Inc., Global

Houser, J. J., & Kondrashov, P. (2018). Gross anatomy education today: the integration of traditional and innovative methodologies. *Missouri medicine*, *115*(1), 61-65 https://ncbi.nlm.nih.gov/pmc/articles/PMC6139807

Iwanaga, J., Loukas, M., Dumont, A. S., & Tubbs, R. S. (2021). A review of anatomy education during and after the COVID-19 pandemic: Revisiting traditional and modern methods to achieve future innovation. *Clinical Anatomy*, *34*(1), 108-114. https://doi.org/ 10.1002/ca.23655

Jamil, Z., Saeed, A. A., Madhani, S., Baig, S., Cheema, Z., & Fatima, S. S. (2019). Three-dimensional visualization software assists learning in students with diverse spatial intelligence in medical education. *Anatomical Sciences Education*, *12*(5), 550-560. https://doi.org/10.1002/ase/1828

Kažoka, D., & Pilmane, M. (2017). Teaching and learning innovation in present and future of human anatomy course at RSU. *Papers on Anthropology*, *26*(2), 44-52. https://doi.org/10.12697/poa.2017.26.2.05

Khammar, A., Yarahmadi, M., & Madadizadeh, F. (2018). What is analysis of covariance (ANCOVA) and how to correctly report its results in medical research? *Iranian Journal of Public Health, 49*(5), 1016-1017. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7475615/

Kim, H. Y. (2015). Statistical notes for clinical researchers: Type I and type II errors in statistical decision. *Restorative dentistry & endodontics*, *40*(3), 249-252. https://doi.org/ 10.5395/rde.2015.40.3.249

Laerd Statistics (2015). Mann-Whitney U test using SPSS Statistics. *Statistical tutorials and software guides*. Retrieved from https://statistics.laerd.com/

Laerd Statistics (2018). Spearman's correlation using SPSS Statistics. *Statistical tutorials and software guides*. Retrieved from https://statistics.laerd.com/

Lin, C., Gao, J., Zheng, H., Zhao, J., Yang, H., Lin, G., ... & Zhao, Y. (2020). Three-dimensional visualization technology used in pancreatic surgery: a valuable tool for surgical trainees. *Journal of Gastrointestinal Surgery*, *24*(4), 866-873. https://doi.org/10.1007/s11605-019-04214-z

Mitrousias, V., Varitimidis, S. E., Hantes, M. E., Malizos, K. N., Arvanitis, D. L., & Zibis, A. H. (2018). Anatomy learning from prosected cadaveric specimens versus three-dimensional software: A comparative study of upper limb anatomy. *Annals of Anatomy-Anatomischer Anzeiger*, *218*, 156-164. https://doi.org/10.1016/j.aanat.2018.02.015

Narnaware, Y. R., & Neumeier, M. (2021). Use of a virtual human cadaver to improve knowledge of human anatomy in nursing students. *Teaching and Learning in Nursing*, *16*(4), 309-314. https://doi.org/10.1016/j.teln.2021.06.003

Ochukut, S. A., & Oboko, R. (2019). A Learner Model for Adaptive e-Leaning Based on Learning Theories. In *2019 IST-Africa Week Conference (IST-Africa)* (pp. 1-8). IEEE. https://doi.ogr/10.23919/ISTAFRICA.2019.8764826

O'Rourke, J. C., Smyth, L., Webb, A. L., & Valter, K. (2020). How can we show you, if you can't see It? Trialing the use of an interactive three-dimensional micro-CT model in medical education. *Anatomical Sciences Education*, *13*(2), 206-217. https://doi.org/10.1002/ase.1890

Paech, D., Giesel, F. L., Unterhinninghofen, R., Schlemmer, H. P., Kuner, T., & Doll, S. (2016). Cadaver-specific CT scans visualized at the dissection table combined with virtual dissection tables improve learning performance in general gross anatomy. *European radiology*, *27*(5), 2153-2160. https://doi.org/10.1007/s00330-

016-4554-5

Paech, D., Klopries, K., Doll, S., Nawrotzki, R., Schlemmer, H. P., Giesel, F. L., & Kuner, T. (2018). Contrast-enhanced cadaver-specific computed tomography in gross anatomy teaching. *European Radiology*, *28*(7), 2838-2844. https://doi.org/10.1007/s00330-017-5271-4

Peterson, C. A., & Tucker, R. P. (2005). Medical gross anatomy as a predictor of performance on the USMLE Step 1. *The Anatomical Record Part B: The New Anatomist: An Official Publication of the American Association of Anatomists*, *283*(1), 5-8. https://doi.org/10.1002/ar.b.20054

Rosa, B. R., Correia, M. M., Zidde, D. H., Thuler, L. C. S., Brito, A. P. C. B. D., & Biolchini, J. C. D. A. (2020). Learning hepatobiliary anatomy through the virtual 3D anatomy table. *Revista Brasileira de Educação Médica*, *43*, 615-622. https://doi.org/10.1590/1981-5271v43suplemento1-20190033.ING

Rosario, M. G. (2022). Virtual Dissection Table: A Supplemental Learning Aid for a Physical Therapy Anatomy Course. *Journal of Learning and Teaching in Digital Age*, *7*(1), 10-15. https://doi.org/10.53850/joltida.884992

Santos, V. A., Barreira, M. P., & Saad, K. R. (2022). Technological resources for teaching and learning about human anatomy in the medical course: Systematic review of the literature. *Anatomical Sciences Education*, *15*(2), 403-419. https://doi.org/10.1002/ase.2142

Shaffer, J. F., Schriner, S. E., Loudon, C., Dacanay, S. J., Alam, U., Dang, J. V., Aguilar-Roca, N., Kadandale, P., & Sato, B. K. (2018). The impact of physiology prerequisites on future anatomy and physiology courses. *Human Anatomy and Physiology Society Educator*, *22*(3), 199-207. https://doi.org/10.21692/haps.2018.025

Shaw, V., Diogo, R., & Winder, I. C. (2022). Hiding in plain sight-ancient Chinese anatomy. *The Anatomical Record*, *305*(5), 1201-1214. https://doi.org/10.1002/ar.24503

Silén, C., Karlgren, K., Hjelmqvist, H., Meister, B., Zeberg, H., & Pettersson, A. (2022). Three-dimensional visualization of authentic cases in anatomy learning–An educational design study. *BioMed Central Medical Education*, *22*(1), 1-14. https://doi.org/ 10.1186/s12909-022-03539-9

Smith, K. E., Ruholl, H.O. and Gopalan, C. (2019), Utilization of Anatomage Table Technology Enhances Knowledge, Comprehension, and Application of Human Anatomy and Physiology in Multiple Settings. *The Journal of the Federation of American Societies of Experimental Biology*, 33, 598.19-598.19. https://doi.org/10.1096/fasebj.2019.33.1_supplement.598.19

Sotgiu, M. A., Mazzarello, V., Bandiera, P., Madeddu, R., Montella, A., & Moxham, B. (2020). Neuroanatomy, the Achilles' heel of medical students. A systematic analysis of educational strategies for the teaching of neuroanatomy. *Anatomical sciences education*, *13*(1), 107-116. https://doi.org/10.1002/ase.1866

Sectra (n.d.). Technology. Retrieved February 11, 2023, from https://medical.sectra.com/product/sectra-table/

Spearman, C. (1904). The proof and measurement of association between two things. *The*

American Journal of Psychology, 15(1), 72-101. https://doi.org/10.2307/1422689

Stecco, A., Boccafoschi, F., Falaschi, Z., Mazzucca, G., Carisio, A., Bor, S., Valente, I., Cavalieri, S., & Carriero, A. (2020). Virtual dissection table in diagnosis and classification of Le Fort fractures: A retrospective study of feasibility. *Translational Research in Anatomy*, *18*. https://doi.org/10.1016/j.tria.2019.100060

Tenaw, B. (2020). Teaching gross anatomy: Anatomage Table as an innovative line of attack. *International. Journal of Anatomical Variations*, *13*(1), 76-79. https://doi.org/10.37532/1308-4038.20.13.76

Triepels, C. P., Smeets, C. F., Notten, K. J., Kruitwagen, R. F., Futterer, J. J., Vergeldt, T. F., & Van Kuijk, S. M. (2020). Does three-dimensional anatomy improve student understanding? *Clinical Anatomy*, *33*(1), 25-33. https://doi.org/10.1002/ca.23405

Varner, C., Dixon, L., & Simons, M. C. (2021). The past, present, and future: a discussion of cadaver use in medical and veterinary education. *Frontiers in Veterinary Science*, *8*, Article 720740. https://doi.org/10.3389/fvets.2021.720740

Wang, C., Daniel, B. K., Asil, M., Khwaounjoo, P., & Cakmak, Y. O. (2020). A randomized control trial and comparative analysis of multi-dimensional learning tools in anatomy. *Scientific reports*, *10*(1), 1-10. https://doi.org/10.1038/s41598-020-62855-6

Whited, T. M., DeClerk, L., Berber, A., & Phelan, K. D. (2021). An innovative technique to promote understanding of anatomy for nurse practitioner students. *Journal of the American Association of Nurse Practitioners*, *33*(5), 348-352.

https://doi.org/10.1097/JXX.0000000000000328